County Kilkenny
Groundwater Protection Scheme

Volume II: Source Protection Zones and Groundwater Quality
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Dunmore Cave, County Kilkenny (photograph Terence P. Dunne)

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Sections 1 to 6 are contained within Volume I. They comprise an overall introduction, classifications of aquifers and vulnerability, and overall conclusions.

Overall conclusions are contained within Volume I.

7. Groundwater Quality

7.1 Introduction

This chapter aims to provide an overview of the groundwater quality characteristics of selected supply sources in County Kilkenny. Relationships are examined between water quality problems and human pressures, vulnerability, and well construction. An understanding of these relationships will help decision-makers prioritise:

- hazard surveys,
- remedial measures,
- well construction measures, and
- more detailed water quality monitoring.

This chapter is intended for use by engineers, planners, regulators and hydrogeologists who are considering the causes of groundwater quality problems across the county.

7.2 Scope

7.2.1 Key Concepts

The report is concerned with the causes of groundwater quality problems.

Assessments are built primarily upon laboratory analyses of raw water samples taken prior to treatment from some of the larger groundwater abstractions in County Kilkenny. Attention is focused upon the following selected indicators of contamination; nitrates, chloride, phosphates, ammonia, *E. coli* or faecal coliforms, potassium, sodium, iron and manganese. Concentrations of these indicators in each supply are compared with GSI recommended guide levels to help identify supplies which may become 'polluted' in the future.

As described in Appendix IV, the contaminant indicators are also helpful in diagnosing the following contamination hazards: landspreading, on-site waste-disposal systems (e.g. septic tank systems), and farmyard point hazards. Clearly, there are many other potential hazards, such as manufacturing industry and small commercial enterprises. Though individual pollution incidents related to these activities can be serious in terms of public health, they are likely to be localised, and rarely influence the regional groundwater quality situation. Consequently, such activities are not considered in this report.

7.2.2 Limitations

The distribution and causes of raw groundwater quality problems are discussed in the context of the contaminant indicators and contaminant hazards described above. Public health considerations are a matter for the relevant Health Authorities. Issues relating to other parameters, such as pesticides and hydrocarbons, and other activities, such as petroleum storage and sheep dipping, are not considered in this report.

No detailed, specific field hazard surveys have been undertaken by GSI. The assessments have been made on the basis of water quality data and cannot be used to link quality problems with specific enterprises unless they are accompanied by field hazard surveys. It is envisaged that any field hazard surveys that are required will be undertaken or commissioned by the Council and/or the relevant Health Authority.

Table 7.1: Inventory of Groundwater Supply Sources used in the Water Quality Assessment

Supply Source Name Used in this Report	Well Type	Rock Type[i]	RPZ[ii]	GSI Well Name	EPA Plot Number[iii]	Public/Group Scheme	Population Served	[iv]Typical discharge m^3/d	Depth Hole	Depth to Rock (m)	Depth well lining (m)	Treatment Process[v]	Potential for surface water ingress
Ahenure	Borehole	WAdo	Rf/L	2313NWW189		GWS	30	160	9.3		-	None	No
Balief/Clomantagh	Borehole	BM	Rk/E	2315NWW051		GWS	70	350	45.7	3.5	-	C	-
	Borehole		Rk/H	2315NW W052					61	3.1	-		-
Ballymack	Dug Well	Wado	Rf/H	2313NWW155		GWS	90	400	1.1	-	-	C	-
Baunmore	Dug Well	Gravel	Lg/H	2015NEW147	KK00100	GWS	50	30	-	-	-	C	Yes
Bausheenmore	Springs	BAdo	Rf/H	2313NEW069	KK00500	Not used	Not in use	>2,300	-	-	-	None	No
Belview proposed scheme	Boreholes	CA	Rf/H	2611SWW152		PWS	-	-	100	15	18	-	No
			Rf/H	2611SW W153					95	3	12		No
			Rf/E	2611SW W154					102	32	33		No
Bennettsbridge	Borehole	BAdo	Lg/H	2313NEW199		PWS	3,500	1250	100	10	11	C&F	Yes
Bennettsbridge	Infiltration Gallery	BAdo, Gravel	Lg/H	2313NEW237				1550	-	-	-		
Caherlesk	Borehole	KT	Rf/E	2313SWW131		GWS	100	70	59.9	0	-	None	-
Callan	Spring	Gravel	Rg/H	2313NWW273		PWS	2,300	1440	-	-	-	C&F	Yes
Castlecomer Yarns	Borehole	CQ	Pu/H	2317SEW255	KK00300	Industrial	-	460	67	20	21	Salt softener	No
Clara	Borehole	BM	Rk/H	2315SEW354	KK00400	GWS	30	140	37	7	10	-	No
Clomantagh "boiling well"	Spring	BM	Rk/H	2315NWW154	KK00900	Not used	-	7000	-	-	-	-	Yes
Cuffesgrange	Borehole	Wado	Rf/M	2315SEW281		GWS	50	120	12.2	12.2	-	-	No
Dunmore Sand&Gavel	Borehole	Gravel	Rg/H	2315NEW204	KK01000	Industrial	n/a	220	46	33	-	-	-
Dunmore	Borehole	Gravel	Rg/H	2315NEW253	KK00700	GWS	30	20	55	-	10	-	No
Galmoy	Borehole	CS	Lm/M	2017SEW309	KK00200	GWS	40	90	30.5	8	-	C	No
Glenmore	Spring	OA	Pl/E	2611NWW094		PWS	200	280	-	-	-	C	Yes
Graine/Craddockstown	Borehole	BM/ Gravel	Rk/H	2315NWW206		GWS	30	190	-	-	-	UV	No

Table 7.1: Inventory of Groundwater Supply Sources used in the Water Quality Assessment

Supply Source Name Used in this Report	Well Type	Rock Type[i]	RPZ[ii]	GSI Well Name	EPA Plot Number[iii]	Public/Group Scheme	Population Served	[iv]Typical discharge m^3/d	Depth Hole	Depth to Rock (m)	Depth well lining (m)	Treatment Process[v]	Potential for surface water ingress
Highrath	Borehole	BUdo/ Gravel	Rf/H	2315SEW351		GWS	60	140	43.3	-	-	None	No
Hugginstown	Borehole	KT	Rf/E	2313SEW157		GWS	20	160	91	-	-	None	No
Kilkenny Mart	Borehole	Gravel	Rg/H	2315SEW353	KK01300	Industrial	-	-	24	>24	-	-	No
Kilmanagh/Ballycallan	Borehole	Gravel	Rg/E	2315SWW226	KK01400	GWS	100	570	15.2	15.2	9.1	None	No
Kiloshulan/Barna	Borehole	BM	Rk/H	2315NWW205		GWS	20	220	-	-	-	C	No
Kilree Stoneyford	Spring	BAdo	Rf/E	2313NEW233		GWS	40	170	-	-	-	None	Yes
Maddoxtown	Borehole	BU/ Gravel	Ll/E	2315SEW352		GWS	40	130	-	-	-	C	No
Newtown Kells	Borehole	AG	Ll/M	2313NEW087		GWS	40	240	12.9	-	-	None	Yes
Paulstown-Gowran-Goresbridge	Spring	BU/ BM	Rk/E	2615SWW107	KK00600	PWS	2,000	2,900	-	-	-	C&F	Yes
Piltown	Springs	CI	Ll/E	2311NEW069		PWS	2,200	780	-	-	-	C&F	Yes
Thomastown BH5 (Creamery)	Borehole	CI	Ll/E	2313NEW234		PWS	2,000	2,600	67	12	63	C&F	No
Thomastown BH9 (GAA)	Borehole	CI	Ll/H	2313NEW236	KK01600				102	12	90		
Tubbrid Lower	Borehole	BM	Rk/E	2315NWW062		GWS	30	90	38.5	2	-	C	-
Tullahought	Borehole	AY	Pl/E	2313SWW167		GWS	10	70	26	-	-	None	No
Tullaroan	Borehole	Gravel	Rg/E	2315SWW096		GWS	80	230	12.2	-	-	UV & C	No
Urlingford/Johnstown	Springs	DW	Ll/E	2315NWW124	KK01500	PWS	1,300	810	-	-	-	C&F	Yes
Windgap	Borehole	CI	Ll/E	2313SWW168		GWS	60	110	91	-	-	None	No
Windgap Private	Artesian Borehole	KT	Rf/M	2313SWW132	KK01900	Domestic		1300	107.1	20	-	-	No

[i] Codes described in Map 1.
[ii] Aquifer type / Groundwater vulnerability. Codes described in Maps 5 and 6
[iii] Reference used in 'The Establishment of a Database for Groundwater in the South East Region of Ireland' (Keohane, 1994).
[iv] Spring supplies include overflow estimates. Group schemes estimated on the basis of the population served.
[v] Information from caretakers and County Council staff. UV - Ultra Violet. C – chlorine. F – Fluorine.

Note that this table comprises abstractions selected for the purposes of an overall assessment of water quality in County Kilkenny. It does not constitute a complete list of Public or Group Scheme groundwater abstractions in County Kilkenny. Data or inferences on abstractions and treatment methods have been obtained from Kilkenny County Council.

7.3 Methodology

7.3.1 Selection of Groundwater Supplies

Table 7.1 outlines the list of supplies under consideration.

Only groundwater supplies with high yields were selected. This was to ensure that samples collected were more representative of the groundwater quality in an area. Average daily discharge was the main selection criterion. Supply sources with less than 60 m^3/d were generally not considered. In the case of group schemes, where discharge data is generally not available, the discharge from the source was estimated by multiplying the number of houses and farms on the scheme (as supplied by the Council) by 0.65 m^3/d for each house and 15 m^3/d for each farm. Note that one domestic well was included (Windgap) on the basis that it is a flowing artesian well and therefore draws much more water than is used by the owners. Note also that it was assumed that the yields of two of the three industrial wells considered (Dunmore sand and gravel and Kilkenny Mart) are in excess of 60 m^3/d.

A total of thirty nine supply sources were included in the study, twelve public supply source abstraction points (nine of which are in use currently), twenty one group supply sources, three industrial supplies, two unused springs, and one domestic well. Locations are provided on Maps 4N and 4S.

7.3.2 Data Sources

The data used were derived from readily-available data on bacteriological and inorganic chemical analyses from late 1982 to early 2001. Data sources examined were the EPA (Environmental Protection Agency), the South Eastern Health Board, and specific sampling organised by the GSI (Geological Survey of Ireland). A detailed examination of other, less readily-available data sources such as individual academic theses or consultants' reports, was beyond the scope of the report.

Data were compiled from the following sources:

- EPA monitoring carried out between late 1992 and early 2001 by the EPA Regional Inspectorate, (Butts Green, Kilkenny). Data was supplied by the Environmental Protection Agency (EPA). All analyses were from raw water samples.
- Monitoring of Public groundwater supply schemes carried out by Kilkenny County Council between 1994 and 2000. Analyses were carried out by the EPA Regional Inspectorate (Butts Green, Kilkenny), the South Eastern Health Board, Waterford and Kilkenny County Council. Data was supplied by the Sanitary Services section of Kilkenny County Council.
- Monitoring of group groundwater supply schemes carried out by Kilkenny County Council between late 1999 and late 2000. Analyses were carried out by the EPA Regional Inspectorate (Butts Green, Kilkenny) and Kilkenny County Council.
- Geological Survey of Ireland sampling in October 2000 and April 2001, carried out in conjunction with the EPA and Kilkenny County Council. Analyses of major ions, total coliforms, *E.coli* and heavy metals were carried out by the EPA Regional Inspectorate, Butts Green, Kilkenny. All analyses were performed on raw water samples.
- Geological survey of Ireland spring sampling, carried out intermittently between late 1982 and late 1987. Major ion analyses, undertaken by the State Laboratory, are available.
- Monitoring of Group groundwater supply schemes carried out as part of the national monitoring project for private group water schemes co-ordinated by the Department of the Environment and Local Government (DoELG). Results for November and December 2000 and January 2001 were obtained from the DoELG. Only certain major ions and total coliforms and *E. coli* were analysed. It is understood that all analyses were performed on raw water samples.

7.3.3 Data Accuracy and Screening

- For samples taken after treatment, data on total coliforms, faecal coliforms / *E. coli*, were ignored unless counts were above 0/100 ml.
- Data was disregarded where there was a possibility that the waters sampled were a mix of ground and surface water.
- Data which was anomalous to the general trend in a given supply source was, where possible, verified with the lab that carried out the analysis. Where verifications were not possible, strongly anomalous data was omitted. This was often the case with ammonia results.
- Note that ionic balances were not carried out as very few results were available in which all major ions were analysed.

7.3.4 Data Analysis

The distribution of each of the key contaminant indicators was assessed in the context of groundwater vulnerability, aquifers, point hazards, and well construction:

- *Vulnerability:* A definition is provided in Volume I. For clarity, the four vulnerability categories were simplified to three: 'moderate-low', 'high', and 'extreme'.
- *Aquifers:* Contaminant migration potential is similar in most Irish bedrock aquifers and the main criterion used in this assessment was the presence of confined aquifers. Where aquifers are 'confined' by overlying rock layers or thick tills, they are usually afforded better natural protection and may provide better contaminant attenuation than 'unconfined' aquifers.
- *Point hazards:* The presence of point hazards close to a groundwater supply will often pose one of the most serious threats to its water quality. This is because contaminants from these hazards can by-pass the natural attenuation afforded by the subsoil. It is often difficult to distinguish point hazards (such as septic tanks and farmyards) from diffuse hazards (such as landspreading of farmyard wastes). However, given appropriate geological conditions, an elevated ratio of potassium to sodium ('K:Na') can provide evidence that 'dirty water' from a nearby farmyard source is contributing to (or causing) contamination in a supply. This issue is discussed further in Appendix IV.
- *Well construction:* The direct ingress of surface water or very shallow groundwater is a common cause of drinking water contamination. Specific information on well construction and wellhead protection measures is commonly only available for public groundwater supplies. However, inferences on these measures can be drawn from information on well depth, well casing depth, the potential for surface water inundation, and the type of source used (borehole, dug well, or spring). On this basis, the 39 supplies have been divided into:
  - Borehole supplies with evidence of good construction; available data indicates total depth in excess of 30 m and casing depth of 10 m or more.
  - Supply sources with evidence of poor construction; springs, dug wells, boreholes of less than 10 m depth and boreholes where there is a risk of surface water inundation.
  - Borehole supplies where the construction is assumed to be of intermediate quality.

