Bawnboy Source

Extracted from: County Cavan Groundwater Protection Scheme, Volume II: Water Quality Report and Source Protection Zones

County Cavan Groundwater Protection Scheme

Volume II: Water Quality Report and Source Protection Zones

Final April 2009

Jack Keyes County Manager Cavan County Council Courthouse Farnham Street Cavan Co. Cavan







Authors

Sonja Masterson, Groundwater Section, Geological Survey of Ireland

With Assistance from:

Eamon O'Loughlin, Caoimhe Hickey, Coran Kelly, Monica Lee, Taly Hunter Williams, Groundwater Section, Geological Survey of Ireland Paul Johnston, Dept. of Civil, Structural & Environmental Engineering, Trinity College Dublin

in partnership with:

Cavan County Council

Table of Contents

Sections 1 to 7 are contained within Volume I. They comprise an overall introduction, classifications of aquifers and vulnerability, and overall conclusions.

8.1 INTRODUCTION 1 8.2 SCOPE 1 8.3 METHODOLOGY 2 8.4 NATURAL GROUNDWATER QUALITY AND CHARACTERISTICS 9 8.5 CHEMICAL SIGNATURES OF GROUNDWATER IN COUNTY CAVAN 9 8.6 INDICATORS OF GROUNDWATER CONTAMINATION 12 8.7 CONCLUSIONS 17 8.8 RECOMMENDATIONS 18 8.9 ACKNOWLEDGEMENTS 18 8.10 REFERENCES 18 9 BAWNBOY SOURCE 20 9.1 INTRODUCTION 20 9.2.0 METHODOLOGY 20 9.3 LOCATION AND SITE DESCRIPTION 20 9.4 GEOLOGY 22 9.5 GROUNDWATER VULNERABILITY 24 9.6 HYDROGEOLOGY 25 9.7 DELINEATION OF SOURCE PROTECTION AREAS 32 9.8 LAND USE AND POTENTIAL POLLUTION SOURCES 35 9.9 CONCLUSIONS AND RECOMMENDATIONS 35 10 BALLYMA CHUGH SOURCE 38 10.1 INTRODUCTON 38 <th>8</th> <th>CA</th> <th>VAN AQUIFER HYDROCHEMISTRY</th> <th> 1</th>	8	CA	VAN AQUIFER HYDROCHEMISTRY	1
9BAWNBOY SOURCE209.1INTRODUCTION.209.2METHODOLOGY209.3LOCATION AND SITE DESCRIPTION209.4GEOLOGY229.5GROUNDWATER VULNERABILITY249.6HYDROGEOLOGY259.7DELINEATION OF SOURCE PROTECTION AREAS.329.8LAND USE AND POTENTIAL POLLUTION SOURCES359.9CONCLUSIONS AND RECOMMENDATIONS3510BALLYMACHUGH SOURCE3810.1INTRODUCTION.3810.2METHODOLOGY3810.3LOCATION AND SITE DESCRIPTION3810.4GEOLOGY4110.5GROUNDWATER VULNERABILITY4410.6HYDROGEOLOGY4510.7DELINEATION OF SOURCE PROTECTION AREAS5310.8LAND USE AND POTENTIAL POLLUTION SOURCES5710.9CONCLUSIONS AND RECOMMENDATIONS5711REFERENCES59		8.1 8.2 8.3 8.4 8.5 8.6 8.7 8.8 8.9 8.10	INTRODUCTION Scope Methodology Natural Groundwater Quality and Characteristics. Chemical Signatures of Groundwater in County Cavan Indicators of Groundwater Contamination Conclusions. Recommendations Acknowledgements. References	1 2 9 9 9 9 9 12 17 18 18 18
9.1INTRODUCTION209.2METHODOLOGY209.3LOCATION AND SITE DESCRIPTION209.4GEOLOGY229.5GROUNDWATER VULNERABILITY249.6HYDROGEOLOGY259.7DELINEATION OF SOURCE PROTECTION AREAS329.8LAND USE AND POTENTIAL POLLUTION SOURCES359.9CONCLUSIONS AND RECOMMENDATIONS3510BALLYMA CHUGH SOURCE3810.1INTRODUCTION3810.2METHODOLOGY3810.3LOCATION AND SITE DESCRIPTION3810.4GEOLOGY4110.5GROUNDWATER VULNERABILITY4410.6HYDROGEOLOGY4510.7DELINEATION OF SOURCE PROTECTION AREAS5310.8LAND USE AND POTENTIAL POLLUTION SOURCES5710.9CONCLUSIONS AND RECOMMENDATIONS5711REFERENCES59	9	BA	WNBOY SOURCE	. 20
10BALLTMACHUGH SOURCE3610.1INTRODUCTION.3810.2METHODOLOGY.3810.3LOCATION AND SITE DESCRIPTION.3810.4GEOLOGY.4110.5GROUNDWATER VULNERABILITY.4410.6HYDROGEOLOGY.4510.7DELINEATION OF SOURCE PROTECTION AREAS.5310.8LAND USE AND POTENTIAL POLLUTION SOURCES5710.9CONCLUSIONS AND RECOMMENDATIONS.5711REFERENCES.59	10	9.1 9.2 9.3 9.4 9.5 9.6 9.7 9.8 9.9	INTRODUCTION METHODOLOGY LOCATION AND SITE DESCRIPTION GEOLOGY GROUNDWATER VULNERABILITY HYDROGEOLOGY. DELINEATION OF SOURCE PROTECTION AREAS LAND USE AND POTENTIAL POLLUTION SOURCES. CONCLUSIONS AND RECOMMENDATIONS.	20 20 20 22 24 25 32 35 35
10.1INTRODUCTION.3810.2METHODOLOGY.3810.3LOCATION AND SITE DESCRIPTION.3810.4GEOLOGY4110.5GROUNDWATER VULNERABILITY.4410.6HYDROGEOLOGY.4510.7DELINEATION OF SOURCE PROTECTION AREAS.5310.8LAND USE AND POTENTIAL POLLUTION SOURCES5710.9CONCLUSIONS AND RECOMMENDATIONS5711REFERENCES59	10	J B A	LLYMACHUGH SOURCE.	. 38
10.2INDITION OF DESCRIPTION3010.3LOCATION AND SITE DESCRIPTION3810.4GEOLOGY4110.5GROUNDWATER VULNERABILITY4410.6HYDROGEOLOGY4510.7DELINEATION OF SOURCE PROTECTION AREAS5310.8LAND USE AND POTENTIAL POLLUTION SOURCES5710.9CONCLUSIONS AND RECOMMENDATIONS5711REFERENCES59		10.1	INTRODUCTION	. 38
10.4GEOLOGY4110.5GROUNDWATER VULNERABILITY4410.6HYDROGEOLOGY4510.7DELINEATION OF SOURCE PROTECTION AREAS5310.8LAND USE AND POTENTIAL POLLUTION SOURCES5710.9CONCLUSIONS AND RECOMMENDATIONS5711REFERENCES59		10.2	Location and Site Description	. 38
10.5GROUNDWATER VULNERABILITY		10.4	Geology	. 41
10.6 Hydrogeology. 45 10.7 Delineation of Source Protection Areas. 53 10.8 Land Use and Potential Pollution Sources 57 10.9 Conclusions and Recommendations 57 11 REFERENCES . 59		10.5	GROUNDWATER VULNERABILITY	. 44
10.7 Delineation of Source Profection Areas		10.6	HYDROGEOLOGY Del difettion of Source Protection Areas	. 45
10.9 Conclusions and Recommendations 57 11 REFERENCES 59		10.7	LAND USE AND POTENTIAL POLLUTION SOURCES	. 33
11 REFERENCES		10.9	Conclusions and Recommendations	57
	11	l RE	FERENCES	. 59

APPENDIX I: DISCUSSION OF THE KEY INDICATORS OF DOMESTIC AND AGRICULTURAL CONTAMINATION OF GROUNDWATER

APPENDIX II: CHEMISTRY DATA FOR BAWNBOY PWS

APPENDIX III: BOREHOLE LOGS FOR BALLYMACHUGH GWS

APPENDIX IV: RAW WATER QUALITY DATA FROM BALLYMACHUGH GWS

APPENDIX V: PUMPING TEST DATA FOR BALLYMACHUGH GWS

FIGURES:

FIGURE 8-1: BOREHOLES/SPRINGS WITHIN COUNTY CAVAN FROM WHICH GROUNDWATER	
CHEMISTRY RESULTS WERE ASSESSED. BEDROCK AQUIFER AND GROUNDWATER BOI	DIES
ARE ALSO SHOWN	6
FIGURE 8-2: BOREHOLES/SPRINGS WITHIN COUNTY CAVAN FROM WHICH GROUNDWATER	
CHEMISTRY RESULTS WERE ASSESSED. GROUNDWATER VULNERABILITY IS ALSO	
SHOWN.	7
FIGURE 8-3: DUROV PLOT OF GROUNDWATER SAMPLES WITH FULL ANALYSIS SUITE. SAM	PLES
GROUPED BY GROUNDWATER BODY.	11
FIGURE 8-4: DIVISION OF E. COLI COUNTS IN COUNTY CAVAN GROUNDWATER SAMPLES	13
FIGURE 8-5: NITRATE, AMMONIUM AND POTASSIUM CONCENTRATIONS IN DIFFERENT	
GROUNDWATER BODIES	15
FIGURE 8-6: CHLORIDE CONCENTRATIONS MEASURED IN GROUNDWATER SAMPLES IN	
COUNTY CAVAN	16
FIGURE 8-7: IRON AND MANGANESE CONCENTRATIONS MEASURED IN GROUNDWATER	
SAMPLES IN COUNTY CAVAN	17
FIGURE 9-1: BAWNBOY SOURCE LOCATION, TOPOGRAPHY AND HYDROLOGY	22
FIGURE 9-2: BEDROCK GEOLOGY IN THE VICINITY OF BAWNBOY SOURCE	23
FIGURE 9-3: SUBSOIL GEOLOGY IN THE VICINITY OF BAWNBOY SOURCE	24
FIGURE 9-4: GROUNDWATER VULNERABILITY IN THE VICINITY OF BAWNBOY SOURCE	25
FIGURE 9-5: SCHEMATIC CONCEPTUAL MODEL OF GROUNDWATER FLOW AT BAWNBOY	
SOURCE	31
FIGURE 9-6: THE PHYSICAL LIMITS OF THE CATCHMENT OF BAWNBOY SOURCE (SO & SI)	34
FIGURE 9-7: THE GROUNDWATER PROTECTION ZONES OF BAWNBOY SOURCE	35
FIGURE 10-1: BALLYMACHUGH SOURCE LOCATION, TOPOGRAPHY AND HYDROLOGY	39
FIGURE 10-2: BALLYMACHUGH SOURCE SITE LAYOUT	39
FIGURE 10-3: BEDROCK GEOLOGY IN THE VICINITY OF BALLYMACHUGH SOURCE	42
FIGURE 10-4: SUBSOIL GEOLOGY IN THE VICINITY OF BALLYMACHUGH SOURCE	44
FIGURE 10-5: GROUNDWATER VULNERABILITY IN THE VICINITY OF BALLYMACHUGH SOU	RCE
	45
FIGURE 10-6: NATURAL (NON-PUMPING) GROUNDWATER LEVELS IN THE VICINITY OF	10
BALLYMACHUGH SOURCE	48
FIGURE 10-7: SCHEMATIC CONCEPTUAL MODEL OF GROUNDWATER FLOW AT	5.0
BALLYMACHUGH SOURCE	53
FIGURE 10-8: THE PHYSICAL LIMITS OF THE CATCHMENT OF THE BALLYMACHUGH SOURC	E
AND INNEK PROTECTION AREA (SO & SI)	56
FIGURE 10-9: THE GROUNDWATER PROTECTION ZONES OF BALLYMACHUGH SOURCE	57

TABLES:

TABLE 8.1 INVENTORY OF GROUNDWATER WELLS USED IN THE WATER QUALITY	
ASSESSMENT	3
TABLE 8.2 MATRIX OF GROUNDWATER RESOURCE PROTECTION ZONES	8
TABLE 8.3: KEY INDICATORS OF DIFFUSE GROUNDWATER CONTAMINATION	12
TABLE 9.1 SUMMARY OF SOURCE DETAILS	21
TABLE 9.2: RAW WATER ANALYSES OF GROUNDWATER AT THE BAWNBOY SOURCE	28
TABLE 9.3: BAWNBOY SOURCE TRANSMISSIVITY VALUES	30
TABLE 9.4: MATRIX OF SOURCE PROTECTION ZONES	34
TABLE 10.1: SUMMARY OF SOURCE DETAILS	4 0
TARE 144 ROOM INTER AND DECONDERONG RECORDED IN THE TWO RODENOLE LOC	4.0
TABLE 10.2: ROCK UNITS AND DESCRIPTIONS RECORDED IN THE TW2 BOREHOLE LOG	
TABLE 10.2: ROCK UNITS AND DESCRIPTIONS RECORDED IN THE TW2 BOREHOLE LOG TABLE 10.3: BALLYMACHUGH GWS CHEMISTRY	42
TABLE 10.2: ROCK UNITS AND DESCRIPTIONS RECORDED IN THE TW2 BOREHOLE LOG TABLE 10.3: BALLYMACHUGH GWS CHEMISTRY TABLE 10.4: ESTIMATED TRANSMISSIVITY VALUES FOR THE BALLYMACHUGH SOURCE	42 49 50
TABLE 10.2: ROCK UNITS AND DESCRIPTIONS RECORDED IN THE TW2 BOREHOLE LOG TABLE 10.3: BALLYMACHUGH GWS CHEMISTRY TABLE 10.4: ESTIMATED TRANSMISSIVITY VALUES FOR THE BALLYMACHUGH SOURCE TABLE 10.5: MATRIX OF SOURCE PROTECTION ZONES	42 49 50 56

9 Bawnboy Source

9.1 Introduction

The objectives of this chapter are:

- To delineate source protection zones for the Bawnboy Water Supply Scheme.
- To outline the principal hydrogeological characteristics of the Bawnboy area.
- To assist Cavan 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 well. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities within the framework of the county groundwater protection scheme. The protection of public water supplies is also referred to 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).

9.2 Methodology

9.2.1 Desk Study

Data on private groundwater wells in the area were taken from GSI archives. Existing data on water quality were taken from the EPA (raw waters) sampling programme. Geological and topographic maps were used, as described in Sections 9.3 and 9.4.

Details about the borehole, such as depth and date of commissioning, were obtained from the County Cavan Strategic Rural Water Plan, Phase II which was undertaken by Jacobs Gibb for Cavan County Council. Further field data were obtained via Jennings O'Donovan who managed the project. Information on pumping operations and estimated abstraction figures was obtained from EPS Ireland Ltd. who maintain and operate the GWS.

9.2.2 Site Visits and Field Work

Site visits and fieldwork to collect data for the Bawnboy source protection consisted of:

- Meetings with County Council personnel and walkover surveys in January and May 2006.
- Depth to bedrock drilling programme in June 2006.
- Vulnerability Mapping in June 2006.
- Meeting with EPS Ireland on site in September 2006.
- Temperature and conductivity monitoring over a 17 hour period of pumping on 12th and 13th October 2006.

9.2.3 Assessment

Field studies and previously collected data were used for aquifer parameter analyses in order to delineate protection zones around the source.

9.3 Location and Site Description

The Bawnboy water supply is a group water scheme (GWS), which originally abstracted from a shallow well located 2 miles north-west of Bawnboy village, along the N87, and prior to this from an older well further east (according to grid references from historic water sampling). A deeper replacement well was constructed in 2001, in Kilsob Townland (south of Bawnboy village), to provide for the 2025 projected demand of 285 m³/day. This well was originally drilled as a trial well but was subsequently found to be adequate for the required demand, so a pump was installed and the supply

connected to the water mains. A point of note is that the well has unusually deep casing: of the 42.7 m total borehole depth, 39 m is cased.

The borehole pumps at approximately 15 m³/hr for 15.5 hrs per day (233 m³/day) to a reservoir, and stops briefly to backwash for half an hour. A standby borehole was drilled 9.6 m from the pumping borehole. The standby borehole is 38 m deep. Both boreholes are completed below ground and have manhole coverings that are flush with the ground. The GWS compound, however, is raised above the surrounding land. Summary details for the well are in Table 9.1.

	Pumping Borehole		
GSI Well Number	2031SEW025		
Grid ref. (1:25,000)	220834, 318031		
Townland	Kilsob		
Source type	Borehole		
Developed	2001		
Owner	Bawnboy GWS		
Elevation (ground level)	~65 m O.D. (Malin)		
Depth	42.7 m		
Depth of casing	39 m		
Inner Casing Diameter	150 mm (6")		
Depth to rock	10 m		
Static water level	3.8m b.g.l. on 21/09/06 (also 3.8m b.g.l. in standby well)		
Pumping water level	Not accessible		
Drawdown	14.55m during 2001 test		
Abstraction rate*	$233 \text{ m}^3/\text{d} \text{ (projected 285 m}^3/\text{day)}$		
Pumping test summary:			
(i) abstraction rate	1706 m ³ /d (averaged)		
(ii) specific capacity	$117 \text{ m}^{3}/\text{d/m}$		
(iii) transmissivity	Average 300 m ² /d		

 Table 9.1 Summary of Source Details

*The current daily consumption is based on 15.5 hours of pumping per day, at $15m^3/hr$. However, the projected 2025 demand figure, plus an additional 50% to allow for variability in the groundwater flow direction, rainfall etc has been used for water balance calculations and the zone of contribution.

9.3.1 Topography and Surface Hydrology

The Bawnboy GWS is located 1.2 km southwest of Bawnboy village (see Figure 9-1). The source is located on the edge of a low-lying river plain, and just upstream of where this river enters Bellaboy Lough.

The general landscape setting is a low-lying area of lakes and drumlins at the base of Slieve Rushen, in which the drumlins are predominantly up to 100 mAOD, and the flat valley areas are between 50-60 mAOD. Where the source is located, the river plain is between 350 m and 500 m wide, based on the extent of alluvial deposits mapped (Meehan, 2004). Much of this low-lying area appears to be a flood plain. The surrounding drainage density is high, most noticeably in the flattest, lowest areas close to the river bank.

A hydrometric station, located approximately 1.4 km upriver from the source and on the same aquifer, has provided some old staff gauge readings. Although the data are limited, the rating curve from this station indicates that the dry weather flows are between 0.15 and 0.2 cumecs, whilst the flood flows are 0.45 cumecs, suggesting approximately one third of the flow may be baseflow along part of the river.