The groundwater vulnerability, aquifers, point hazards, and well construction parameters have been combined into 5 categories:

- *Category 5:* Supply sources with evidence of poor construction (9 supplies in total).
- *Category 4:* Supplies where the K:Na ratio provides evidence of contamination from nearby farmyard point hazards (9 supplies in total).
- *Category 3:* Supplies with good or intermediate construction which are located in extreme vulnerability settings (8 supplies in total).
- *Category 2:* Supplies with good or intermediate construction which are located in high vulnerability settings (7 supplies in total)

- *Category 1:* Supplies with good or intermediate construction which are located in confined aquifers or moderate to low vulnerability settings (6 supplies in total).

These categories form the basis for describing the distribution of each key contaminant in Section 7.5.

Having examined the distribution in general terms, the supplies were grouped to provide a prioritisation for additional action measures. Groupings were made on the basis of concentrations of key contaminant indicators in relation to the European Union Maximum Admissible Concentration (MAC) and to the GSI guide levels as follows:

- *Group 1:* Sources in which one or more contaminant indicators in the available data set exceeded 10 counts / 100 ml for *E.coli*, or the EU MAC for the remaining indicators.
- *Group 2:* Sources which show concentrations of the contaminant indicators chloride, nitrate, ortho-phosphate, iron, manganese and potassium:sodium ratio GENERALLY in excess of the GSI guide levels (or *E.coli* >0 in any one sample). Some interpretation is required as levels in excess of these guide levels can reflect natural conditions in some cases (e.g. elevated potassium and/or iron can occur naturally in sandstone groundwaters).
- *Group 3:* Sources with slight anomalies in the analyses which may be naturally induced or indicative of some slight contamination (i.e. indicator levels OCCASIONALLY in excess of the GSI guide levels).
- *Group 4:* Sources showing no evidence of contamination from the analyses carried out for the project.

Results of the grouping exercise are outlined in Section 7.6. Section 7.7 uses the combination of contaminant indicators at each supply to provide some guidance on the generic type of hazards which might be influencing groundwater quality.

7.4 Groundwater Occurrence and Exploitation in County Kilkenny

7.4.1 Geology, Aquifers and Vulnerability

The vulnerability of the groundwater and the flow regimes within an aquifer both have a strong bearing on the ease with which contaminants can reach a supply source abstracting from it. Chapters 2 and 4 in Volume I discuss the geology and consequent aquifer characteristics in the county, while Chapter 5 of Volume I outlines the basis for vulnerability classifications.

Certain water quality issues can derive from natural conditions within the aquifers and subsoil. Depending on local hydrochemical processes such as oxidation and reduction, problems can include:

- Iron/manganese in sandstone and shaley limestone aquifers.
- Hydrogen sulphide in shaley limestone aquifers.
- Hardness in limestone aquifers.
- Corrosion in sandstone, mudstone, granite and volcanic aquifers where they are overlain by thin subsoil.

These issues are discussed further as part of aquifer classification in Chapter 4 of Volume I.

7.4.2 Exploitation

As described in Chapter 4 of Volume I, there are 9 public supply schemes and at least 143 group schemes supplied by groundwater in Kilkenny. Based on data taken from the County Council and from M.C. O'Sullivan Consulting Engineers (1999), the total daily public water usage in Kilkenny is estimated to be approximately 29,000 m^3/d, of which groundwater comprises approximately 9,000 m^3/d (one third of the total). Using additional data on the population served by each group scheme registered in Kilkenny, it is estimated that the total public and group scheme groundwater usage in Kilkenny is approximately 13,000 m^3/d. This estimate excludes households which are not served by the County Council or group water schemes. These households generally rely on individual private wells as their source of water.

7.5 Indicators of Groundwater Contamination

7.5.1 Introduction

GSI has developed guide levels for certain key chemical and microbiological parameters. These guide levels can be used to help indicate situations where the water quality of a groundwater supply source has been affected to a significant degree by certain human activities but not necessarily to the extent that concentrations exceed the EU MAC for drinking water. In essence, the indicators help identify groundwater supply sources which are *contaminated* but not necessarily *polluted*. The benefits of examining contamination in addition to pollution are:

- An 'early warning' can be provided for supplies which may become polluted in the future.
- Evidence of contamination may provide an indication that the supply is polluted at certain times of the year but that these incidences of pollution are not being identified by the existing monitoring regime.

Consequently, supplies with concentrations of indicator parameters above GSI guide levels may benefit from measures including additional monitoring, improved well head engineering, and hazard surveys, to help prevent more significant water quality problems.

In addition, an examination of the combination of indicator parameters exceeding GSI guide levels can provide valuable information on the cause of the water quality problems at a supply source. For example, depending on the nature of the geology, a ratio of potassium to sodium ('K:Na ratio') greater than 0.4 can be used to indicate contamination by plant organic matter - usually from farmyard 'dirty water', but occasionally from landfill sites (from the breakdown of paper). The use of contaminant indicators is described in more detail in Appendix IV.

The key indicators are given below, along with the GSI's guide levels and the EU MAC level:

Parameter	**GSI Guide Level** (mg/l)	**EU MAC** (mg/l)
Faecal bacteria	0	0
Nitrate	25	50
Potassium	4	12
Chloride	30	250
Ammonia	0.15	0.4
K/Na ratio	0.4	-
Phosphate (as P)*	0.02	2.2
Iron**	-	0.2
Manganese**	-	0.05

**Levels higher than the guide are likely to influence river phosphate problems where groundwaters contribute more than 50% of the annual flow to rivers.*
***Elevated levels of iron and manganese, though often influenced by the natural geology, can also provide an indirect indication of contamination.*

Sections 7.5.2 to 7.5.8 provide a discussion of each contaminant indicator in the context of:

- *Occurrence:* the number of supplies where one or more available analysis exceeds the GSI guide level or EU MAC.
- *Variation with time:* any water quality trends that are apparent in those supplies where sufficient data are available.
- *Distribution:* the links between contaminant levels, the vulnerability of the groundwaters feeding the supply, the inferred quality of the supply construction, and any chemical evidence of point hazards near the supply. The methodology is explained in Section 7.3.4.

Table 7.2 Groundwater Quality Classification of Selected Co. Kilkenny Groundwater Supply Sources

Group	Supply Source	Exceedances by Key Indicators of Contamination[1]								
		NO_3	Cl	PO_4	NH_x	*E.coli*[2]	K	K:Na	Fe	Mn
1	Ahenure	*Excess guide*			*Excess guide*	**excess 10**				**excess MAC**
	Balief Clomantagh	**excess MAC**			*Excess guide*	**excess 10**	*Excess guide*	*Excess guide*	**excess MAC**	
	Baunmore	*Excess guide*			*Excess guide*	**excess 10**	*Excess guide*	*Excess guide*		
	Bausheenmore	*Excess guide*	*Excess guide*	*Excess guide*		**excess 10**	*Excess guide*	*Excess guide*		
	Belview 3	**excess MAC**	*Excess guide*							
	Bennettsbridge[3]	*Excess guide*	*Excess guide*		*Excess guide*	**excess 10**				
	Callan	*Excess guide*		*Excess guide*		**excess 10**				
	Clara	*Excess guide*		*Excess guide*		**excess 10**				
	Clomantagh	*Excess guide*		*Excess guide*		**excess 10**	*Excess guide*	*Excess guide*		
	Cuffesgrange			*Excess guide*	*Excess guide*	**excess 10**	*Excess guide*	*Excess guide*		
	Dunmore Sand and Gravel					**excess 10**				**excess MAC**
	Dunmore	**excess MAC**			*Excess guide*	**excess 0**				
	Galmoy	**excess MAC**	*Excess guide*							
	Glenmore	**excess MAC**			*Excess guide*	**excess 10**				
	Graine/Craddockstown	**excess MAC**			*Excess guide*	**excess 0**				
	Highrath	*Excess guide*	*Excess guide*	*Excess guide*	*Excess guide*	**excess 10**	*Excess guide*	*Excess guide*		
	Hugginstown	*Excess guide*		*Excess guide*	*Excess guide*	**excess 10**	*Excess guide*	*Excess guide*		
	Kilkenny Mart	*Excess guide*				**excess 10**				
	Kilmanagh	*Excess guide*			*Excess guide*	**excess 10**			**excess MAC**	
	Kiloshulan/Barna	*Excess guide*		*Excess guide*	*Excess guide*	**excess 10**				
	Kilree Stoneyford	**excess MAC**		*Excess guide*	*Excess guide*	**excess 10**				
	Maddoxtown	**excess MAC**				**excess 0**				
	Paulstown	*Excess guide*	*Excess guide*	*Excess guide*		**excess 10**		*Excess guide*		
	Piltown			*Excess guide*		**excess 10**				
	Urlingford	*Excess guide*				**excess 10**	*Excess guide*	*Excess guide*		
	Windgap Group	**excess MAC**		*Excess guide*	*Excess guide*	**excess 0**				
	Windgap Private			*Excess guide*	**Excess MAC**	**excess 0**				
2	Ballymack	*Excess guide*				**excess 0**				
	Belview 1	*Excess guide*								
	Belview 2	*Excess guide*	*Excess guide*			**excess 0**				
	Caherlesk	*Excess guide*			*Excess guide*	**excess 0**				
	Newtown Kells	*Excess guide*			*Excess guide*	**excess 0**	*Excess guide*			
	Thomastown GAA	*Excess guide*	*Excess guide*	*Excess guide*		**excess 0**				
	Tubbrid Lower	*Excess guide*				**excess 0**				
	Tullahought	*Excess guide*		*Excess guide*	*Excess guide*					
3	Castlecomer Yarns			*Excess guide*					**excess MAC**	**excess MAC**
	Thomastown Creamery			*Once in excess of*						
	Tullaroan	*Excess guide*								
4										

[1] *NO_3: Nitrate. Cl: Chloride. PO_4: Phosphate. NH_x: Ammonia. K: Potassium. K:Na ratio: potassium:sodium ratio. Fe: Total Iron. Mn : Manganese. NH_x: Ammonia.*

[2] *These figures represent mainly untreated samples. They are not necessarily indicative of human health concerns.*

[3] *For the purposes of the grouping exercise, the borehole and gallery abstractions have been included together at Bennettsbridge because only one raw sample is available from the borehole. The data are therefore insufficient to group the borehole separately.*

7.5.2 E.coli

Background: E. coli is commonly analysed because it is easily detected and identified, and because it originates in the intestine, along with many pathogenic organisms. More information is provided in Appendix IV.

*Occurrence***:** Summary water quality information for each supply source is presented in Table 7.2, and in graphical form in Appendix VI. Analytical results are presented in Appendix V. Key points to note are as follows:

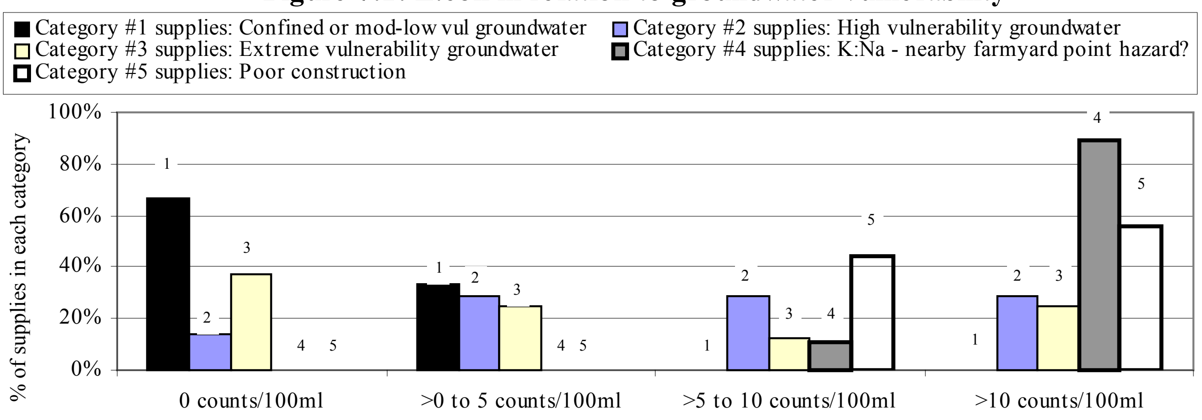
- *E. coli* or faecal coliforms are in excess of 0 counts/100 ml in one or more raw water samples from thirty one (80%) of the thirty nine supply sources.
- One or more raw water samples are greater than 10 counts per 100 ml in twenty supplies (50% of all supplies studied), including six out of nine currently used public supply abstraction points and ten out of twenty-one group scheme supplies examined.

It is stressed that these figures do not necessarily represent human health concerns. Samples are mainly of 'raw waters', having been taken from points prior to water treatment at the supplies.

Variations with time: No strong trends were detected.

Distribution: Results are presented in Figure 7.1 and the methodology is explained in Section 7.3.4.

Figure 7.1: E.coli in relation to groundwater vulnerability



The key points to note are as follows:

- There is a clear link between well construction, proximity to point hazards and high levels of *E.coli* in raw water samples. Categories 4 and 5 on Figure 7.1 comprise eighteen supplies where there is some chemical evidence of contamination from a nearby farmyard point hazard, or where there is evidence that the well construction measures are limited. Of these eighteen supplies, all had at least one *E.coli* result in excess of 5 counts /100 ml, and most of them had *E.coli* levels in excess of 10 counts/100 ml.
- There is also a clear link between low levels of *E.coli* and lower groundwater vulnerability. There are six supplies which are properly constructed and which draw groundwater from either a confined aquifer, or from moderate to low vulnerability groundwater (category 1 on Figure 7.1). No results available from these six supplies exceeded 5 counts /100 ml, whilst no *E.coli* was detected in any available samples from four of the six supplies.
- In areas of high and extreme vulnerability (categories 2 and 3 on Figure 7.1), there is no clear link with *E.coli* levels. This is despite the fact that there should be enough natural attenuation capacity to reduce *E.coli* released at surface to low levels even in high vulnerability areas. This suggests that subsurface point hazards such as poorly-constructed or poorly located on-site wastewater treatment systems are contributing to *E.coli* levels in Kilkenny's groundwaters. Where contaminants are released underground, the potential for attenuation

within the subsoil pathway will be significantly reduced. The influence of subsurface point hazards would be expected to be significantly greater in high and extreme vulnerability areas because the mapped subsoil thickness in these areas will generally be much less than in moderate and low vulnerability areas.

7.5.3 Nitrate

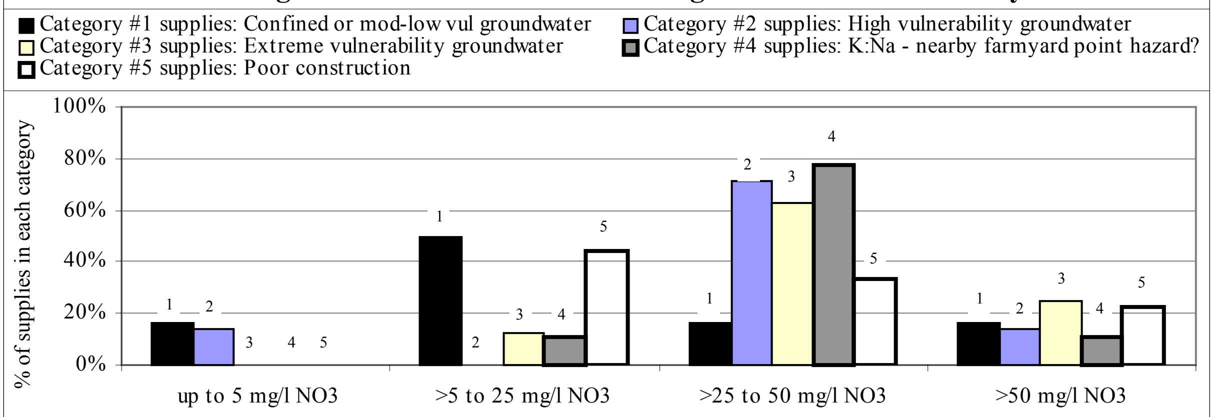
Background: As the normal concentration in uncontaminated groundwater is low (less than 5 mg/l), nitrate can be a good indicator of contamination by fertilisers and waste organic matter. The nitrate ion is not adsorbed on clay or organic matter. It is highly mobile, and under wet conditions is easily leached out of the rooting zone and through soil and permeable subsoil. Consequently, groundwater nitrate concentrations are more influenced by dilution and less influenced by groundwater vulnerability than concentrations of parameters such as *E.coli* or ammonia. More information is provided in Appendix IV.

Occurrence: Summary water quality information for each supply source is presented in Table 7.2, and in graphical form in Appendix VI. Analytical results are presented in Appendix V. Key points to note are as follows:

- Of the thirty nine supply sources, nine (23%) have nitrate levels in excess of the EU MAC, while nineteen (49%) have two or more exceedances of the GSI guide level. An explanation of the GSI guide level and the EU MAC is provided in Section 7.5.1.
- Of the available data from the nine currently used public supply abstraction points examined, five (56%) have exceedances of the GSI guide level on at least two occasions. Of available data from the twenty one group schemes examined, ten (48%) have exceedances of the GSI guide level on at least two occasions.
- Only seven supplies have all available sample results below the GSI guide level of 25 mg/l. Of these, only three supplies could be described as having levels of nitrate sufficiently low to indicate no contamination from human activities. These are Castlecomer Yarns, Windgap domestic well and Dunmore Sand and Gravel.

Variations with time: Of the thirty nine supply sources examined, eighteen have data spanning five or more years. Of these eighteen, only five demonstrate a trend over time. Nitrate levels in Baunmore, Paulstown and Galmoy follow an overall upward trend, with levels in excess of GSI guide levels in most samples since 1997. Levels in Clomantagh and Dunmore group scheme have generally decreased since 1997.

Figure 7.2: Nitrates in relation to groundwater vulnerability



Distribution: Results are presented in Figure 7.2 and the methodology is explained in Section 7.3.4. Key points to note are as follows:

- Consistently low levels of nitrate were <u>not</u> found in the eighteen category 4 and 5 supplies where either the well construction was limited or where there was some chemical evidence of contamination from a nearby farmyard point hazard.

- Elevated nitrate levels can occur even in supplies located in generally moderate and low vulnerability areas (category 1 supplies on Figure 7.2). This is to be expected, given the mobility of nitrate in the subsurface environment.
- As described above, the available data suggest that elevated nitrates are relatively widespread in Kilkenny. Two of the three supplies with no evidence of nitrate contamination (Castlecomer Yarns, and Windgap domestic) both draw their water from deep confined aquifers in upland settings. Of the twenty-two supplies situated in the Limestone Lowlands, available results from most are typically in excess of 15 to 25 mg/l as NO_3. The largest source, Bausheenmore springs, discharges water from both deep and shallow dolomites and limestones. Due to the size of the discharge, and its location, it is believed to be representative of typical nitrate levels across the limestone lowlands. Available concentration data from this spring (presented in Appendix VI) are typically around 25 mg/l as NO_3.
- Lowest nitrate levels appear to be restricted to supplies with good well construction and large yields, which are drilled into deeper aquifers. Most aquifers of this type occur in the Castlecomer Plateau and Southern Uplands. In the Central Lowlands, future boreholes may have low nitrate levels if they are deep, of good construction, and drilled within large areas of moderate to low vulnerability groundwater away from point hazards. Of the supply sources sampled, only Ahenure occurs within a low vulnerability limestone area. This source has nitrate, bacteria and ammonia problems, which are thought to be associated with poor well construction and nearby point sources (refer to Section 7.7). Consequently, Ahenure is not regarded as representative of groundwater quality in lower vulnerability limestone areas.

7.5.4 Ammonia

Background: Ammonia concentrations in excess of 0.15 mg/l (as NH_3 or NH_4) are generally indicative of contamination from organic wastes and indicate that pathogenic micro-organisms may also be present (Flanagan, 1992). Ammonia has a low mobility in soil and subsoil and its presence at concentrations greater than 0.15 mg/l in all but the most vulnerable groundwater indicates a nearby point organic waste hazard and/or poor well construction. More information is provided in Appendix IV.

Occurrence: Summary water quality information for each supply source is presented in Table 7.2, and in graphical form in Appendix VI. Analytical results are presented in Appendix V. Key points to note are as follows:

- Eighteen of the thirty nine supplies each have one exceedance of the GSI guide level (47%). This includes one supply (Windgap domestic) which also exceeded the MAC, though this occurred in one sample from 1993 and has not re-occurred in the six available samples since that time. An explanation of the GSI guide level and the EU MAC is provided in Section 7.5.1.
- Of the nine currently used public supply abstraction points examined, available data from two (22%) exceed the GSI ammonia guide level on one occasion each. Of the twenty one group schemes examined, available data from fifteen (71%) are in excess of the GSI guide level.
- There is a close link between the occurrence of ammonia and *E.coli* contamination. *E.coli* was detected in seventeen of the eighteen supplies where elevated ammonia was also found.

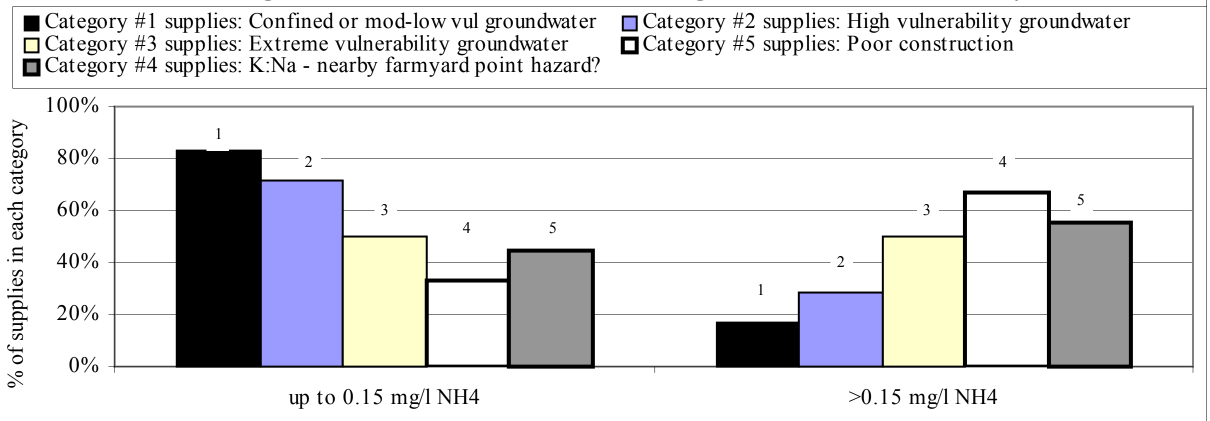
Variations with time: Levels are generally low and no temporal or seasonal variations can be detected.

Distribution: Results are presented in Figure 7.3 and the methodology is explained in Section 7.3.4. There is a link between vulnerability, well construction, proximity to point hazards and ammonia levels:

- Most supplies in moderate-to-low and high vulnerability groundwaters (categories 1 and 2 in Figure 7.3) have low levels of ammonia, while most supplies which are poorly constructed or located close to point hazards (categories 4 and 5) have elevated levels of ammonia.

- As with *E.coli*, the link between ammonia and vulnerability is stronger in moderate and low vulnerability groundwaters than in extreme vulnerability groundwaters. This is despite the fact that there should be enough natural attenuation capacity to reduce ammonia released at surface to low levels even in high vulnerability areas. This suggests that subsurface point hazards such as poorly-constructed or poorly located on-site wastewater treatment systems are contributing to ammonia levels in Kilkenny's groundwaters. Where contaminants are released underground, the potential for attenuation within the subsoil pathway will be significantly reduced. The influence of subsurface point hazards would be expected to be significantly greater in high and extreme vulnerability areas because the mapped subsoil thickness in these areas will generally be much less than in moderate and low vulnerability areas.

Figure 7.3: Ammonia in relation to groundwater vulnerability



7.5.5 Chloride

Background: Chloride, like nitrate, is a mobile cation. It is a constituent of organic wastes and levels appreciably above background levels (say in excess of 30 mg/l) have been taken to indicate contamination by organic wastes such as on-site systems (septic tanks). More information is provided in Appendix IV.

Occurrence: Summary water quality information for each supply source is presented in Table 7.2, and in graphical form in Appendix VI. Analytical results are presented in Appendix V. Key points to note are as follows:

- Of the thirty nine supply sources examined, eight (20%) have several sample results in excess of the GSI guide level of 30 mg/l. An explanation of the GSI guide level and the EU MAC is provided in Section 7.5.1.
- Of the nine currently used public supply abstraction points examined, only results from the Thomastown GAA borehole are regularly in excess of the GSI guide level. Note that Belview 3 has reported chloride levels of 41 to 43 mg/l, but is located 2 km from an estuary. Consequently, levels here may be naturally higher, as a result of higher salt levels in coastal rainfall.

Variations with time: Four of the eight supply sources with elevated chloride have data for over five years. None of these datasets demonstrate a discernible temporal or seasonal pattern.

Distribution: Chloride is a conservative ion, and levels are not expected to be influenced by groundwater vulnerability or aquifer type. Further, chloride in itself is not a contaminant of concern and is mainly studied in combination with other contaminants to help identify possible hazards.

7.5.6 Potassium and sodium

Background: The potassium:sodium 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 potassium:sodium ratio greater than 0.4 can be used, subject to some geological constraints, to indicate contamination by plant organic matter - usually from poorly managed farmyard 'dirty water', and occasionally landfill sites (from the breakdown of paper). More information is provided in Appendix IV.

Occurrence: Summary water quality information for each supply source is presented in Table 7.2, and in graphical form in Appendix VI. Analytical results are presented in Appendix V. Key points to note are as follows:

- Of the thirty nine supply sources examined, available potassium:sodium ratios from nine (23%) are in excess of the guide level of 0.4. An explanation of the GSI guide is provided in Section 7.5.1. Only one of the nine supplies occurs in sandstones, granites or mudstones, where the ratio might have been affected by naturally elevated potassium. Further, ratio peaks in all nine supplies are coincident with peaks in either *E.coli*, ammonia or nitrate. Consequently, it is thought unlikely that the elevated ratios are due to natural, geological causes in any of the nine supplies.
- Of the nine supply sources, five are group schemes and two are public schemes.

Variations with time: No long term trends are apparent in the available data set.

Distribution: The elevated levels found in the Bausheenmore springs are worthy of some additional discussion. Concentrations of potassium and sodium in five of the seven available samples are such that their ratio is above or close to the guide level of 0.4 (depicted in Appendix VI). Given the high discharge from the Bausheenmore springs, it is likely that the influence of potassium from of one or two farmyard point hazards would be diluted to low levels. Diffuse landspreading of organic and inorganic fertiliser are therefore also thought to be a possible influence on potassium concentrations. Potassium is relatively immobile in soil and subsoil and potassium spread on the soil surface will generally attenuate before reaching groundwater. However, in areas of extreme vulnerability, intensive applications of potassium may result in elevated potassium levels. The area upslope of the springs is mapped as generally extreme (as is a significant proportion of the limestone lowlands of Kilkenny) and occurs within a region of intensive agriculture. Consequently, it is considered that landspreading of slurries, manures and inorganic fertilisers may be contributing to elevated potassium levels across the catchment of the spring, and, by inference, across much of the limestone lowlands of Kilkenny where the vulnerability is extreme.