Figure 9-1: Bawnboy Source Location, Topography and Hydrology

9.4 Geology

9.4.1 Introduction

This section briefly describes the relevant characteristics of the geological materials and the geological setting that underlies the source area. It provides a framework for the conceptualisation of groundwater flow and, hence, the delineation of the source protection zones.

Geological information was taken principally from a desk-based study of data, which comprised:

- Bedrock Geology 1:100,000 Map Series Sheet 7, Sligo-Leitrim (MacDermot, Long and Harney, 1996) and Sheet 8, Monaghan Carlingford (Geraghty, 1997), Geological Survey of Ireland
- 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, 2004).

9.4.2 Bedrock Geology

The Bawnboy source is in an area underlain by the Dartry Limestone rock unit. Figure 9-2 shows the geology in the locality of the source. A total thickness of 90 m has been recorded at a borehole drilled in the Dartry Limestone about 6 km east of the source (in the townland of Ardlougher N.G.R. 228140 313700), although it is located on the opposite side of a major fault.

The Dartry Limestone is a pure bedded limestone, described as having a "mostly fine grained and dark" matrix with "pervasive dolomitisation and silicification". The drillers description of "soft broken rock" in the borehole, and coloured grey and brown and white (12.2 m to 42.7 m), suggests that the

Dartry Limestone is dolomitised³ in this area, which in turn implies the presence of fractures for the dolomitising fluids to have moved through. The borehole log records broken rock from 12.2 m below ground to the base of the borehole. Due to the broken and dolomitised nature of the rock, deep casing is likely to have been required in order to prevent the borehole collapsing (refer to Section 9.3).

The Dartry Limestone is classified as a Regionally Important Karstified Aquifer in which conduit flow is dominant (\mathbf{Rk}^{c}). There are no recorded karst features in the area around the source, although a low density (three features altogether) of karst features have been recorded approximately 3.5 km to the northwest in the same rock unit. Flow is expected to comprise a large component of fissure flow, as was found in the same aquifer in Blacklion (An Foras Forbartha, 1981), although fracture enlargement by dolomitisation and dissolution would enhance the flow.

The Bawnboy source is situated to the south of a major east-west trending fault, which is actually part of a northeast-southwest trending series of faults. Although this fault series is not expected to be particularly transmissive to groundwater (Dunphy, 2004), there are not enough data to determine conclusively whether this particular fault provides a barrier to groundwater flow, especially as the same rock is found on either side of the fault.



Figure 9-2: Bedrock Geology in the Vicinity of Bawnboy Source

9.4.3 Subsoil Geology

The main subsoil types in the area comprise chert and Carboniferous sandstone till, with river deposited alluvium and intermittent raised peat deposits that have been cutover (Meehan, 2004). These materials are described in more detail in Chapter 3 of Volume I. Their distribution in the vicinity of the Bawnboy source is shown on Figure 9-3. Samples from five auger holes in the till within 1 km of

³ Dolomitisation (replacement of calcium ions by magnesium ions in the crystal lattice, to form dolomite (Ca Mg (CO_3)₂), can be associated with an increase in the porosity and permeability of the rock. In general, the purer the original limestone, the greater the degree of dolomitisation

the Bawnboy source were described as CLAY (BS5930). One grain size analysis is available for this till (Auger hole 3-9SE) and it has 18% clay and 55% total fines, thus supporting this description.



Figure 9-3: Subsoil Geology in the Vicinity of Bawnboy Source

Depth to rock data indicate that the hills generally have thicker till cover (greater than 11.5 m on an adjacent hill to the northwest), compared to the low lying areas. The exception is the hill to the west of the Bawnboy source, which has outcrop on the crest and 4.5 m of subsoil at other locations.

Three auger holes around the source show that the till varies from 10.7 m to 12 m in thickness. A hard, clay matrix-supported cobble layer was encountered at between 6 m and 7.5 m b.g.l. at an auger hole south of the GWS.

"Undifferentiated" alluvial deposits are located along the Bawnboy River, in the valley floor. The thickness of these deposits is assumed to be in the order of 5 m, overlying a thickness of glacial tills. Alluvial deposits elsewhere in the country are classed as having moderate permeability, although the deposits along the Bawnboy River are more likely to have a low permeability (Meehan pers. comm.).

The subsoil deposits are not considered an aquifer; their main significance is the protection from contaminants they afford to the underlying aquifer, and the amount of recharge they allow through to the bedrock aquifer. These issues are described in Sections 9.5 and 9.6.

9.5 Groundwater Vulnerability

The concept of vulnerability is discussed in detail in Chapter 5 of Volume I. Groundwater vulnerability is dictated by the nature and thickness of the material overlying the aquifer, which is the Dartry Limestone in the area of the Bawnboy source. Regionally, the till is described as CLAY (BS 5930), which is categorised as having a low permeability. Vulnerability categories range from

'high' to 'low' where till is thicker than 3 m^4 , with the thickest and lowest permeability subsoil providing the greatest protection to the underlying aquifer. Where the subsoils are interpreted as being less than 3 m in thickness, the vulnerability is categorised as 'Extreme'. The mapped vulnerability for the area of interest is shown in Figure 9-4 below.



Figure 9-4: Groundwater Vulnerability in the Vicinity of Bawnboy Source

9.6 Hydrogeology

9.6.1 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;
- Site walkovers in January and May 2003;
- A drilling programme carried out by GSI to ascertain depth to bedrock and subsoil permeability;
- Jacobs Gibb Report on the Cavan Strategic Rural Water Plan, including an investigation of Bawnboy supply;
- Environmental Protection Agency water quality data (1996-2005);
- Cavan County Council treated drinking water samples for 2002 to 2006.

⁴ The permeability estimations and depth to rock 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.

9.6.2 Aquifer Setting

The Bawnboy source is located in the Dartry Limestone bedrock aquifer. This aquifer is classified as a **Regionally Important karstified bedrock aquifer dominated by conduit flow** (\mathbf{Rk}^{c}). In the vicinity, there are no karst features recorded. However, this may be due to the thick subsoil cover and/or prior karst mapping not being undertaken.

9.6.3 Rainfall, Evaporation and Recharge

The term 'recharge' refers to the amount of water replenishing the groundwater flow system. Recharge is generally estimated on an annual basis, and is assumed to consist of an input (i.e. annual rainfall) less water losses (i.e. annual evapotranspiration and runoff). The estimation of recharge is critical in source protection delineation as, in combination with abstractions and overflows at the source, it largely dictates the size of the zone of contribution. Figures used for the calculation of recharge are as follows:

• Average annual rainfall: 1453 mm

Rainfall figures have been taken from the average annual rainfall (1961-1990; Fitzgerald & Forrestal, 1996) at the three closest stations; Cuilcagh (located in the mountains where the rainfall is slightly higher), Belturbet (located away from the rainfall shadow), and (Swanlinbar, which is between the two other stations). This is expected to give a representative average for Bawnboy, as it is located on the edge of the Cuilcagh Mountains rainfall shadow. Rainfall data since 1990 are not available for the nearby stations, although a comparison between more recent data at the Cavan station (1990-2005) and the 1961-1990 data indicates that rainfall in that area has increased in the order of 15%. However, use of a lower annual rainfall figure provides a more conservative estimate of the zone of contribution.

• Average annual evapotranspiration losses: **585 mm** The figures for actual evapotranspiration (A.E.) are taken from Ballinamore synoptic station (1971-2000, Met Éireann, 2006) which is 10 km to the southwest in County Leitrim.

• Average annual effective rainfall: **868 mm**

This figure is based on subtracting estimated monthly evapotranspiration losses from average monthly rainfall (and thereby accounts for months in which evaporation losses exceed rainfall). It represents an estimation of the excess soil moisture available for either vertical downward flow to groundwater or runoff.

- Estimated actual recharge: 148 mm
 - The amount of water that will infiltrate to groundwater (recharge) is influenced by the subsoil permeability and thickness, as well as the aquifer characteristics. Recharge coefficients (rc) have been derived for various combinations of these factors (Water Framework Directive (WFD) Pressures and Impacts Assessment Methodology, 2003). Over the entire area of interest, recharge estimates are thought to be in the order of 17% of effective rainfall. The low recharge is reflected in the high natural and artificial surface drainage in the area around the Bawnboy source. This is also likely to be a consequence of the high water table in the inter-drumlin areas.

These calculations are summarised as follows:

Potential Recharge (R – A.E.)	868 mm
Overall Recharge Coefficient	17%
Estimated Actual Recharge	1/% 148 mm

9.6.4 Groundwater levels

The GSI database does not contain any records on groundwater levels in the immediate area of the source. Although the regional groundwater level would be generally flat, it has been found from water levels elsewhere that slight mounds in the groundwater levels occur in the drumlins. NERDO (An Foras Forbartha, 1981) boreholes in the general area indicate that water levels are 10 m to 15 m below the ground surface on the sides of drumlins. This indicates that a 5-10 m difference in water table elevation between the site boreholes and the drumlin centre would be reasonable. The groundwater levels at the source borehole and at a domestic well supply source on the opposite bank of the Bawnboy River indicate that the water level in the low lying area around the Bawnboy River is close to the surface: 3 m to 4 m below ground level.