7.5.7 Iron and Manganese

Background: Although they are present under natural conditions (groundwater in muddy limestones, shales and boggy areas may contain high iron and manganese), they can also be good indicators of contamination by organic wastes. High manganese concentrations can be a good indicator of pollution by silage effluent and other high BOD wastes such as milk, landfill leachate and perhaps soiled water and septic tank effluent. More information is provided in Appendix IV.

Occurrence: Summary water quality information for each supply source is presented in Table 7.2, and in graphical form in Appendix VI. Analytical results are presented in Appendix V. Key points to note are as follows:

- Of the thirty nine supply sources examined, a proportion of the available samples from five (13%) were in excess of the EU MAC for iron or manganese.
- None of the five supplies in excess of the EU MAC for iron or manganese are public supplies. Three of the supplies are group schemes (Ahenure, Balief/Clomantagh and Kilmanagh) and two are industrial (Castlecomer Yarns and Dunmore sand and gravel).

Variations with time: No long term trends are apparent in the available data sets.

Distribution: Summary water quality information for each supply source is presented in Table 7.2, and in graphical form in Appendix VI. Key points to note are as follows:

- Of the five supply sources with elevated iron or manganese, one (Castlecomer Yarns) is situated within a sandstone aquifer. Given the absence of nitrate, chloride or *E.coli* problems in the available data set, it is likely that the high iron and manganese in this source is naturally derived from the sandstones, coals and muddy sandstones of the Castlecomer Plateau.
- The remaining four supply sources with elevated iron or manganese are all drawing water from relatively clean limestones (or overlying gravels) and consequently would not normally be associated with high natural levels of iron and manganese. Further, three also have ammonia problems; Ahenure, Balief/Clomantagh and Kilmanagh. Both ammonia and iron/manganese are often associated with reducing conditions in groundwaters contaminated by organic effluent. Consequently, iron and manganese levels in Ahenure, Balief/Clomantagh and Kilmanagh are thought to indicate groundwater contamination by organic effluent. The manganese problems in Dunmore sand and gravel may be associated with organic contamination, but the evidence is weaker.

7.5.8 Phosphate

Background: The principal significance of phosphate is as a cause of eutrophication in surface water. Sources of phosphate include slurries, dirty water, inorganic fertilisers, farmyard runoff and detergents. Phosphate is strongly adsorbed onto soil but can show enhanced leaching to groundwater in coarse subsoils, thin subsoils, and areas with a shallow watertable, amongst others (Kilroy et al 1999). Consequently, elevated levels in groundwater generally occur if the vulnerability is extreme or if point sources of phosphate are present.

Occurrence: Summary water quality information for each supply source is presented in Table 7.2, and in graphical form in Appendix VI. Analytical results are presented in Appendix V. Key points to note are as follows:

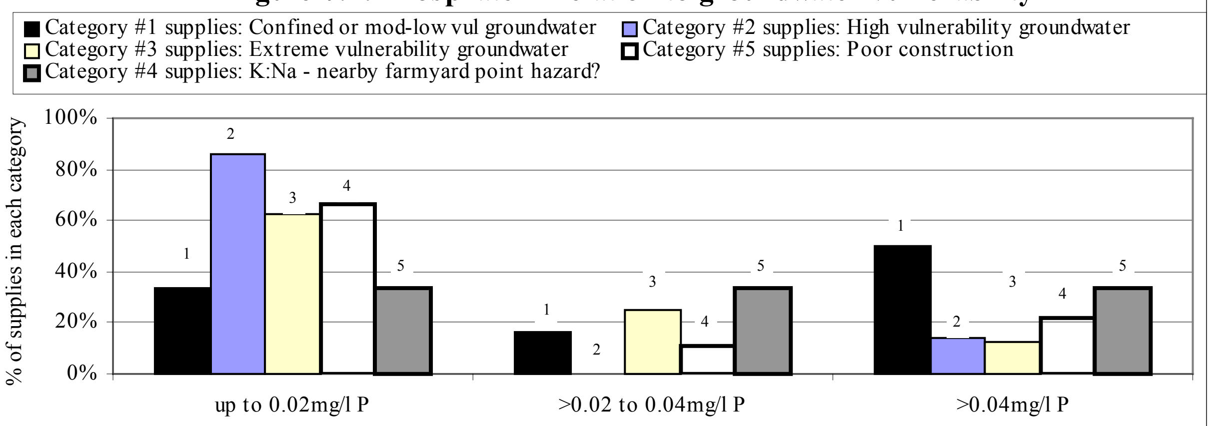
- Of the thirty nine supply sources examined, available data from sixteen (41%) exceed the guide level of 0.02 mg/l (as P) for ortho-phosphate. An explanation of the GSI guide level and the EU MAC is provided in Section 7.5.1.
- These sixteen supplies include five of the nine currently used public supply abstraction points examined (56%), and seven of the twenty one group water schemes examined (33%).

It is stressed that these levels do not necessarily represent human health concerns. The guide levels are set because phosphate in groundwater can contribute to surface water eutrophication problems.

Variations with time: No one supply source has more than seven ortho-phosphate data points, and no trends were apparent.

Distribution: Results are presented in Figure 7.4 and the methodology is explained in Section 7.3.4.

Figure 7.4: Phosphate in relation to groundwater vulnerability



Key points to note are as follows:

- Given the potential for phosphate to adsorb within soil materials, it would be expected that levels would be relatively low in most vulnerability situations. The presence of phosphate levels in excess of 0.01 to 0.02 mg/l PO_4 in all vulnerability types and in a number of supply sources studied suggests that underground point hazards are contributing to many of the contamination problems identified in this study.
- As with the potassium:sodium ratio, the presence of elevated levels of phosphate in samples from Bausheenmore springs (up to 0.08 mg/l P in 1993) suggests that landspreading of slurries, manures and inorganic fertilisers may be contributing to phosphate levels across the catchment of the spring, and, by inference, across much of the limestone lowlands of Kilkenny where the vulnerability is extreme. The groundwater contribution to the Nore in the vicinity of Bausheenmore (i.e. between Kilkenny City and Thomastown) is thought to be significant. Consequently, groundwaters with elevated phosphate are likely to be contributing to surface water quality problems in the Nore along this stretch.

7.6 General Groundwater Quality Assessment of Supply Sources

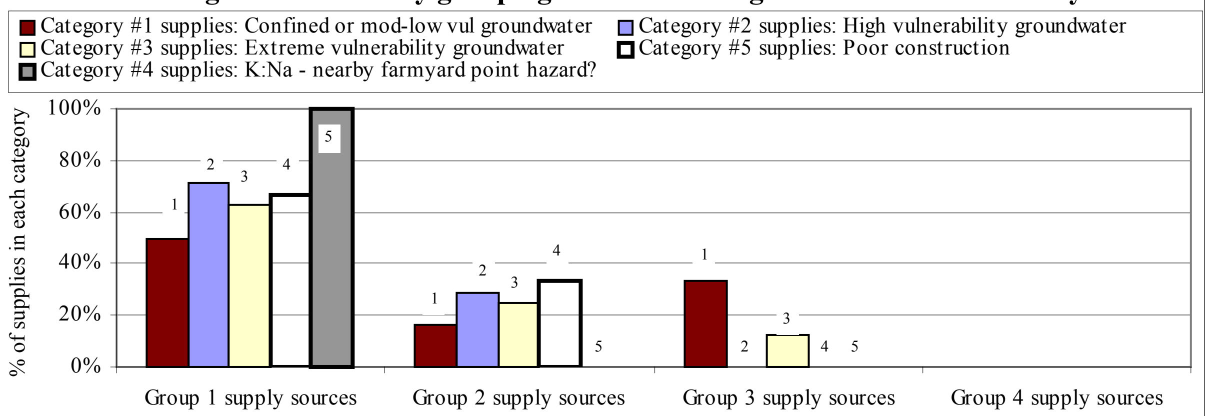
7.6.1 Introduction

The previous Section examined the distribution of contaminant indicators across Kilkenny. Section 7.6 aims to group supplies with a view to providing a prioritisation which could be used to plan additional action measures. The grouping methodology is described in Section 7.3.4. In essence, there are four groups, with supplies in Groups 1 and 2 having the highest levels of contamination.

7.6.2 Discussion

Table 7.2 provides the results, while Figure 7.5 depicts the relationships between the numbers of supplies in Groups 1 and 2 with well construction, information on farmyard point hazards, and vulnerability.

Figure 7.5: Priority groupings in relation to groundwater vulnerability



Points to note are as follows:

- Of the thirty nine supply sources considered, 71% occur in Group 1, 21% in Group 2 and 8% within Group 3. No supplies have been categorised within Group 4.
- Well construction and proximity to point hazards are a significant influence on overall water quality in a supply. None of the supplies with apparently poor construction occurred in Group 3 (the group comprising the least contaminated supplies).
- However, the adequate construction and siting of a supply cannot guarantee low levels of contaminants. The data appear to confirm that the vulnerability of groundwaters feeding a

supply is also an important factor. Of the three Group 3 supplies (the group comprising the least contaminated supplies), two were located in confined or moderate to low vulnerability groundwaters. Of the twenty eight Group 1 supplies (the group comprising the most contaminated supplies), only three are considered to have adequate construction, and these three supplies are all located in an area of extreme or high groundwater vulnerability.

- However, lower vulnerability situations cannot guarantee low levels of contaminants. Two of the six supplies in lower vulnerability situations were classed as Group 1 (the group comprising the most contaminated supplies). Contaminant indicators other than the potassium:sodium ratio suggest that both of these supplies are located close to subsurface point hazards such as poorly-constructed or poorly located on-site wastewater treatment systems (e.g. septic tanks).

7.7 Appraisal of Water Quality Issues at Specific Supply Sources

As discussed in Section 7.2.2, no field hazard surveys have been undertaken as part of this report. Assessments have been made on the basis of water quality data and cannot be used to link quality problems with specific enterprises unless they are accompanied by field hazard surveys. Nevertheless, in order to provide some initial guidance, the combination of contaminant indicators at each supply has been assessed in the context of generic hazard types. Results are presented in Table 7.3.

Table 7.3. Generic Hazard Types Influencing Selected Groundwater Supplies in County Kilkenny

Releases of domestic or agricultural organic wastes likely to have influenced groundwater quality			
Evidence of point releases		Evidence of diffuse releases	Releases may be point and / or diffuse
Elevated K:Na ratios	*Combination of indicators such as E.coli and ammonia in high, moderate or low groundwater vulnerability settings*	*High-yielding springs with elevated nitrate, potassium and phosphate **	*The origin cannot be discerned using quality data & vulnerability mapping alone*
Possible farmyard hazard nearby	*Possible hazards include nearby septic systems and/or sewerage pipes and/or farmyard hazards.*		
Balief, Baunmore, Clomantagh, Cuffesgrange, Highrath, Hugginstown, Urlingford.	Ahenure, Dunmore, Graine, Kilmanagh, Kiloshulan/Barna, Kilree Stoneyford, Maddoxtown, Windgap Group, Windgap Private, Newtown Kells, Thomastown GAA.	Bausheenmore, Paulstown.	Belview 3, Bennettsbridge, Callan, Clara, Dunmore Sand and Gravel, Galmoy, Glenmore, Kilkenny Mart., Piltown, Ballymack, Belview 1, Belview 2, Caherlesk, Tubbrid Lower, Tullahought.

** Discharge is such that releases from one or two poorly-maintained farmyards may not be sufficient to produce the measured potassium and phosphate concentrations.*

7.8 Conclusions

- *E. coli* or faecal coliforms are in excess of 0 counts per 100 ml in at least one raw water sample from 80% of the supply sources examined. Further, at least one raw water sample from 51% of all supplies has greater than 10 counts per 100 ml. Ammonia follows a similar pattern. It appears that lowest levels of *E.coli* and ammonia are found in supplies that are properly constructed and that are located in confined or moderate-to-low vulnerability groundwaters. Levels are generally higher in supplies that are poorly constructed or that are located in high to extreme vulnerability groundwaters in the vicinity of subsurface point hazards.

- Nitrates are in excess of 50 mg/l NO_3 in at least one sample from 23% of all supplies studied while 56% of all supplies have two or more exceedances of the GSI indicator guide level of 25 mg/l. Lowest nitrate levels appear to be restricted to supplies which have large yields, which have been drilled into deeper aquifers, and which are constructed so as to prevent the ingress of surface water and shallow groundwater.

- In combination with inferences from vulnerability mapping, the contaminant indicators suggest that point releases of domestic or agricultural organic wastes, such as poorly-managed farmyard 'dirty water' and poorly-located or poorly-constructed on-site wastewater treatment systems (e.g. 'septic tanks'), are a significant influence on groundwater quality across the county.
- Iron and manganese are in excess of the EU MAC as a result of the natural geological conditions in one supply (Castlecomer Yarns) and in excess of the EU MAC as a result of contamination in a further four supplies. Naturally high iron and manganese are expected in several aquifers in Kilkenny.
- Phosphate is in excess of the guide level of 0.02 mg/l P in 40% of the supplies examined, including two very large limestone springs. Groundwater phosphate levels are likely to be an influence on river water phosphate levels in the Nore and the Barrow in County Kilkenny.
- Natural water quality problems can also occur. Sandstones, shaley limestones, and the deeper, confined aquifers can be associated with iron and manganese problems. Hardness problems can be associated with the limestone aquifers, while low pH and corrosion problems can occur where the older aquifers in the south of the county coincide with thin or peaty subsoil cover.

7.9 Recommendations

- In order to try to minimise the potential for contamination, new supplies would ideally comprise boreholes drawing water from confined aquifers or from moderate to low vulnerability groundwater in areas away from point hazards such as poorly maintained farmyards. These boreholes would preferably be constructed so as to seal off shallow groundwater strikes and to eliminate the potential for surface water ingress to the well. The bottled water standards produced by the Irish Standards Authority give guidance as to the correct procedure for well production and maintenance (EOLAS, 1992).
- Hazard surveys are recommended for Group 1 and 2 sources to remove or improve contaminant hazards. For public supplies where source protection areas have been delineated, these surveys should be conducted within the source protection areas identified as part of the groundwater protection scheme. Priority surveys might first concentrate within the inner source protection areas (SI) of each supply. For group scheme and industrial supplies where no source protection areas have been delineated, surveys might best begin within an area between 300 m downslope and 500 m upslope for boreholes and between 100 m downslope and 1 km upslope for large springs.
- Sampling of raw water as well as treated water is recommended for all supplies on a regular basis. Full analyses (including major ions) are also recommended. The frequency of sampling is best determined by the degree of concern at each supply. The following is recommended:

Group	Number of Supply Source Abstraction Points in Each Group	Recommended Raw Water Sampling Frequency
Group 1	28	At least *monthly*, until conclusions can be drawn on the origin of the contamination and appropriate alleviation measures are taken. Then down-grade to Group 3 sampling frequency.
Group 2	8	At least *quarterly*, until conclusions can be drawn on the origin of the contamination and appropriate alleviation measures are taken.
Group 3	3	At least *quarterly*.
Group 4	0	At least *twice yearly*.

In addition to the usual analytes, indicators of petroleum, sheep dip, pesticides and herbicides should also be examined, perhaps on a less frequent basis (e.g. twice yearly).

7.10 Acknowledgements

The following people provided water chemistry information:

- Dermot Druhan, Sanitary Services, Kilkenny County Council.
- Caroline Bowden and Michael Neill, EPA Regional Inspectorate, Butts Green, Kilkenny.
- Carthage Cusack, Department of the Environment.

The following organisations carried out analysis specifically for this report:

- EPA Regional Inspectorate, Butts Green, Kilkenny.
- EPA Regional Inspectorate, Pottery Road, Dun Laoghaire, County Dublin.

The following people collected water samples specifically for this report:

- Mícheál Daly, Kilkenny County Council.
- Christy Murray, EPA Regional Inspectorate, Kilkenny.

8. Bennettsbridge Source

8.1 Introduction

The objectives of this chapter are:

- To delineate source protection zones for the Bennettsbridge Water Supply Scheme.
- To outline the principal hydrogeological characteristics of the Bennettsbridge area.
- To assist Kilkenny 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. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

8.2 Location and Site Description

During GSI's investigations, the Bennettsbridge public drinking water source comprised two elements; a borehole drilled into rock in 1999, and an infiltration gallery constructed in the 1960's into sands and gravels alongside the River Nore. The location of the Bennettsbridge source is shown on Map 4S and 8. Both the borehole and gallery are located in the townland of Knockanore, 5 km south of Bennettsbridge.

During GSI's investigations, water from the borehole was pumped into the infiltration gallery, which fed a pump sump beneath the nearby pump-house via a gravity main. For the summer months, the supply was augmented with water from the Nore.

There are three access manholes to the infiltration gallery set 120 m apart, and no less than 16 m back from the river's edge, with each consisting of a 1.8 m high concrete cylinder. This height of cylinder prevents inundation of the gallery by river water during most flood events. The borehole is situated about 10 m from the most southerly infiltration gallery entrance, with it's top raised 26 cm from the ground level. Although a large diameter pipe exits from the borehole, the top is not sealed around the pipe edge, and during flood events in the winter, the borehole is at risk of inundation.

Note that, since the Protection Scheme for Kilkenny was completed, the County Council have indicated that additional drilling and well-head protection works are planned for Bennettsbridge:

- Additional borehole drilling to remove the need for river water augmentation. The original arrangement whereby the borehole drilled in 1999 discharged directly into the infiltration gallery will be terminated in 2002 and all boreholes will pump directly to the pump house.
- The borehole well-heads on the river bank will be constructed so as to avoid the risk of inundation from the river.

The County Council have indicated that the planned capacity for the infiltration gallery and new well field is intended to be approximately 33,000 gallons per hour (3600 m^3/day). This figure is some 30% higher than the abstraction rates quoted in Section 8.3. The County Council have indicated that the abstraction rates quoted in Section 8.3 should be used in the assessments at Bennettsbridge. However, should the planned rate be attained in the future, the size of the source protection areas delineated in this document may require re-evaluation.

8.3 Summary of Source Details

	Borehole	**Infiltration Gallery**
GSI Well Number	2313NEW199	2313NEW237
Grid ref. (1:25,000)	25472 14451	25473 14450
Townland	Knockanore	Knockanore
Source type	Borehole	Infiltration gallery
Developed	September 1999	1960's
Owner	Kilkenny County Council	Kilkenny County Council
Elevation (ground level)	28.6 m O.D.	28.5 m O.D.
Depth	100 m	-
Depth of casing	11 m	-
Diameter	200 mm (8")	1.68 m (at entrance to gallery)
Depth to rock	10 m	unknown
Static water level	26.86 m O.D. (1.74 m b.g.l.) on 05/10/99	25.1 m O.D. (3.4 m b.g.l.) on 20/07/01
Pumping water level	-21.54 m O.D. (50.14 m b.g.l.) on 07/10/99*	Discharges via gravity feed
Drawdown	48.4 m	-
Normal consumption**	[illegible]4 m[illegible]	[illegible] m^3/d
Pumping test summary:		
(i) abstraction rate	[illegible]-1571 m^3/d***	
(ii) specific capacity	[illegible] m^3/d/m	
(iii) transmissivity	[illegible] m^2/d	

* *Pumping water level could not be measured [illegible] to the depth to water and interference from rising main and power cable.*
** *The average scheme consumption, 2806 m^3/d, has been obtained from County Council meter readings taken in 2000 and 2001. The borehole is reportedly pumped at the capacity of the pump, 1254 m^3/d, and the infiltration gallery usage is obtained by deducting this from the total.*
*** *The borehole was tested at various rates in October 1999, the longest test abstracting on average 1380 m^3/d and lasting 15 days.*

Note that the GSI is aware that the supply needs of the Bennettsbridge scheme are increasing. However, an examination of the test pumping drawdown data suggest that there is little scope for increasing the original borehole's yield, and that the current design yield of the borehole may not be sustainable in the long term. It has not been possible to examine trends in pumping water levels in the well or trends in abstraction rates from the well since it was commissioned in late 1999.

8.4 Methodology

8.4.1 Desk Study

Bedrock geology information was compiled from original 1:10560 (six inch) field sheets and from the GSI bedrock report for the area (Tietzsch-Tyler *et al*, 1994a). Details of the current abstraction rate were obtained from Kilkenny County Council. Drilling and pumping test data for the supply wells were obtained from Brian P. Connor, the consultant involved with their development (Connor, 1999). Data on private groundwater wells in the area was taken from GSI archives and work carried out by the Groundwater section throughout the course of 2000 and 2001.

8.4.2 Site Visits and Field Work

- Site visits and fieldwork included walkover surveys undertaken by both the Groundwater (2 days) and Quaternary (1 day) sections of the GSI to further investigate the subsoil and bedrock geology, the hydrogeology, the vulnerability to contamination and the current pollutant loading.
- Groundwater Section also carried out 3 days of exploration drilling in both the bedrock and the sand and gravel components of the scheme. Two observation wells were drilled. One was installed in gravel close to the well, and one was installed in rock adjacent to the pump house (see Figure 8.1). The latter was destroyed during the drilling of a new county council borehole at the site, and measurements relate to the new County Council borehole.

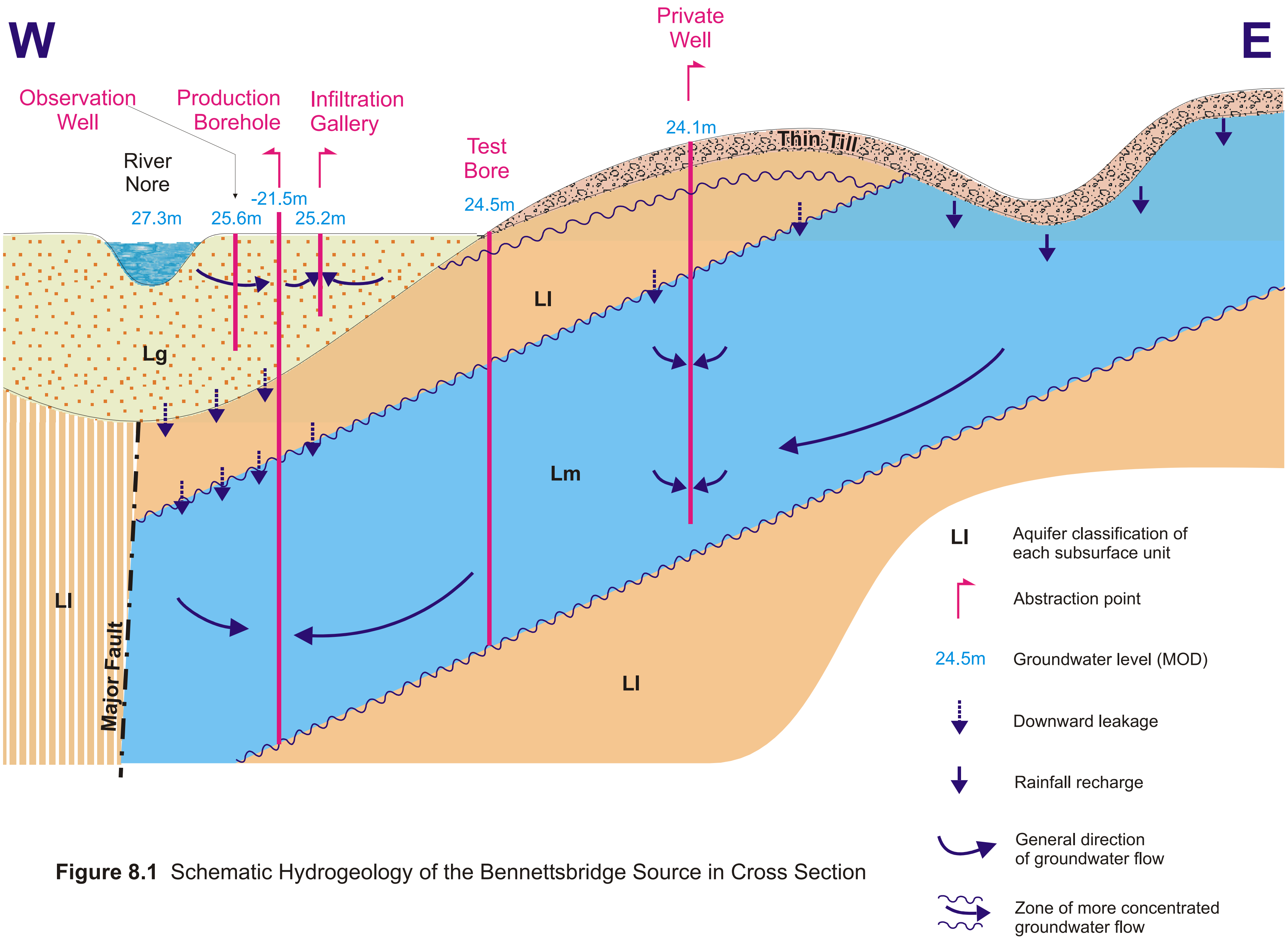


Figure 8.1 Schematic Hydrogeology of the Bennettsbridge Source in Cross Section

- Water levels and elevations were recorded in the river, infiltration gallery, production well, gravel observation well and adjacent private well (see Figure 8.1).
- A raw water sample was taken on 02/10/00 by GSI staff and was submitted for analysis at the EPA laboratories in Kilkenny in accordance with their sampling and transportation guidelines. (see Table 8.1 for results).

8.4.3 Assessment

Analytical equations and hydrogeological mapping were utilised to delineate protection zones around the source.

8.5 Topography and Surface Hydrology

The Bennettsbridge source is located on the eastern bank of the River Nore, almost 5 km south of Bennettsbridge Town (Map 8). The Kings river flows into the Nore just 400 m to the south of the source.

At this point, the Nore lies at approximately 27 m O.D. in a narrow north-south trending valley which rises steeply to ridges on either side. These ridges separate the valley from the Ennisnag River valley to the west and the Kilfane River valley to the east. Although the inclines are steep, the crests of the hills are only up to 120 m O.D.

The valley floor is only about 160 m wide, but is almost entirely flat, with a very gentle gradient of 0.006 (1 in 160). The valley sides steepen dramatically to 0.07 (1 in 10).

The nearest streamflow gauges on the River Nore are 12 km upstream at John's Bridge in Kilkenny City and 2 km downstream at Mount Juliet. Low flows[4] at these stations are of the order of 3.75 m^3/sec and 4 m^3/sec, respectively (EPA, 2001). A group of large springs emerge on the eastern floodplain of the Nore at Bausheenmore, approximately 3 km north of the pump house. Total flows at these springs are estimated to be in the order of 0.1 to 0.3 m^3/sec. The level of the River Nore at the source was 27.3 m O.D. on 02/10/01.

The drainage density in the surrounding ridges is very low, and rock is close to the surface, suggesting that a high proportion of excess soil moisture can infiltrate down to groundwater.

8.6 Geology and Aquifers

8.6.1 Bedrock

The main rock type in the vicinity of the Bennettsbridge source is the Ballysteen Formation. The formation is present in two forms; a dolomitised and an undolomitised portion. It is described in more detail in Chapters 2 and 4 of Volume I and its distribution in the vicinity of the Bennettsbridge source is shown on Map 8.