EPA 'spot water level monitoring' records at the old Bawnboy water supply in Bawnboy village show a 9 m variation between the low and high groundwater levels, which are indicative of a significant seasonal variation in the overall aquifer water levels. Significant seasonal variation and fluctuation with heavy rainfall periods is likely to be due to karstic flow in these limestones. The demarcation of large flood areas along the banks of the Bawnboy River is also likely to be influenced by this type of aquifer flow system.

The static water level in the current source borehole was at 3.8 m b.g.l. on 21/9/06, which is 6.2 m above the top of the bedrock (~58 mAOD). The overlying till material in boreholes in the area has a low permeability, so the same is assumed of the subsoils at the source itself. This indicates the groundwater in the immediate area around the borehole is confined.

9.6.5 Groundwater Flow Directions and Gradients

The regional flow direction is generally eastwards (WFD Initial Groundwater Body Characterisation, Newtown-Ballyconnell GWB description). However, in the specific area around the source it is likely to be more south to south-eastwards due to the topographic and hydraulic gradient created by Slieve Rushen, north of Bawnboy. The piezometric surface in the vicinity of the source is assumed to reflect topography, with groundwater flowing from the drumlins into the valleys. This would also imply a component of eastward and southwards flow towards the source under non-pumping conditions.

The drilling contractor's log for the source borehole indicates that the greatest inflows occurred at the base of the borehole (33-42.5 m b.g.l.), where the groundwater flow may intercept a more distant flow and recharge. Flow from a surface water source may also contribute to the well, as the pumping test for the borehole reached steady state after just 6 hours of pumping, which indicates the presence of a recharge boundary near the well, although this was at a much greater pumping rate (1,706 m^3/day).

Groundwater gradients local to the source have been estimated using the source water level (west of the Bawnboy River), a water level in a domestic borehole on the eastern side of the Bawnboy River, and the water level in the nearby Lough Bellaboy. The calculated gradient is 0.016 (1 in 63), which reflects the surface topography in the flood plain stretching from the source to the River. The gradient in the elevated area further west and northwest of the source borehole is likely to increase slightly. Using a water level of 15 m below the top of the drumlin (see Section 9.6.4), the up-gradient groundwater flow gradient is in the order of 0.02 (1 in 50).

9.6.6 Water Quality

Raw water quality analyses for the new Bawnboy supply borehole is limited to three samples: two taken by Cavan County Council during the course of the investigations carried out for this GWPS, and one by the consultants following the start-up of the scheme. These are summarised in Table 9.2. Electrical conductivity, pH, bacterial analyses, nitrate and nitrite have all been analysed regularly on the treated water from the source and are included in Appendix II. Key points on the source water quality are summarised below.

- The groundwater at the source is calcium-bicarbonate type, which is typical of groundwater found in limestone environments throughout Ireland.
- Hardness: the hardness calculated from the calcium and magnesium concentrations indicates that the groundwater at the site is moderately hard. In a limestone aquifer, this would be expected to be higher. However, groundwater flowing from the more sand- and shale-rich Carboniferous units on Slieve Rushen, and any possible contributions from surface waters, could result in less hard groundwater than expected, particularly where groundwater flow is relatively fast, thus not allowing full dissolution of limestone into the groundwater.
- Faecal coliforms: no faecal coliforms (including E. Coli) were identified in the two available samples. However, bacterial results from the old Bawnboy supply (Appendix II), which is located in the same aquifer unit, show repeated occurrence of faecal coliforms in the raw water. As bacterial contamination often occurs erratically and in response to weather events as well as local potentially contaminating activities, further results are required to provide confidence that the raw waters are not contaminated on an ongoing basis.
- Other contaminant indicators: concentrations of nitrate are below typical background levels and are within the EU drinking water regulations (S.I. 439 of 2000). These, together with the concentration of ammonia, indicate a degree of confinement by the low permeability subsoil surrounding the well.
- The elevated concentration of aerobic mesophyllic bacteria (bacteria which thrive at 20°C to 45°C) may be an indication of contribution from surface waters to the borehole supply at the time of measurement. These bacteria are also commonly associated with wastewater treatment works and with aerobic digesters. However, the pumping test provides evidence to support the former source.

Parameter	May 2001	December	April 2007	EC Drinking
	Sample	2006 Sample	Sample	Water Regs,
				2000
Conductivity (µS/cm)	320	438	484	2500
pH	7.5	not measured	7.8	>=6.5 & <=9.5
Total Alkalinity (mg/l CaCO ₃)	not measured	not measured	222	n/a
Chemical Oxygen Demand (mg/l)	3	not measured	not measured	n/a
Biological Oxygen Demand (mg/l)	2.5	not measured	not measured	n/a
Calcium (mg/l)	not measured	70.2	69.6	n/a
Magnesium (mg/l)	not measured	15.6	15.4	50
Hardness (mg/l)	n/a	239	237	n/a
Chloride (mg/l)	17.7	not measured	11	250
Sulphate (mg/l)	10	8.9	8.8	250
Sodium (mg/l)	not measured	8.4	8.7	200
Potassium (mg/l)	not measured	1.0	<1	n/a
Nitrate (mg/l as NO ₃)	0.1	3.6	not measured	50
Nitrite (mg/l as NO ₂)	0.03	< 0.02	not measured	0.5
Iron (mg/l)	0.018	0.08	0.098	0.2
Manganese (mg/l)	0.016	0.0024	0.003	0.05
Dissolved Oxygen	9.97	not measured	not measured	n/a
Aluminium (mg/l)	0.039	not measured	not measured	0.2
Ammonia (mg/l as NH ₄)	0.26	< 0.01	not measured	0.3
Total Aerobic Mesophyllic Bacteria	700	not measured	not measured	n/a
(no./100ml at 37°C)				
Total Aerobic Mesophyllic Bacteria	86000	not measured	not measured	n/a
(no./100ml at 25°C)				
Total Coliform Bacteria (no./100ml)	Nil	not measured	not measured	0
Faecal Coliform Bacteria	Nil	0	not measured	0
(no./100ml)				
Sulphate Reducing Clostridia	Nil	not measured	not measured	n/a
(no./100ml)				

Table 9.2: Raw Water Analyses of Groundwater at the Bawnboy Source

Further to the analyses given above, conductivity measurements were taken over a 17 hour pumping period (12-13th October 2006) to assess for potential surface water contributions. No significant change was found (Appendix II).

9.6.7 Aquifer Parameters

The main aquifer parameters of significance are permeability and porosity. Together with groundwater gradients, these parameters are used to estimate the extent of the inner source protection area, which is described in Section 9.7.3.

The aquifer parameters used for the Bawnboy GWS hydrogeological conceptual model are derived from pumping test analyses (Jacobs Gibb, 2001), which was undertaken shortly after the well was drilled. The well was pumped at a rate of $1,706 \text{ m}^3/\text{day}$ for 72 hours, resulting in a maximum drawdown of 14.55 m after 6 hours of pumping. A recovery test was undertaken following the constant rate test, during which the well reached 95% recovery after 2 minutes.

The time-drawdown data curve of the pumping test shows evidence of a 'recharge boundary effect' after the first 6 hours of pumping. Given the low-lying position of the well, and the high proportion of surface water in this region, the recharge is assumed to come from one of the surface water bodies. As outlined in Section 9.4.3, the alluvium underlying the Bawnboy River is understood to be low permeability. Therefore recharge from the river to the borehole via this low permeability alluvium is unlikely. The most likely source of surface water recharge at this pumping rate is from the Bellaboy Lake, which is 325 m away at its closest point, through the actual bedrock itself.

Reports relating to the testing of the well have no dates for the test, therefore the degree of surface water contribution cannot be assigned any seasonality, although it is expected that a greater input may come from the lake in the summer season, when aquifer recharge and groundwater heads are lower.

From the pumping test, there are two main characteristics that can be inferred: 1) the transmissivity, or capability of the aquifer to transmit groundwater, and 2) the efficiency of the well, which often reflects on the construction.

The step pumping test results indicate that the borehole efficiency is very low. The likely cause of this is the construction - as there is casing to 39 m below ground, only 3.7 m at the base of borehole remains open for inflow. Although the drilling logs indicate that uncased part of the borehole corresponds to the main zone of flow, when the borehole is pumped, vertical flows are induced in the aquifer, which creates longer groundwater flowpaths and disproportionately large drawdowns.

A number of transmissivity values (T-values) were calculated using the Logan approximation and analytical methods in the Aquifer Win32 software package (Table 9.3). The calculated T-values range from 143 m²/day to 933 m²/day⁵, which is reasonable for this type of aquifer. A median T-value of $300 \text{ m}^2/\text{day}$ is used for further calculations in Section 9.7.3.

 $^{^{5}}$ The range of T-values does not include those calculated for steps 2 and 3 of the Step test as these also gave rise to low borehole efficiency values: 30% and 21% respectively).

	Т
Analytical Method	(m ² /day)
Logan Approximation (CRT drawdown)	143
Logan Approximation (step test; step no. 2)	1561
Logan Approximation (step test; step 3)	1434
Logan Approximation (step test; step 4)	407
Theis recovery analysis	933
Theis drawdown analysis	275
Cooper-Jacob drawdown analyses	360
DeLange & Van Tonder (apparent fracture T), 2000	204

Table 9.3: Bawnboy Source Transmissivity Values

A porosity of 0.01 has been applied to this aquifer. This is at the lower end of the typical range used by the GSI for bedrock aquifers (0.01 to 0.025), and reflects the understanding that most flow will occur in discrete fissures and conduits. A similar value has been used for pure bedded limestones elsewhere in the country.