A comparison of the production borehole log (Connor, 1999), GSI observation well drilling, and the GSI's geological map (see Map 1) suggests that:

- Approximately 30 m of shaley Ballysteen limestone overlies the dolomitised Ballysteen limestone.
- Most water flows are derived from the dolomitised Ballysteen Formation.

This is depicted schematically in Figure 8.1.

In Chapter 4 of Volume I, the undolomitised portion, through which the production borehole was drilled, has been classified as a **locally important aquifer** which is **moderately productive only in local zones** (**Ll**). The dolomitised portion, however, has been classified as a **locally important**

[4] Flow which is equalled or exceeded at least 95% of the time.

aquifer which is **generally moderately productive (Lm).** Note that ½ km further north from the pump house, the dolomite is so well developed that the bedrock is classified as a **regionally important** fissured bedrock aquifer (**Rf**). In the **Ll** portion of the aquifer, flow is expected to be concentrated in the upper weathered fraction, with most groundwater movement expected within the top 10 or 15 m of the rock profile. In the dolomitised **Lm** portion, borehole information suggests that local groundwater circulation occurs at depths of at least 70 m (~30 m below the top of the dolomite).

In the Bennettsbridge area, the bedrock aquifers have been affected by a large north-south trending fault which is believed to follow the Nore River channel. As a consequence, a different, less productive bedrock aquifer (the Butlersgrove Formation) abuts-against the dolomite to the west of the river (Figure 8.1).

The Bennettsbridge source is situated on the southern side of a major syncline (downward fold in the rock mass) at the centre of which are the young rocks of the Slievardagh and Castlecomer Hills. As a consequence, the Ballysteen Formation dips at 5° to 6° north- westwards in the immediate vicinity of the source.

8.6.2 Subsoil

The main subsoil types are gravel, till and alluvium. These materials are described in more detail in Chapter 3 of Volume I and their distribution in the vicinity of the Bennetsbridge source is shown on Map 2S.

The gravel deposits occupy the valley floor. Drilling by the GSI indicated at least 8 m of silty SAND and GRAVEL lie below 2 m of SILT adjacent to the infiltration gallery. As described in Chapter 4 (Volume I), the gravels in this part of the Nore valley are considered to constitute a **locally important** gravel aquifer (**Lg**).

The till deposits are found on the valley sides (see Figure 8.1), where they form a thin covering which rarely exceeds 3 m. They are not considered an aquifer, and their main significance is in vulnerability and recharge assessments. These issues are described in Sections 8.7 and 8.8.

The alluvial deposits are recent, and are found at points along the river bank where flooding is common. Their main significance is in vulnerability and recharge assessments.

8.7 Groundwater Vulnerability

8.7.1 Introduction

The concept of vulnerability is discussed in Chapter 5 of Volume I. In essence, however, groundwater vulnerability is dictated by the nature and thickness of the material overlying the main groundwater 'target'. As discussed in Section 8.6, two groundwater resources are utilised, one in fractured bedrock and the other in the overlying sands and gravels. Where the sand and gravel aquifer occurs at the surface, the overall vulnerability will be dictated by the vulnerability of groundwater within this aquifer. On the valley sides where the sand and gravel aquifer is absent, vulnerability will be dictated by the overall subsoil permeability and by the depth to bedrock.

8.7.2 Vulnerability in Areas where the Sand and Gravel Aquifer Occurs

GSI drilling adjacent to the infiltration gallery indicated that 2 m of SILT can overly the sand and gravel aquifer at the site. It is likely however, that this silt is variable in thickness, and even absent in places. The drilling also indicated that the groundwater level lies at approximately 3 m below ground level, and that the sand and gravel aquifer is unconfined. The unsaturated zone thickness is likely to increase moving away from the river and it is therefore likely that the sand and gravel aquifer is unconfined in most areas near the infiltration gallery.

In unconfined situations, the vulnerability of a sand and gravel aquifer is dictated by the thickness of the unsaturated zone. Given that the unsaturated zone is likely to be at least 3 m thick over much of the area upgradient of the source, the vulnerability of the sand and gravel aquifer is considered to be generally 'high' (see Map 9).

8.7.3 Vulnerability in Areas where the Sand and Gravel Aquifer is Absent

These areas are situated on the valley sides overlooking the site and groundwater vulnerability is determined by the permeability and thickness of the tills overlying the bedrock. The observation borehole drilled by the GSI at the pump house hit rock at 1.8 m below ground, indicating that the subsoil deposits thin rapidly on the valley sides. In addition, there are at least two mapped rock outcrops in excess of 200 m long, and subsoils are therefore thought to be generally less than 3 m thick. At subsoil thicknesses of less than 3 m, bulk permeability becomes less relevant in mapping vulnerability across wide areas (as opposed to specific sites), because permeability becomes increasingly variable and increasingly influenced by the presence of 'bypass flow' mechanisms such as cracks in the subsoil. Accordingly, on the basis of the general depth to bedrock on the valley sides, a vulnerability classification of 'extreme' has been assigned.

8.7.4 Summary

Groundwater vulnerability is generally 'high' on the valley floor and generally 'extreme' on the valley sides.

Note that the permeability estimations are based on regional-scale evaluations, while depth to rock and water level interpretations are based on the available data cited here. However, permeability, water level and particularly depth to rock can vary over a very small scale. Consequently, the vulnerability mapping provided will not be able to anticipate all the natural variation that occurs in an area. 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. More detail can be found in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

8.8 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.

In areas where point recharge from sinking streams, etc, is discounted, the main parameters involved in recharge rate estimation are annual rainfall, annual evapotranspiration, and annual runoff[5]:

- Annual rainfall: 890 mm (Met Eireann average annual (1961-90), average of rainfall measured at Bennettsbridge, Stoneyford and Thomastown).
- Annual actual evapotranspiration (A.E.) losses: 450 mm. This figure ('actual evapotranspiration') was calculated assuming 95% of the country-wide potential evapotranspiration data presented in the "Agroclimatic Atlas of Ireland" (Collins and Cummins, 1996). Local measurements of actual evapotranspiration are not available.
- Potential recharge: 440 mm/year, based on average annual rainfall less estimated evapotranspiration.

[5] *Estimations used in this report have generally been rounded off to two significant figures*

- Annual runoff losses (RO): 90 mm. This estimation is based on the assumption that, due the predominance of either thin or permeable subsoils over much of the area upgradient of the source (refer to Section 8.7), only 20% of the potential recharge will be lost to overland flow and soil quickflow. Losses of 20% are typically used by the GSI in similar areas.

These calculations are summarised below:

Average annual rainfall (R)	890 mm
Estimated A.E.	450 mm
Potential recharge (R – A.E.)	440 mm
Runoff losses (RO)	90 mm
Estimated actual recharge (R-A.E.) – (RO)	350 mm

8.9 Groundwater levels

Information on the groundwater levels in the two aquifers comes from measurements taken as part of this study from the abstraction points and also from two GSI drilled observation holes. The following two tables outline the findings:

Gravel aquifer:

Measurement Point	Infiltration Gallery	Observation Borehole	River
Distance from river	16 m	9.5 m	-
Measured water level	3.3 m b.g.l. (25.2 m O.D.)	3 m b.g.l. (25.6 m O.D.)	27.3 m O.D.

Dolomitised limestone aquifer:

Measurement Point	Private Well	Test Borehole	Pumping Well	River
Distance from river	184 m	73 m	9.2 m	-
Measured water level	22.54 m b.g.l. (24.06 m O.D)	4.7 m b.g.l. (24.5 m O.D)	53.7 m b.g.l. (-21.54 m O.D)	27.3 m O.D.

The measurements taken in the sand and gravel aquifer show a gentle downward gradient from the river towards the infiltration gallery. The measurements for dolomitised limestone aquifer indicate that the aquifer has a low bulk permeability - the pumping water level is very deep compared to the water level in a borehole less than 70 m away and compared to the water level in the gravel aquifer above. The water levels also indicate that the dolomitised aquifer is generally confined on the valley floor and lower valley sides.

8.10 Groundwater Flow Directions and Gradients

The water table in the area is assumed to reflect topography, with groundwater flowing from the hills and valley sides, and discharging into the Nore at the base of the valley.

In three dimensions, the flow pattern is probably somewhat different in the undolomitised and dolomitised portions of the aquifer, and the proposed flow regime is shown in schematic form in Figure 8.1. It seems likely that water recharging the undolomitised limestone travels at shallow depths (possibly within 15 m of the top of the rock) before discharging into the Nore and the sand and gravel alongside it. In the dolomitised portion, however, drilling data from the site (Connor, 1999) suggests significant water strikes can occur more than 70 m below the top of the rock (~ 30 m below the top of the dolomite). It is therefore likely that recharge to this aquifer is not controlled by local sub-catchment watersheds and that groundwaters supplying the source can be recharged from the area 2 km to the east where the dolomitised limestone outcrops at surface (refer to Map 8).

Given that pumping water levels in the borehole are much lower than the water levels in the gravels and in the river, it is likely that the dolomitised aquifer is recharged to a significant degree by vertical leakage from the river, the gravel aquifer, and the upper shaley limestone aquifer.

Groundwater gradients in the sand and gravel aquifer have been calculated using water level readings in the observation borehole in the sand and gravel and the infiltration gallery. The calculated gradient is 0.14 (1 in 7) from the river towards the infiltration gallery. Though no data is available for the gravels up-slope of the gallery, it is likely that a component of flow will also be from the valley sides to the gallery.

A groundwater gradient of 0.02 (1 in 50) has been calculated in the dolomitised limestone using water level readings in two observation boreholes. Closer to the pumping well the gradient increases dramatically, probably in the order of 0.7 (1 in 1.4). The groundwater gradient in the undolomitised portion is likely to mimic the topographic gradient of 0.07 (1 in 10).

8.11 Water Quality

Data on recent trends in water quality at the Bennettsbridge source are presented in Appendix V and are summarised graphically in Figure 8.2. It should be noted that the borehole only came on line in November 1999, and that data prior to this date only apply to the infiltration gallery. Also, water is abstracted from the Nore to augment the supply in the summer months.

The following key points have been identified from the data:

- *Hardness:* Only one data point is available (from GSI sampling in October 2000) The result suggests the groundwater has a 'very hard' (>350 mg/l $CaCO_3$) calcium-bicarbonate hydrochemical signature. This is typical of the limestone lowlands of the Irish midlands.
- *Faecal coliforms:* Of the five available raw[6] water samples from the infiltration gallery or mixed waters since 1994, all show some counts of faecal coliforms. Note, however, that of these five samples, only one is available in combination with a separate raw water sample from the borehole. Analysis of this one borehole sample is presented in comparison with raw water samples from the bore and the river in Table 8.1. A count of 5600 faecal coliforms per 100 ml was found in the sample from the river, while no faecal bacteria were detected in the borehole supply. Given that the river is thought to recharge the lower dolomitised aquifer as well as the upper sand and gravel aquifer, this suggests that significant contaminant attenuation occurs vertically between the gravels and the dolomitised limestone bedrock. The data also suggests that the most likely cause of the bacterial pollution in the Bennettsbridge mixed source is the River Nore. In winter, the river can rise above the level of the borehole, entering it via the unsealed top. Though no data are available for flood periods, it is likely that the borehole is contaminated with faecal coliforms for at least the period of inundation.
- *Other contaminant indicators*: Only one raw water sample is available from the borehole itself. Concentrations of nitrate, ammonia and chloride are below GSI guide levels in the borehole sample.
- Water quality data from the borehole and river are compared in Table 8.1. The elevated groundwater temperature of 12.9 °C, taken during early autumn, provides qualitative evidence that the proportion of river water in the recharge to the borehole is significant. Additional, quantitative estimates of the proportion of river water recharging the borehole can be made from nitrates and chlorides, which are not expected to be attenuated significantly by materials below the river. Assuming the Bausheenmore springs are representative of typical nitrate and chloride concentrations in the dolomitised Ballysteen limestone (refer to Section 7.5.3), the groundwater contribution to the Bennettsbridge borehole is typically 25 mg/l nitrate (NO_3) and 30 mg/l chloride. Taking equivalent borehole and river water concentrations from Table 8.1, a river contribution of 40% of the total borehole abstraction is required to dilute regional groundwater concentrations to those found in the borehole.

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[6] *Raw water samples are taken prior to treatment. Assessments are aimed at identifying contamination hazards rather than direct human health issues.*

Table 8.1: Selected Laboratory Analyses of Groundwater at the Bennettsbridge Source

Parameter	Results of EPA Laboratory Analyses (samples taken 2/10/00)		
	Borehole Sample	River Sample	Mixed Sample[7]
Conductivity (μS/cm)	721	447	681
Temperature (°C)	12.9	13.2	
pH	7.3	8	7.4
Total Hardness	424	255	390
Total Alkalinity (mg/l)	317	185	291
Calcium	128	89	124.4
Magnesium	25.4	7.8	19.2
Chloride	24	16	23
Sulphate	28.5	15.8	23
Sodium	16.1	10.3	16.7
Potassium	2.3	4.4	3.3
Nitrate (as NO_3)	19	9.3	19.9
Iron	< 0.05	0.279	<0.05
Faecal coliforms / 100 ml.	None detected	5600	5

The natural hydrochemistry of the Ballysteen aquifer systems is discussed in Chapter 4 of Volume I.

8.12 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 in Section 8.14.3).

Dolomitised limestone: A discharge test in October 1999 of between 1571 and 1229 m^3/day for 2 days gave a final drawdown of 48.4 m, and a specific capacity of 25 m^3/day/m (see Section 8.3). Recovery was not measured as the borehole was put into commission immediately and has been pumped constantly ever since. Analysis of the drawdown pattern during pumping provided a transmissivity estimate of 15 m^2/d. Close to the end of the second day of the pump test described above, a second borehole, located at the other end of the infiltration gallery began pumping at 440 m^3/day. Both wells pumped together for a further 12 days. The yield obtained from the second borehole was not considered sufficient for the needs of the scheme and it was abandoned. An additional trial well was drilled at the site in 2001, but was also found to be inadequate. Clearly, flow and aquifer parameters in the aquifer are quite variable, but the available data suggest that both the transmissivity and permeability at depth in the aquifer are quite low.