9.6.8 Conceptual Model

This section provides a qualitative overview of the geological framework, recharge, groundwater flow and discharge patterns across the aquifer contributing groundwater to the source. It represents a summary of the main inferences drawn in previous sections, and provides a foundation upon which the quantitative analyses required for delineating source protection areas can be drawn.

The conceptual model is based on available data in relation to the source and in the vicinity of the source. The detail provided by the conceptual model is constrained as a consequence of the limited data available as follows:

- The aquifer from which the Bawnboy Water Supply abstracts is a pure bedded limestone, which is karstified in places and has proven high yields. It is classified as a **Regionally Important Karst Limestone** with dominant conduit flow, **Rk**^c. However, the lack of karst features observed in the area around the source support the view that the degree of conduit flow is limited, and fracture flow that has been enhanced by dolomitisation is expected to dominate the flow regime to the source.
- The natural groundwater flow direction around the source is south-eastwards. Flow is also induced southwards along the low-lying area to the north of the source when abstraction is ongoing. Average groundwater gradients in the limestone are estimated at 0.02 (1 in 50), getting steeper closer to the abstraction well due to the influence of pumping.
- Groundwater in the immediate vicinity of the site is considered to be confined beneath the low permeability subsoil cover.
- High drainage density, particularly in flat low lying areas, is likely to be a reflection of the low permeability subsoils and high water table in the area. Surface runoff is expected to be high, except in the limited areas where the depth to bedrock is thin.
- Recharge to the aquifer in the Bawnboy source area is expected to occur via:
 - diffuse recharge from rainfall falling on the aquifer outcrop and subcrop across the region;
 - diffuse local recharge, which is limited by percolation through the low permeability till.
- The possibility exists of surface water and groundwater interaction, particularly due to the karstified nature of the aquifer, but there is no evidence to support this in the area of the source

(except for possible lakewater inflow to the aquifer under high pumping rates, as suggested by the pumping test described in Section 9.6.7).

Based on the information above, a schematic depiction of the groundwater flow to the source is shown in Figure 9-5.

The conceptual model is based on available data in relation to the source and in the vicinity of the source. The conceptual model is constrained by the limited nature of the data available, which include:

- Estimated groundwater gradients that are based on topography and only two water levels, as there are no other wells near to the source.
- Seasonal water levels for the source only pumped water levels during periods of fieldwork are available.
- Accurate aquifer parameters the calculations are limited by the borehole construction, which was originally intended as a trial well.
- Aquifer chemistry data three sample results available taken upon completion of the initial pumping test at a rate of 1,706 m³/day, and by Cavan County Council during the course of the project.

Figure 9-5: Schematic Conceptual Model of Groundwater Flow at Bawnboy Source

See Figure 9-6 for location of cross-section.



9.7 Delineation of Source Protection Areas

9.7.1 Introduction

This section describes the delineation of the area around the borehole at Bawnboy that is understood to contribute groundwater to the source, and that therefore requires protection. The area is delineated on the basis of the conceptualisation of the groundwater flow pattern as described in Section 9.6.8.

Two source protection areas are delineated:

- Inner Protection Area (SI), designed to give protection from microbial pollution;
- Outer Protection Area (SO), encompassing the remainder of the zone of contribution (ZOC) of the source.

9.7.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, i.e. the zone of contribution (ZOC), and is defined as the area required to support an abstraction from long-term recharge. The ZOC is controlled primarily by (a) the borehole abstraction rate, (b) the groundwater flow direction and gradient, (c) the subsoil permeability and (d) the recharge in the area. The delineation of the ZOC uses:

- i. hydrogeological mapping techniques to determine 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 to account for the larger ZOC required during the drier summer months.
- iv. Calculated aquifer parameters to estimate the flow rate to the source.

The average abstraction rate for the borehole is taken as the 2025 projected yield plus a 50% margin, to account for extended drier (summer) periods and potential increases in projected yields. A resulting rate of 428 m^3/d was used to determine the ZOC.

The boundaries of the conceptual model were taken from hydrogeological mapping and the conceptualisation outlined in Section 9.6.8, and are as follows:

- Northern boundary: Due to the high transmissivity of the aquifer and the assumed additional groundwater flow that is induced from the north along the low lying flood plain area, it is likely that groundwater is being pulled from slightly beyond the topographic divide located c. 0.3 km north of the borehole. As a consequence, the elevated area approximately 1 km northwest of the borehole is also included, as groundwater naturally flows from this area into the zones of induced flow.
- **Eastern boundary:** The eastern boundary to the ZOC is based on the understanding that natural west-to-east flow towards the Bawnboy River in this specific zone will instead be pulled southwards towards the source, resulting in north-south flow along this boundary, and parallel to the ground contours, towards the source.
- **Southeast boundary:** The south-eastern boundary to the ZOC is determined by the no-flow or "null point" (see below), down-gradient of the borehole.
- **Southern boundary:** The southern boundary joins the no-flow boundary in the southeast at the topographic divide, which is assumed to determine the natural groundwater divide by creating a slight water table mound under the drumlin to the west of the source.
- Western boundary: This is initially based on the topographic divide c. 0.5 km from the borehole, which is assumed to reflect the groundwater divide. However, given the high

transmissivity of the aquifer, it is likely that the pumping will pull groundwater from slightly beyond this divide. Beyond this, it is likely that the groundwater naturally flows westwards into Lakefield Lough.

These boundaries delineate the physical limits within which the ZOC is likely to occur. Calculations that have been performed to help constrain the ZOC to the area which provides sufficient recharge for the source abstraction rate are as follows:

<u>Water Balance</u>: The water balance was calculated on a monthly basis to allow for zero recharge during months in which the actual evaporation exceeded the average monthly rainfall.

Recharge area required to sustain discharge	= abstraction rate \div average annual depth of recharge. = (428 m ³ /d × 365 days) \div 0.148 m/yr
Recharge area required to sustain discharge	$= 1.05 \text{ km}^2$

<u>Uniform Flow Equation:</u> this was applied as a check on the downgradient ZOC extent:

Approximate down-gradient extent =	(discharge rate)
	$2 \times \Pi \times (\text{transmissivity}) \times (\text{hydraulic gradient})$

The down gradient extent or "null point" was calculated to be approximately 34 m.

Further to the delineated ZOC based on an abstraction value of 428 m^3 /day (the 2025 projected rate plus 50% to take account of drier spells/slight increases in abstraction), it is noted that the 72 hours pumping test data indicates that a 'recharge boundary' was reached after 6 hours of pumping at the higher rate (1,706 m^3 /day). From an assessment of the available information on the surrounding conditions, such recharge is most likely to be coming from Bellaboy Lough. Therefore, if the pumping rate were to increase significantly, water will possibly be pulled in from this source and thus the ZOC described above would have to be reassessed based on the newer abstraction rates.

9.7.3 Inner Protection Area

The Inner Protection Area (SI) is the area defined by a 100 day time of travel (TOT) to the source from a point below the water table. It is delineated principally to protect against the effects of potential bacteriological contamination, which may have an immediate influence on water quality at the source.

Generally, when the aquifer is designated as karstified, as it is here, the inner source protection area will often encompass the outer source protection as flow velocities through the solutionally enlarged fractures and fissures have been found to be extremely fast. However, as there are no karst features recorded in this specific area, a more diffuse, fracture flow is thought to dominate. As such, analytical modelling was therefore used to estimate the extent of the inner source protection area, which was also considered to be the more conservative approach.

Subject to certain assumptions and conditions, Darcy's Law can be used to approximate groundwater flow velocities, as follows:

Velocity = groundwater gradient × permeability ÷ porosity

Using the estimates derived in Sections 9.6.7 and 9.6.5 for gradient, permeability (T-value divided by the thickness of the aquifer, which in this instance is taken as the depth of the borehole), and porosity (0.02 upgradient and 0.016 downgradient, 7 m/day, and 0.01 respectively), the equation gives a

velocity of 14 m/day on the upgradient side of the source and 11 m/day on the downgradient side of the source. Given these high velocities, groundwater and potential contaminants at any point within the ZOC can reach the source within 100 days. Therefore the inner source protection area is considered to encompass the entire outer source protection area.

Figure 9-6: The Physical Limits of the Catchment of Bawnboy Source (SO & SI)

Refer to Figure 9-5 for cross-section indicated by the line A-A'



9.7.4 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the source protection areas and vulnerability categories – giving a possible total of eight source protection zones (see the matrix in the table below). 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 <u>Inner Source Protection area</u> where the groundwater is <u>highly</u> vulnerable to contamination. The hydrogeological settings within the Bawnboy ZOC are highlighted in Table 9.4 below. The groundwater protection zones for Bawnboy source are shown in Figure 9-7.

Table 9.4: M	latrix of	Source	Protection	Zones
--------------	-----------	--------	------------	-------

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

The appropriate responses imposing restrictions on development are presented in the document 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).