Shaley limestone: Data from a well in shaley Ballysteen limestone near Mount Juliet (reference 2313NEW170) suggest a specific capacity of 14 m^3/day/m and a transmissivity of 32 m^2/d and a permeability of 3.2 m/day for this aquifer in the vicinity of the source. The permeability was derived assuming a minimum aquifer thickness of 10 m and is therefore likely to be at the higher end of typical bulk permeabilities in the aquifer.

A porosity of 0.025 has been assumed for the bedrock aquifers. This is at the upper end of the typical range used by the GSI for bedrock aquifers (0.025 to 0.01) and reflects the belief that the aquifers are densely fractured in the vicinity of the fault zone which runs along the River Nore.

[7] *Taken from the mixed gallery and borehole discharge just prior to treatment.*

The average abstraction rate for the borehole is estimated as approximately 1250 m^3/d. Additional safety factors are considered inappropriate given that the borehole appears to close to its maximum yield. The average discharge from the infiltration gallery is estimated as approximately 1550 m^3/day (see Section 8.3).

The boundaries of the analytical model were taken from hydrogeological mapping and the conceptualisation outlined in Section 8.13, and were as follows:

	Infiltration Gallery	**Borehole**
Northern boundary	Ridge of higher ground overlooking the bank of the Nore, 0.3 km north of site.	Ridge of higher ground overlooking the bank of the Nore, 0.3 km north of site.
Southern boundary	Ridge dividing catchment from valley to the south, 0.1 km from the site.	Ridge dividing catchment from valley to the south, 0.1 km from the site.
Eastern boundary	Local topographic divide: Hill crest in Rathduff townland, 1.8 km east of the site.	Regional topographic divide running across the outcrop area of dolomitised Ballysteen limestone, 4 km from the borehole.
Western boundary	River Nore	River Nore
Total area	1.2 km^2	1.3 km^2

These boundaries delineate the physical limits within which the ZOC is likely to occur and are shown on Maps 8, 9 and 10. Some additional calculations can be performed to assess if the ZOC for the Protection Scheme should be smaller or larger than the area contained within the physical constraints:

- *Water balance*: The area required to balance the total abstraction with rainfall recharge is:
  Recharge area required to sustain discharge = discharge ÷ average annual depth of recharge.
  Recharge area required to sustain discharge = ((1550 + 1250) × 365) ÷ 0.35
  Recharge area required to sustain discharge = 2.9 km^2
  Total area available = 1.3 km^2 *+ 1.2* km^2 *= 2.5* km^2

  In other words, the area contained within the physical constraints under-estimates the groundwater recharge required to balance abstraction by a shortfall of 15%. However, significant river recharge is anticipated in the conceptual model. Using a chemical mass balance, river recharge has been estimated to make up 40% of the abstraction at the borehole, and, by inference, more than 40% of the abstraction at the gallery. Clearly, river recharge will be more than sufficient to make up the shortfall in the water balance, which amounts to only 0.1% of low flows in the Nore close to Bennettsbridge.

- *Width of ZOC at the local topographic divide 1.8 km east of the site*: The ZOC at this location approximates the upgradient limit of recharge waters feeding the infiltration gallery. It can be estimated using the "uniform flow equation", as follows:
  Width = 2 × abstraction ÷ (permeability × thickness × hydraulic gradient)
  = 2 × 1600 ÷ (10 × 10 × 0.06)
  = 530 m

  The equivalent figure using physical constraints alone is 800 m. Thus, it appears that the figure derived from the physical constraints represents a reasonable, if slightly conservative approximation of the upgradient width of the ZOC for the infiltration gallery.

- *Width of ZOC at the River Nore*: Evidence from water levels (Section 8.9) suggests that the width of the upgradient cone of depression of the borehole is less than 65 m. This compares with a southern boundary distance of 100 m derived from the physical constraints. The northern boundary is extended further than 100 m to account for the width of the gallery.

In summary:

- The physical constraints are generally appropriate to utilise as the boundary of the ZOC.

- River recharge is thought to make up a significant proportion of the total recharge to the source and, on this basis, the mapped ZOC is slightly conservative.
- The ZOC delineated in Map 10 comprises the ZOC for both the gallery and the borehole.

8.14.3 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 and it is delineated to protect against the effects of potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination.

Estimations of the extent of this area cannot be made by hydrogeological mapping and conceptualisation methods alone. Analytical modelling was therefore used to estimate the extent of this zone upgradient of the well. Note that only the sand and gravel and shaley aquifers were considered in terms of the inner protection area. This is because, close to the source, waters reaching the deeper dolomite aquifer would first have to percolate through the weathered and unweathered zones of the shaley limestone.

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

$$Velocity = groundwater\ gradient \times permeability \div porosity$$

Using the estimates derived in Sections 8.12 and 8.10 for gradient, permeability, and porosity (0.07, 3.2 m/day, and 0.025 respectively), the equation gives a velocity of 9 m/day. This could be treated as a 'reasonable worst case estimate'. In other words, though some very rapid flow paths may occur, it is thought that most groundwater will move up to 900 m in 100 days. Accordingly, the boundary of the SI has been delineated 900 m upgradient of the source (refer to Map 10).

8.14.4 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the source protection areas and vulnerability categories – giving a possible total of 8 source protection zones (see the matrix in the table below). In practice, this is done 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 Source Protection area where the groundwater is highly vulnerable to contamination. All of the hydrogeological settings represented by the zones may not be present around any given source. Just three groundwater protection zones are present around the Bennettsbridge source (Map 10), as shown in the matrix below.

Matrix of Source Protection Zones

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

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

8.15 Land Use and Potential Pollution Sources

Agriculture in the area is mainly based on livestock.

Though a significant proportion of contaminants found in the source are expected to be derived from the River Nore, some are also likely to be derived from inorganic fertilisers and/or the disposal and management of organic wastes.

8.16 Conclusions and Recommendations

- ♦ It is unlikely that the bedrock aquifers will provide water supplies at the site that are significantly greater in the long term than those provided currently. Pumping water levels at the production borehole are deep and river recharge is required to balance abstraction. It may be that the current supply from the borehole will not be sustainable through future dry summers. Regionally important aquifers lie within 1.5 km of the north and south of the site. These might be explored if future increases in supply were needed or if an alternative to direct intake from the river is sought.
- ♦ The groundwater around the supply is 'highly' to 'extremely' vulnerable to contamination. Further, the well-head is vulnerable to surface water inundation during flooding of the River Nore.
- ♦ The available data suggest that the gallery supply is contaminated by river water and by groundwater contamination (possibly due to the disposal and handling of agricultural organic wastes) from the valley floor and sides. There is insufficient data from the production borehole to indicate whether this source is also contaminated, but some contamination is likely during floods which inundate the borehole.
- ♦ 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:
  - – chemical and bacteriological analyses of raw water as well as treated water be carried out regularly. Given some of the raw water quality issues at the source, a monthly frequency has been recommended in Section 7.9. The chemical analyses should include all major ions - calcium, magnesium, sodium, potassium, ammonium, bicarbonate, sulphate, chloride, and nitrate. More occasional analyses of other parameters such as pesticides and hydrocarbons is also recommended;
  - – sampling include separate waters from the borehole and the gallery, as well as the final mixed water;
  - – the potential hazards in the ZOC be located and assessed;
  - – the flow data from the borehole be examined regularly to identify decreases in yield which may be the result of dropping water levels.
  - – the pumping borehole be protected from inundation by the river.
- ♦ The planned groundwater abstraction at Bennettsbridge is greater by some 30% than the current abstraction figures used in this document. The abstraction rate is a key factor in determining the size of protection zones around a source. The County Council indicated that the current abstraction rate should be used in the assessments at Bennettsbridge. However, should the planned rate be attained in the future, the size of the source protection areas delineated in this document may require re-evaluation.

9. Callan Source

9.1 Introduction

The objectives of this chapter are:

- To delineate source protection zones for the Callan Water Supply Scheme.
- To outline the principal hydrogeological characteristics of the Callan area.
- To assist Kilkenny 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. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

9.2 Location and Site Description

The public drinking water source for Callan Town is a spring situated in the townland of Westcourt South (1.5 km to the north west of Callan). The location of the spring is shown on Map 8.

The spring is located within a concrete chamber which is 2 m wide, 5 m long and 0.7 m high. The area is fenced off from animals. The top of the chamber is at 70 m O.D. Overflow is channelled away from the spring into a ditch to the east, which, in turn, flows into the Kings River 400 m to the south east of the spring. The water from the spring flows under gravity along a six inch diameter pipe to the south side of the Kings River to a pump sump in the townland of Mullaunglass.

The spring is situated 100 m north of the Kings River with a height difference between the two of 2.6 m. County Council staff have indicated that the Kings River does not inundate the spring during flood periods.

9.3 Summary of Source Details

GSI no.	2313NWW273
Grid ref. (1:25,000)	24004 14446
Townland	Westcourt South
Source type	Spring
Development date	1934
Owner	Kilkenny County Council
Elevation (ground level)	69.55 m O.D.
Depth to rock	unknown
Static water level	surface
Discharge summary:	
(i) average consumption*	[illegible] m^3/d
(ii) estimated overflow**	[illegible] m^3/d
(iii) estimated total discharge***	[illegible]0 m^3/d

**Information supplied by County Council staff*
***Refer to Section 9.9*
*** M.C. O'Sullivan Consulting Engineers (1999) report a dry weather flow of 1080 m^3/day.*

9.4 Methodology

9.4.1 Desk Study

Bedrock geology information was compiled from original 1:10560 (six inch) field sheets and from the GSI bedrock report for the area (Archer *et al*, 1996). Details of the current abstraction rate were obtained from Kilkenny County Council. Data on private groundwater wells in the area were taken from GSI archives. Information on flow regime's in the area was taken from reports and academic theses (Ball, 1972; Daly, 1993; and Naughton, 1978). Data on existing water quality were taken from the EPA (raw waters) and the County Council/Health Board (treated waters).

9.4.2 Site Visits and Field Work

- Site visits and fieldwork included walkover surveys undertaken by both the Groundwater (3 days) and Quaternary (1 day) sections of the GSI to further investigate the subsoil and bedrock geology, the hydrogeology, and the vulnerability to contamination.
- Overflow measurements were taken by the GSI from May to October of 2000, using a piping system installed by Kilkenny County Council.
- Water levels and elevations were recorded in the spring and river.
- Raw water samples were taken on 03/10/00 and 25/04/01 by GSI staff and submitted for analysis at the EPA laboratories in Kilkenny in accordance with their sampling and transportation guidelines.

9.4.3 Assessment

Analytical equations and hydrogeological mapping were utilised to delineate protection zones around the source.

9.5 Topography and Surface Hydrology

Westcourt spring is located 100 m north of the King's River (Map 8). At this point, the King's River meanders across a broad, flat plain with elevations of 60 to 70 m O.D. It's confluence with the Munster River is just 600 m to the west of the spring, and the Munster is joined by the Kilmanagh River just 2.3 km to the north of this confluence. All three rivers originate in the Slieveardagh Hills, which form the north western watershed of the area. The crests of the Slieveardagh hills rise to just over 320 m O.D. The area around the Callan spring appears to be a groundwater discharge zone, with at least three other springs coming to the surface in the vicinity (see Maps 4N and 4S). At least one of these, lying at the confluence of the Munster and Kings Rivers, is a warm spring.

Slopes on the wide valley floor are generally in the order of 0.0014 (1 in 714), and they only steepen appreciably 5.5 km to the north west of the spring, on the slope-side of the Slieveardagh Hills, where they are in the order of 0.08 (1 in 12).

There is a streamflow gauge on the Kings River at Callan, 1.5 km downstream of the spring. Low flow[8] measurements at this station are not thought to be reliable, but have been estimated to be in the order of 0.2 m^3/sec (EPA, 2001).

The natural drainage density is very high on the valley floor upstream of the springs, with the Kings, Kilmanagh and Munster Rivers all flowing within a few square kilometres, and with many artificial drainage ditches.

[8] *Flow which is equalled or exceeded at least 95% of the time.*

A permeability of 10 m/d and a porosity of 0.2 has been assumed for the gravel aquifer, based on experience in other sources.

8.13 Conceptual Model

This section provides a qualitative overview of the geological framework, recharge, 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.

- A schematic depiction is provided in Figure 8.1.
- Three main geological layers occur below the site: (i) sand and gravel overlying (ii) shaley limestone, which overlies (iii) dolomitised limestone. The sand and gravel supplies the infiltration gallery, while the dolomitised limestone is the main source of water for the borehole.
- In the vicinity of the site, groundwater in the sand and gravel and shaley limestone is considered to be unconfined, while groundwater in the dolomitised limestone is considered to be confined (see borehole water levels in Section 8.9).
- During pumping at the gallery, the sand and gravel aquifer is expected to be recharged by the River Nore, by rainfall falling on the aquifer outcrop, and by shallow flow in the top 10 to 15 m of the shaley limestone.
- During pumping from the borehole, the dolomitised limestone is expected to be recharged in generally equal proportions by downward percolation from the River Nore, and by rainfall falling on the dolomitised outcrop area almost 2 km to the east of the site.
- Faulting under the river is such that the dolomitised aquifer does not occur on the western bank and recharge to the source is not expected to occur from the western bank of the Nore.
- Groundwater gradients in the sand and gravel aquifer are estimated at 0.14 (1 in 7), with flow being from the river to the infiltration gallery. Groundwater gradients in the undolomitised limestone are estimated to be 0.1 (1 in 10), while a gradient of 0.02 (1 in 50) has been calculated in the dolomitised limestone, steepening to over 0.7 closer to the pumping well.