Figure 9-7: The Groundwater Protection Zones of Bawnboy Source

9.8 Land Use and Potential Pollution Sources

The land surrounding Bawnboy source is principally used for livestock agriculture, such that landspreading is the greatest potential pollution source. An agricultural storage area (materials and machinery) is located within the inner source protection area, 35 m to the south of the borehole compound.

Several domestic dwellings (that are thought to have on-site wastewater treatment systems) and two farmyards are located within the source protection area, both of which present potential sources of microbial pollution.

The borehole compound is securely fenced off. However, the compound is down-slope from the road, and the flush finish of supply borehole potentially exposes it to surface ingress of contaminants via onsite work or road spillages.

It should also be noted that detailed assessments of hazards were not carried out as part of this study.

9.9 Conclusions and Recommendations

From analysis of all available data, and hydrogeological inferences made, the following conclusions can be drawn:

• The Bawnboy Source abstracts from a Regionally Important Karstified Limestone Aquifer, although given the absence of karst features in the immediate area, conduit flow is not considered to be dominant.

- The groundwater immediately around the supply is well protected by low permeability till over much of the zone of contribution to the well, i.e. the catchment area.
- The limited water quality sample results from the source indicate that the source water is calcium bicarbonate type. Regular raw water sampling of major cations, anions and bacteriological counts are required to have confidence in this assessment.
- The ZOC identified allows for continued supply over a drier (summer) period or a slight increase in 2025 projected demand of 285 m³/day.
- ♦ At an averaged pumping rate of 1,706 m³/day, the initial pumping test indicates the presence of a 'recharge boundary'. A high concentration of mesophyllic bacteria recorded at the end of this test provided further evidence of a surface water input. These results suggested that the source may be able to sustain significantly increased abstraction rates. However, the sustainability of the yield and water quality cannot be ascertained from the available data. Furthermore, such abstraction rates are likely to significantly alter the ZOC delineated for the currently projected 2025 demand.
- The protection zones delineated in this chapter 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. Chemical and bacteriological analyses of raw water as well as treated water should be carried out monthly. The analyses should include all major ions calcium, magnesium, sodium, potassium, ammonium, bicarbonate, sulphate, chloride, and nitrate plus bacteriological parameters. More occasional analyses of other parameters such as pesticides and hydrocarbons is also recommended.
- 2. The input of surface water to the source at higher abstraction rates be further investigated. This would include continuous field chemistry measurements of the discharge water during a future pump test, to more accurately determine the surface water contribution. A sample of Bellaboy Lough and Lakefield Lough should be taken simultaneously, to allow direct comparison between the source water chemistry and the lakes' water chemistry.
- 3. The potential hazards in the ZOC should be located and assessed, especially with regard to the upgradient proximity of farmyards and houses.
- 4. Particular care should be taken when assessing the location of any activities or developments that might cause contamination at the borehole.

11 References

An Foras Forbartha, 1981. Groundwater Resources in The N.E.(R.D.O.) Region; V1 Summary report, V2 Main Report & V3 Technical Appendices.

Arup, 2005. N3 Butlers Bridge to Belturbet Road Improvement Scheme, Environmental Impact Statement.

Ashton, J.H.; Holdstock, M.P., Geraghty, J.F., O'Keefe, W.G., Martinez, N., Peace, W. and Philcox, M.E. 2003. The Navan Orebody – Discovery and Geology of the South West Extension, Europe's Major Base Metal Deposits, Irish Association for Economic Geology.

Bates, R.L. and Jackson, J. A. 1984. Dictionary of Geological Terms: Third Edition. Prepared by the American Geological Institute. Anchor Books.

Baker G., Crean D., & Moran S. (OCM & Associates), 2007. Establishing Natural Background Levels for Groundwater Quality in Ireland; *G.S.I. Groundwater Newsletter No. 46*.

British Standards Institution, 1999. BS 5930:1999, Code of practice for site investigations. British Standards Institution, London.

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

Daly, D., 1994. Chemical Pollutants in Groundwater: a Review of the Situation in Ireland. Paper presented at *Conference "Chemicals – a Cause for Concern?"* in Cork, 3-4 November 1994.

Daly, D., Moore, Meehan, R., Murphy, G., Fitzsimons, V., Clenaghan, C., Beirne, M., Carty, G., O'Leary, G., O'Dwyer, R., 2000. Site Suitability Assessments for On-site Wastewater Treatment Systems: Course Manual. FÁS and Geological Survey of Ireland.

Daly, E. P., 1989. Natural Chemistry of Groundwater. Paper presented at the 9th Annual Groundwater Seminar held in Portlaoise on: *Groundwater Chemistry and Groundwater for the bottled Water and Aquaculture Industries*. IAH (Irish Group).

Daly, E.P., 1995. The Principal Characteristics of the Flow Regime in Irish Aquifers. Paper presented at the 15th Annual Groundwater Seminar held in Portlaoise, on: *The Role of Groundwater in Sustainable Development*. Published by: IAH (Irish Group).

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

Dunphy, R.B., 2004. The Role of fracture systems in controlling groundwater yields in the post-Silurian rocks of Ireland, University of Dublin Trinity College MSc Thesis.

Environmental Protection Agency, 2001. Website: www.epa.ie/techinfo/default.htm

Environmental Protection Agency, 2000. Wastewater Treatment Manuals: Treatment Systems for Single Houses, Environmental Protection Agency.

European Communities (Drinking Water) Regulations, 2000. S.I. No. 439 of 2000.

Fetter, C.W., 1980. Applied Hydrogeology, Charles E. Merrill

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).

Friel, G. & Quinn, M.,1994. STRIDE Environment Sub-Programme Measure 1, groundwater Assessment in Counties Cavan, Louth and Monaghan.

Geraghty, M., 1997. Bedrock Geology 1:100,000 Scale Map Series Sheet 8/9, Monaghan – Carlingford, *and* A Geological Description to Accompany the Bedrock Geology Sheet Series; Geological Survey of Ireland.

Working Group on Groundwater (GWWG), 2004. Guidance Document GW8: *Methodology for Risk Characterisation of Ireland's Groundwater*, 70pp. Available on the www.wfdireland.ie website.

Hammond, R.F., (An Foras Taluntais), 1979. The Peatlands of Ireland. Soil and Survey. Bulletin. No. 35. An Foras Taluntais (Teagasc), Dublin.

Hem, 1992. USGS Water Supply Paper 2254; Study and Interpretation of the Chemical Characteristics of Natural Water, Third Ed.

Jacobs Gibb, 2001. County Cavan Strategic Rural Water Plan. Phase Two. Groundwater Resource Investigation. Report including investigation of Bawnboy supply for Cavan County Council.

K.T. Cullen & Co. Ltd., 1997. Drilling and Testing of Trial Wells at Bracklagh, Co. Cavan, January 2000, Report submitted to the Ballymachugh Group Water Scheme.

Kruseman, G.P. & de Ridder N.A., 1994. Analysis and Evaluation of Pumping Test Data, ILRI publication 47, sec. Ed.

Lee, M., 1999. Surface indicators and land use as secondary indicators of groundwater recharge and vulnerability. Unpublished (Research) MSc thesis. Department of Civil, Structural and Environmental Engineering, Trinity College Dublin.

MacDermot, C.V., Long C.B., and Harney S.J., 1996. Bedrock Geology 1:100,000 Map Series, Sheet 7, Sligo-Leitrim; *and* A Geological Description to Accompany the Bedrock Geology Sheet Series; Geological Survey of Ireland.

Meehan, R., 2003. Forest Inventory and Planning System – Irish Forest Soils, Methodology for Subsoil Mapping.

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

Met Éireann, 1996. Potential Evapotranspiration. In: Collins, J.F, and Cummins, T (Ed) 'Agroclimatic Atlas of Ireland', pp 134-137

Minerex Environmental Ltd, 2005. Hydrogeology Assessment Report for N3 Butlers Bridge to Belturbet Road Improvement Scheme, Environmental Impact Statement.

Misstear B., Banks D., Clarke L., 2006. Water Wells and Boreholes, Wiley & Sons.

Morris, J.H., Somerville I.D. and MacDermot C.V.; 2003; Bedrock Geology 1:100,000 Map Series, Sheet 12, Longford-Roscommon, *and* A Geological Description to Accompany the Bedrock Geology Sheet Series; Geological Survey of Ireland.

Ni Bhroin, C., 2001. The Carboniferous Geology of Sheet 8: (including County Monaghan and eastern County Cavan; Geological Survey of Ireland unpublished report.

O Suilleabhain, C., 2000. Assessing the Boundary Between High and Moderately Permeable Subsoils. Unpublished MSc thesis. Department of Civil, Structural and Environmental Engineering, Trinity College Dublin.

Sjors, H. & Gunnarsson, U., 2002. Calcium and pH in north central Swedish mire waters, Journal of Ecology, V 90, pp650-657.

Swartz, M. and Daly, D.; (2002). County Monaghan Groundwater Protection Scheme, Main Report; Geological Survey of Ireland.

Todd, D.K. (1980), Groundwater Hydrology (2nd ed.). J. Wiley and Sons, New York, 336 pp.

Van der Schaaf, Sake, 1999. Analysis of the Hydrology of Raised Bogs in the Irish Midlands, A case study of Raheenmore Bog and Clara Bog.

Working Group on Groundwater, March 2005. Approach to Delineation of Groundwater Bodies, Guidance Document No. GW2.

Water Framework Directive Working Group on Groundwater; March 2003. Guidance on Pressures and Impacts Methodology, Guidance Document No. GW4.

Water Framework Directive Working Group on Groundwater; March 2005. Guidance on the Assessment of the Impacts of Groundwater Abstractions, Guidance Document No. GW5.

Wright, G.R., 2000. QSC Graphs: and Aid to Classification of Data-poor Aquifers in Ireland. From: Robins, N.S. and Misstear, B.D.R. (eds.) Groundwater in the Celtic Regions: Studies in Hard Rock and Quaternary Hydrogeology. Geological Society, London, Special Publications, **182**. The Geological Society of London 2000.

Appendix I

Discussion of the Key Indicators of Domestic and Agricultural Contamination of Groundwater

Appendix I: Discussion Of the Key Indicators of Domestic and Agricultural Contamination of Groundwater

A.1 Introduction

This appendix is adapted from Daly, 1996.

There has been a tendency in analysing groundwater samples to test for a limited number of constituents. A "full" or "complete" analysis, which includes all the major anions and cations, is generally recommended for routine monitoring and for assessing pollution incidents. This enables (i) a check on the reliability of the analysis (by doing an ionic balance), (ii) a proper assessment of the water chemistry and quality and (iii) a possible indication of the source of contamination. A listing of recommended and optional parameters are given in Table A1. It is also important that the water samples taken for analysis have not been chlorinated - this is a difficulty in some local authority areas where water take-off points prior to chlorination have not been installed.

The following parameters are good contamination indicators: E. coli, nitrate, ammonia, potassium, chloride, iron, manganese and trace organics.

Recommended Parameters					
Appearance	Calcium (Ca)	Nitrate (N0 ₃)*			
Sediment	Magnesium (Mg)	Ammonia (NH4and NH3)*			
pH (lab)	Sodium (Na)	Iron (Fe)*			
Electrical Conductivity (EC)*	Potassium (K)*	Manganese (Mn)*			
Total Hardness	Chloride Cl)*				
General coliform	Sulphate (S0 ₄)*				
E. coli *	Alkalinity				
Optional Parameters (depending on local circumstances or reasons for sampling)					
Fluoride (F)	Fatty acids *	Zinc (Zn)			
Orthophosphate	Trace organics *	Copper (Cu)			
Nitrite $(N0_2)^*$	TOC *	Lead (Pb)			
B.O.D.*	Boron (B) *	Other metals			
Dissolved Oxygen *	Cadmium (Cd)				
* good indicators of contamination					

TABLE A1

A.2 Faecal Bacteria and Viruses

E. coli is the parameter tested as an indicator of the presence of faecal bacteria and perhaps viruses; constituents which pose a significant risk to human health. The most common health problem arising from the presence of faecal bacteria in groundwater is diarrhoea, but typhoid fever, infectious hepatitis and gastrointestinal infections can also occur. Although E. coli bacteria are an excellent indicator of pollution, they can come from different sources - septic tank effluent, farmyard waste, landfill sites, birds. The faecal coliform : faecal streptococci ratio has been suggested as a tentative indicator to distinguish between animal and human waste sources (Henry *et al.*, 1987). However, researchers in Virginia Tech (Reneau, 1996) cautioned against the use of this technique.

Viruses are a particular cause for concern as they survive longer in groundwater than indicator bacteria (Gerba and Bitton, 1984).

The published data on elimination of bacteria and viruses in groundwater has been compiled by Pekdeger and Matthess (1983), who show that in different investigations 99.9% elimination of *E. coli* occurred after 10-15 days. The mean of the evaluated investigations was 25 days. They show that 99.9% elimination of various viruses occurred after 16-120 days, with a mean of 35 days for Polio-, Hepatitis, and Enteroviruses. According to Armon and Kott (1994), pathogenic bacteria can survive for more than ten days under adverse conditions and up to 100 days under favourable conditions; enteroviruses can survive from about 25 days up to 170 days in soils.

Bacteria can move considerable distances in the subsurface, given the right conditions. In a sand and gravel aquifer, coliform bacteria were isolated 100 ft from the source 35 hours after the sewage was introduced (as reported in Hagedoorn et al., 1981). They can travel several kilometres in karstic aquifers. In Ireland, research at Sligo RTC involved examining in detail the impact of septic tank systems at three locations with different site conditions (Henry, 1990; summarised in Daly, Thorn and Henry, 1993). Piezometers were installed down-gradient; the distances of the furthest piezometers were 8 m,10 m and 9.5 m, respectively. Unsurprisingly, high faecal bacteria counts were obtained in the piezometers at the two sites with soakage pits, one with limestone bedrock at a shallow depth where the highest count (max. 14 000 cfu's per 1000 ml) and the second where sand/gravel over limestone was present (max 3 000 cfu's per 100 ml). At the third site, a percolation area was installed at 1.0 m b.g.l.; the subsoils between the percolation pipes and the fractured bedrock consisted of 1.5 m sandy loam over 3.5 m of poorly sorted gravel; the water table was 3.5 b.g.l. (So this site would satisfy the water table and depth to rock requirements of S.R.6:1991, and most likely the percolation test requirement.) Yet, the maximum faecal coliform bacteria count was 300 cfus per 100 ml. Faecal streptococci were present in all three piezometers. It is highly likely that wells located 30 m down gradient of the drainage fields would be polluted by faecal bacteria.

As viruses are smaller than bacteria, they are not readily filtered out as effluent moves through the ground. The main means of attenuation is by adsorption on clay particles. Viruses can travel considerable distances underground, depths as great as 67 m and horizontal migrations as far as 400 m have been reported (as reported in US EPA, 1987). The possible presence of viruses in groundwater as a result of pollution by septic tank systems is a matter of concern because of their mobility and the fact that indicator bacteria such faecal coliforms have been found not to correlate with the presence of viruses in groundwater samples (US EPA, 1987).

The natural environment, in particular the soils and subsoils, can be effective in removing bacteria and viruses by predation, filtration and absorption. There are two high risk situations: (i) where permeable sands and gravels with a shallow water table are present; and (ii) where fractured rock, particularly limestone, is present close to the ground surface. The presence of clayey gravels, tills, and peat will, in many instances, hinder the vertical migration of microbes, although preferential flow paths, such as cracks in clayey materials, can allow rapid movement and bypassing of the subsoil.

A.3 Nitrate

Nitrate is one of the most common contaminants identified in groundwater and increasing concentrations have been recorded in many developed countries. The consumption of nitrate rich water by young children may give rise to a condition known as methaemoglobinaemia (blue baby syndrome). The formation of carcinogenic nitrosamines is also a possible health hazard and epidemiological studies have indicated a positive correlation between nitrate consumption in drinking water and the incidence of gastric cancer. However, the correlation is not proven according to some experts (Wild and Cameron, 1980). The EC MAC for drinking water is 50mg/l.

The nitrate ion is not adsorbed on clay or organic matter. It is highly mobile and under wet conditions is easily leached out of the rooting zone and through soil and permeable subsoil. As the normal

concentrations in uncontaminated groundwater is low (less than 5 mg/l), nitrate can be a good indicator of contamination by fertilisers and waste organic matter.

In the past there has been a tendency in Ireland to assume that the presence of high nitrates in well water indicated an impact by inorganic fertilisers. This assumption has frequently been wrong, as examination of other constituents in the water showed that organic wastes - usually farmyard waste, probably soiled water - were the source. The nitrate concentrations in wells with a low abstraction rate - domestic and farm wells - can readily be influenced by soiled water seeping underground in the vicinity of the farmyard or from the spraying of soiled water on adjoining land. Even septic tank effluent can raise the nitrate levels; if a septic tank system is in the zone of contribution of a well, a four-fold dilution of the nitrogen in the effluent is needed to bring the concentration of nitrate below the EU MAC (as the EU limit is 50 mg/l as NO₃ or 11.3 mg/l as N and assuming that the N concentration in septic tank effluent is 45 mg/l).

The recently produced draft county reports by the EPA on nitrate in groundwater show high levels of nitrate in a significant number of public and group scheme supplies, particularly in south and southern counties and in counties with intensive agriculture, such as Carlow and Louth. This suggest that diffuse sources – landspreading of fertilisers – is having an impact on groundwater.

In assessing regional groundwater quality and, in particular the nitrate levels in groundwater, it is important that:

- (i) conclusions should not be drawn using data only from private wells, which are frequently located near potential point pollution sources and from which only a small quantity of groundwater is abstracted;
- (ii) account should be taken of the complete chemistry of the sample and not just nitrate, as well as the presence of *E. coli*.;
- (iii) account should be taken of not only the land-use in the area but also the location of point pollution sources;
- (iv) account should be taken of the regional hydrogeology and the relationship of this to the well itself. For instance, shallow wells generally show higher nitrate concentrations than deeper wells, low permeability sediments can cause denitrification, knowledge on the groundwater flow direction is needed to assess the influence of land-use.

A.4 Ammonia

Ammonia has a low mobility in soil and subsoil and its presence at concentrations greater than 0.1 mg/l in groundwater indicates a nearby waste source and/or vulnerable conditions. The EU MAC is 0.3 mg/l.

A.5 Potassium

Potassium (K) is relatively immobile in soil and subsoil. Consequently the spreading of manure, slurry and inorganic fertilisers is unlikely to significantly increase the potassium concentrations in groundwater. In most areas in Ireland, the background potassium levels in groundwater are less than 3.0 mg/l. Higher concentrations are found occasionally where the rock contains potassium e.g. certain granites and sandstones. The background potassium:sodium ratio in most Irish groundwaters is less than 0.4 and often 0.3. The K:Na ratio of soiled water and other wastes derived from plant organic matter is considerably greater than 0.4, whereas the ratio in septic tank effluent is less than 0.2. Consequently a K:Na ratio greater than 0.4 can be used to indicate contamination by plant organic matter - usually in farmyards, occasionally landfill sites (from the breakdown of paper). However, a K:Na ratio lower than 0.4 does not indicate that farmyard wastes are **not** the source of contamination (or that a septic tank is the cause), as K is less mobile than Na. (Phosphorus is increasingly a significant pollutant and cause of eutrophication in surface water. It is <u>not</u> a problem in groundwater as it usually is not mobile in soil and subsoil).

A.6 Chloride

The principle source of chloride in uncontaminated groundwater is rainfall and so in any region, depending on the distance from the sea and evapotranspiration, chloride levels in groundwater will be fairly constant. Chloride, like nitrate, is a mobile cation. Also, it is a constituent of organic wastes. Consequently, levels appreciably above background levels (12-15 mg/l in Co. Offaly, for instance) have been taken to indicate contamination by organic wastes such as septic tank systems. While this is probably broadly correct, Sherwood (1991) has pointed out that chloride can also be derived from potassium fertilisers.

A.7 Iron and manganese

Although they are present under natural conditions in groundwater in some areas, they can also be good indicators of contamination by organic wastes. Effluent from the wastes cause deoxygenation in the ground which results in dissolution of iron (Fe) and manganese (Mn) from the soil, subsoil and bedrock into groundwater. With reoxygenation in the well or water supply system the Fe and Mn precipitate. High Mn concentrations can be a good indicator of pollution by silage effluent. However, it can also be caused by other high BOD wastes such as milk, landfill leachate and perhaps soiled water and septic tank effluent.

Box A1 Warning/trigger Levels for Certain Contaminants As human activities have had some impact on a high proportion of the groundwater in Ireland, there are few areas where the groundwater is in a pristine, completely natural condition. Consequently, most groundwater is contaminated to some degree although it is usually not polluted. In the view of the GSI, assessments of the degree of contamination of groundwater can be beneficial as an addition to examining whether the water is polluted or not. This type of assessment can indicate where appreciable impacts are occurring. It can act as a warning that either the situation could worsen and so needs regular monitoring and careful land-use planning, or that there may be periods when the source is polluted and poses a risk to human health and as a consequence needs regular monitoring. Consequently, thresholds for certain parameters can be used to help indicate situations where additional monitoring and/or source protection studies and/or hazard surveys may be appropriate to identify or prevent more significant water quality problems.

Parameter	Threshold	EU MAC
	mg/l	mg/l
Nitrate	25	50
Potassium	4	12
Chloride	30 (except near sea)	250
Ammonia	0.15	0.3
K/Na ratio	0.3-0.4	
Faecal bacteria	0	0

Box A2 Summary : Assessing a Problem Area

Let us assume that you are examining an area with potential groundwater contamination problems and that you have taken samples in nearby wells. How can the analyses be assessed?

E. coli present \Rightarrow organic waste source nearby (except in karst areas), usually either a septic tank system or farmyard.

E. coli absent \Rightarrow either not polluted by organic waste or bacteria have not survived due to attenuation or time of travel to well greater than 100 days.

Nitrate > 25 mg/l \Rightarrow either inorganic fertiliser or organic waste source; check other parameters.

Ammonia > 0.15 mg/l \Rightarrow source is nearby organic waste; fertiliser is not an issue.

Potassium (*K*) > 5.0 *mg*/*l* \Rightarrow source is probably organic waste.

K/Na ratio > 0.4 (0.3, *in many areas*) \Rightarrow Farmyard waste rather than septic tank effluent is the source. If < 0.3, no conclusion is possible.

Chloride > 30 $mg/l \Rightarrow$ organic waste source. However this does not apply in the vicinity of the coast (within 20 km at least).

In conclusion, faecal bacteria, nitrate, ammonia, high K/Na ratio and chloride indicate contamination by organic waste. However, only the high K/Na helps distinguish between septic tank effluent and farmyard wastes. So in many instances, while the analyses can show potential problems, other information is needed to complete the assessment.

A.8 References

- Armon, R. and Kott, Y., 1994. The health dimension of groundwater contamination. In: Zoller, U. (Editor), Groundwater Contamination and Control. Published by Marcel, Dekker, Inc., pp71-86.
- Daly, D. 1996. Groundwater in Ireland. Course notes for Higher Diploma in Environmental Engineering, UCC.
- Daly, D., Thorn, R. and Henry, H., 1993. Septic tank systems and groundwater in Ireland. Geological Survey Report Series RS 93/1, 30pp.
- Gerba, C.P. and Bitton, G., 1984. Microbial pollutants : their survival and transport pattern to groundwater. In: G. Bitton and C.P. Gerba (Editors), Groundwater Pollution Microbiology, Wiley Intersciences Publishers, pp 65-88.
- Hagedoorn, C., McCoy, E.L. and Rahe, T. M. 1981. The potential for ground water contamination form septic tank effluents. Journal of Environmental Quality, volume 10, no. 1, p1-8.
- Henry, H. (1990). An Evaluation of Septic Tank Effluent Movement in Soil and Groundwater Systems. Ph.D. Thesis. Sligo Regional Technical College. National Council for Education Awards Dublin.
- Reneau, R.B. 1996. Personal communication. Virginia Polytechnic Institute and State University.
- Sherwood, M., 1991. Personal communication, Environmental Protection Agency.
- US EPA. 1987. Guidelines for delineation of wellhead protection areas. Office of Ground-water Protection, U.S. Environmental Protection Agency.
- Wild, A. and Cameron, K.C., 1980. Nitrate leaching through soil and environmental considerations with special reference to recent work in the United Kingdom. Soil Nitrogen Fertilizer or Pollutant, IAEA Publishers, Vienna, pp 289-306.

Appendix II

Chemistry Data for Bawnboy PWS

Appendix II - Chemistry Data for Bawnboy Source							
Bawnboy P.W.S. SI	Ballinamore Road						
Date	Residual Chlorine (mg/l)	T.Coli	E.Coli	рН	EC_Electrical conductivity us/cm	NO3 (Nitrate) mg/l	NO ₂ Nitrite mg/l
22/01/2001	0.16	0	0	7.11	346		
26/02/2001	0.02	0	0	7.59	349		< 0.01
26/03/2001	0.08	0	0	7.36	310		
30/04/2001	0.85	0	0	7.71	292		
29/05/2001	1.38	0	0	7.66	356		
25/06/2001	0.07	0	0	7.24	333		
30/07/2001	0.22	0	0	7.44	365		< 0.01
20/08/2001	0.06	0	0	7.27	282		
24/09/2001	0.12	0	0	7.43	377		< 0.01
22/10/2001	0.02	0	0	7.43	276		
19/11/2001	0.04	0	0	7.3	328		< 0.01
17/12/2001	0.09	0	0	7.28	377		
28/01/2002	0.09	0	0	7.08	334		0.027
25/02/2002	0.25	0	0	7.38	350		
25/03/2002	0.17	0	0	7.34	330		
22/04/2002	0.1	0	0	7.45	309		< 0.01
23/05/2002	0.03	0	0	7.37	314		
24/06/2002	0.02	0	0	7.44	304		< 0.01
31/07/2002	0.05	0	0	7.83	300		
26/08/2002	0.05	0	0	7.28	361		<0.01
23/09/2002	0.02	0	0	7.41	383		
07/10/2002	0.03	0	0	7.44			
18/10/2002	-						
29/10/2002	0.04	0	0	7.15	361		<0.01
25/11/2002	0.02	0	0	7.41	358		
16/12/2002	0.03	0	0	7.23	359		< 0.01
27/01/2003	0.02	0	0	7.08	327		
17/02/2003	0.05	0	0	7.2	338	2.65	< 0.01
19/03/2003	0.04	0	0	7.29	368		
28/04/2003	0.02	0	0	7.5	349	2.89	< 0.01

Date	Residual Chlorine (mg/l) T.Coli	E.Coli	рН	EC_Electrical conductivity us/cm	NO3 (Nitrate) mg/l	NO ₂ Nitrite mg/l
08/05/2003	0.03	3 0	7.46	280		
12/05/2003	0.04	0 0	7.35	332		
19/05/2003	0.04	0 0	7.38	291		
26/05/2003	0.03	0 0	7.35	314		
03/06/2003	0.02	0 0	7.44	357		
30/06/2003	0.04	0 0	7.32	393	2.13	0.047
28/07/2003	0.03	0 0	7.41	281		
30/07/2003						
25/08/2003		0 0	7.46	393	1.22	<0.01
22/09/2003		4 0	7.43	311		
30/09/2003		0 0	7.3	385		
05/10/2003		0 0	7.31	384		
15/10/2003		0 0	7.45	314	1.48	<0.01
29/10/2003		0 0	7.43	398		
17/11/2003		0 0	7.33	315		
22/12/2003		0 0	7.46	337	2.72	< 0.01
13/12/2006				438	3.63	< 0.02