8.14 Delineation of Source Protection Areas

8.14.1 Introduction

This section delineates the areas around the source that are believed to contribute groundwater to the source, and that therefore require protection. The areas are delineated on the basis of the conceptualisation of the groundwater flow pattern as described in Section 8.13.

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.

8.14.2 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 pumping rate, (b) the groundwater flow direction and gradient, (c) the aquifer permeability and (d) the recharge in the area. The ZOC is delineated using both analytical modelling and the results of hydrogeological mapping and conceptualisation. Given the limited amount of calibration data available, a full groundwater numerical model was not undertaken.

9.6 Geology and Aquifers

9.6.1 Bedrock

The Callan source lies in the mid-Kilkenny limestone basin (see Maps 1N and 1S) where the main rock types in the vicinity of the Callan source are all limestones and consist of the Aghmacart, Durrow, Crosspatrick, and Waulsortian Formations. These formations are described in more detail in Chapter 2 of Volume I. Their distribution is quite complex, with vertical and horizontal dimensions playing an important role in groundwater flow to the source. Key points are highlighted below:

- The vertical distribution is presented schematically in Figure 9.1, while the horizontal distribution is presented on Map 8.
- The Callan spring is situated in the middle of an area of Aghmacart and Durrow shaley limestones. Both are classified as **locally important aquifers** which are **moderately productive only in local zones** (**Ll**) (see Section 4.13, Volume I). Fracture flow is expected to be dominant. Regionally, flows are expected to be concentrated in fractured and weathered zones. Given common weathering patterns, most flow is thought to be relatively shallow; concentrating in the top 10 m to 30 m of the rock profile. Crosspatrick Formation limestones lie close-by. They are 'cleaner' and classed as a slightly better aquifer - **locally important aquifer** which is **generally moderately productive** (**Lm**) – but flow patterns are believed to be similar to those in the shaley limestones.
- The regionally important, dolomitised Waulsortian limestone aquifer has been up-faulted nearer to the surface underneath the spring, or is linked to the surface via faults (refer to Figure 9.1). The unit may lie some 500 m below the spring, but deep flows can occur in this aquifer (refer to Chapter 4 of Volume I) and it may be contributing groundwater to the spring. This is supported by the presence of warm springs in the vicinity of the Callan spring.

9.6.2 Subsoil

The main subsoil types are gravel, till and alluvium. These materials are described in more detail in Chapter 3 of Volume I and their distribution in the vicinity of the Callan source shown on Maps 2N, 2S and 8.

As described in Section 4.18.2 of Volume I, the gravels associated with the Kilmanagh and Kings Rivers are considered large, thick and clean enough to be classified as a **Regionally important** gravel (**Rg**) aquifer. The gravels are considered to supply, and form the medium through which bedrock aquifers supply groundwaters to the Callan spring. The deposit is probably up to 15 m thick, and is believed to be predominantly composed of fine gravels and sands interbedded with silts and clays. The silts and clays are believed to become more common between Kilmanagh and the Callan spring. The area of gravel is 1 km wide at the spring, but widens to almost 2 km further north (see Map 8), and extends up to Tullaroan, 14 km to the north. A layer of till, generally 3-4 m in thickness, is thought to overly the gravels between Kilmanagh and Callan spring (see Figure 9.1)

In many places, the rivers have reworked the top layer of the sand and gravel deposit to form a well-sorted fine-grained alluvial deposit. It is only found in a narrow strip along the banks of the rivers, and is thought to be rarely more than 1 or 2 m thick.

Glacial till deposits cover the valley sides of the Munster and Kilmanagh Rivers. Their thickness is variable (less than 1 m to 10 m thick), but they are generally thicker towards the valley floor. The main significance of these tills is in vulnerability and recharge assessments. These issues are described in Sections 9.7 and 9.8.

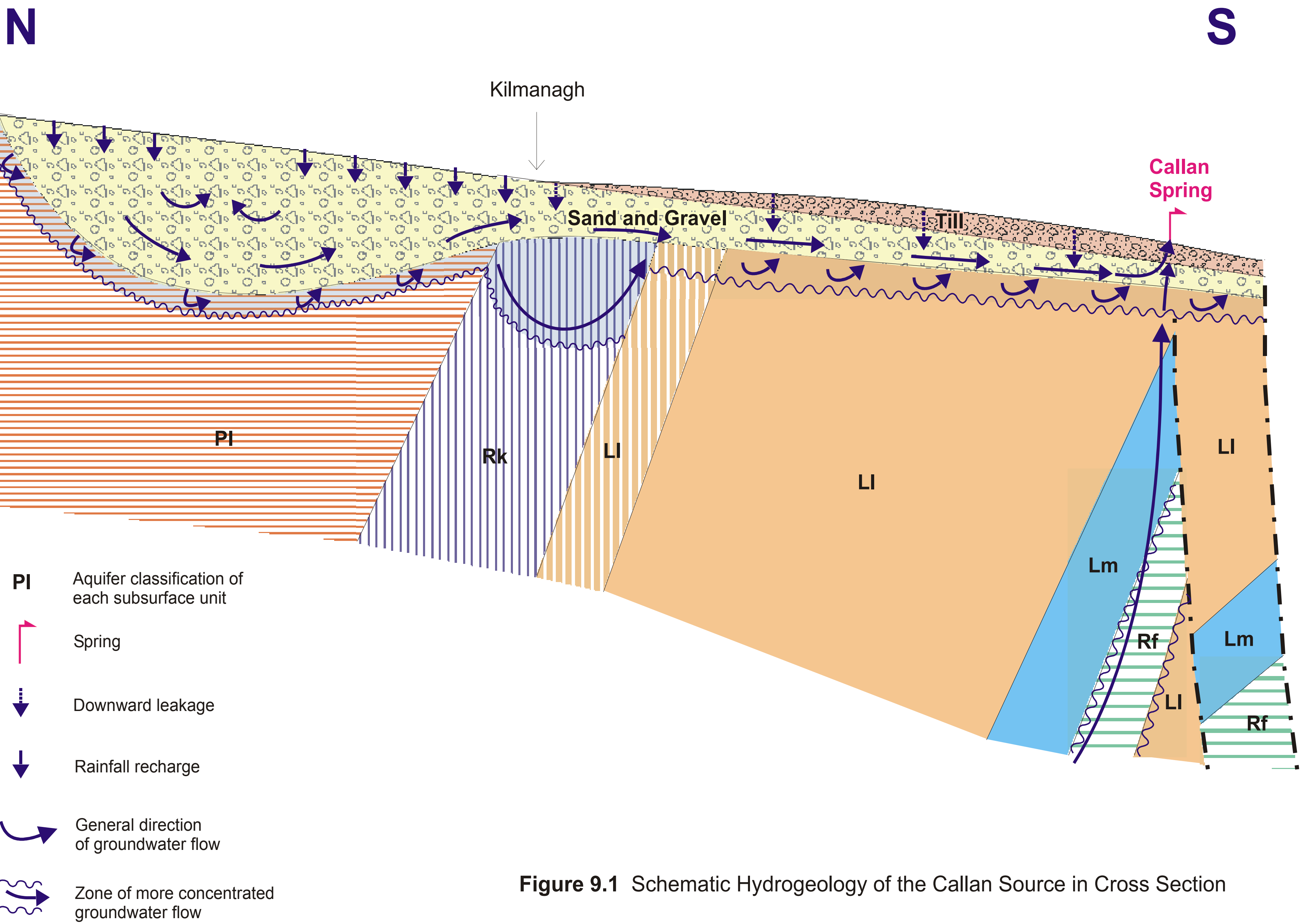

Figure 9.1 Schematic Hydrogeology of the Callan Source in Cross Section

9.7 Groundwater Vulnerability

9.7.1 Introduction

The concept of vulnerability is discussed in Chapter 5 of Volume I. In essence, however, groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. As discussed in Section 9.6, the uppermost groundwater resource in the vicinity of the Callan spring occurs within sands and gravels. Where covered by tills, the vulnerability of groundwater within the sand and gravel aquifer is dictated by the permeability and thickness of the overlying till. Elsewhere, the vulnerability is dictated by the thickness of the unsaturated zone in the gravels.

9.7.2 Groundwater Vulnerability in Unconfined Areas to the North of Kilmanagh

Depth to water is a key influence on groundwater vulnerability in these areas. Hydrograph data from well 2315SWW233, lying within 100 m of the Kilmanagh River, indicates water levels frequently less than 2 m below ground (see Figure 4.20 in Volume I). Given that the depth to water will generally increase moving away from a river, it is likely that the thickness of the unsaturated zone will generally be less than 3 m close to the river and in excess of 3 m over most of the remainder of the aquifer. Consequently, the vulnerability has been mapped as generally 'extreme' along a band 100 m wide on either side of the Kilmanagh River where it flows over the unconfined portion of the aquifer. Elsewhere, the vulnerability is considered to be 'high'.

9.7.3 Groundwater Vulnerability in Confined Areas Between Kilmanagh and Callan

Till thickness is a key influence on groundwater vulnerability in the these areas. The overlying tills are believed to have a moderate permeability (see Section 5.3.3, Volume I) and a typical thickness of 3 m to 4 m. Consequently, the vulnerability of groundwater in the gravels below is expected to be generally 'high'.

9.8 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 it largely dictates the size of the zone of contribution.

In areas where point recharge from sinking streams, etc, is discounted, the main parameters involved in recharge rate estimation are annual rainfall, annual evapotranspiration, and annual runoff[9]:

- Annual rainfall: 910 mm (average of Met Eireann average annual (1961-90) rainfall measured at two sites in Callan).
- Annual actual evapotranspiration (A.E.) losses: 370 mm. This figure ('actual evapotranspiration') was calculated using an extrapolation for the Callan area computed by Ball (1972), using the average 1968 to 1971 data from the station in Oak Park, Co Carlow. More local measurements of actual evapotranspiration are not available.
- Potential recharge: 540 mm/year, based on average annual rainfall less estimated evapotranspiration.
- Annual runoff losses:
  - *Area of thin till cover north of Kilmanagh*: 110 mm/year (20% of potential recharge). This is a typical figure used by the GSI in areas where the till cover is thin.

[9] *Estimations used in this report have generally been rounded off to two significant figures*

- *Confined area south of Kilmanagh*: 510 mm/year (95% of potential recharge). This particularly high runoff estimation is based on visual observations in the area which indicate waterlogged soils and high drainage densities (Chapter 5, Volume I). Ball (1972) estimates that the annual baseflow to the Kings River at Callan is 12%. This suggests that 88% of potential recharge is lost to runoff over the sub-catchment as a whole. Given that this sub-catchment includes areas of high infiltration, it is likely that the proportion lost to runoff exceeds 88% in the poorly drained area to the south of Kilmanagh. The figure of 95% represents a nominal quantity between 88% and 100%.

The calculations are summarised below:

	Confined Portion:	Unconfined Portion:
Average annual rainfall (R)	910 mm	910 mm
Estimated A.E.	370 mm	370 mm
Potential Recharge (R – A.E.)	540 mm	540 mm
Runoff losses factor (RO)	95%	20%
Estimated Actual Recharge (R-A.E.) x (1-R.O)	30 mm	430 mm

9.9 Groundwater Discharge and Groundwater Levels

The supply scheme does not use all of the water discharging from the Callan spring; a proportion overflows from the concrete chamber (see Section 9.3). Discharge from this overflow was measured by the GSI, using a weir constructed by the Sanitary Services section of the County Council.

Results were as follows:

Date	**Usage by Scheme (m^3/d)**	**Overflow (m^3/d)**	**Spring Discharge (m^3/d)**
19/05/2000	800	280	1080
31/05/2000	830	260	1090
18/08/2000	945	0	945
18/10/2000	1110	1390	2500
Average	920	480	1405

This indicates that the quantity of overflow is very much dependent on seasonal recharge to the aquifer. In August, when recharge is expected to be at its lowest, the overflow dried up. In October, after a week of heavy rain, the overflow exceeded the usage by the supply scheme.

The sand and gravels along the river are considered to be confined by the overlying tills between Callan and Kilmanagh. Ball (1972) found that a dug well in the portion of the aquifer from Kilmanagh to Callan was confined in the winter. In addition, a pumping test carried out by the GSI in 1977 provided evidence that there is little hydraulic connection between the sand and gravel and overlying sediments in the area. A dug well installed within the sediments overlying the sand and gravel aquifer was unaffected by pumping at a rate of 30 m^3/day from the aquifer below in a well just 6 m away.

Upstream of Kilmanagh, Naughton (1978) has indicated that the gravel aquifer is unconfined.

9.10 Groundwater Flow Directions and Gradients

Due to the range of aquifer types in the Callan area, the groundwater flow directions are somewhat complex. Data is limited, but it is expected that flows to the spring will generally be from north to south.

The area around the Callan spring seems to be a groundwater discharge zone, with at least four springs in close proximity (Section 9.5). It is envisaged that the discharging water comes from two sources:

- *Northern unconfined portion of the sand and gravel aquifer, lying between Kilmanagh and Tullaroan:* The till cover is thin or absent, drainage densities are low, and there is evidence that rivers lose some or all of their water to ground as they flow across the area (see Section 4.18.2, Volume I). All three factors suggest recharge to the sand and gravel aquifer is high in this area. Though much of the groundwater is expected to discharge back to surface water close to Kilmanagh, it is likely that a significant quantity flows underground southward into the confined portion of the sand and gravel aquifer. Some evidence for this is described by Naughton (1978).
- *Deep groundwater flow from the dolomite aquifer:* As discussed in Section 9.6.1, deep faults are believed to link the dolomite aquifer with the surface in the vicinity of Callan. Figure 9.1 outlines a possible scenario whereby groundwater in the dolomite aquifer is forced to the surface along a fault zone by the presence of a low permeability shaley limestone barrier. Water that has come from depth is likely to have slightly elevated temperatures, and although this is not the case at the Callan spring, two springs a few hundred meters to the north-west are denoted as warm springs (Burdon, 1983).

In summary, it is expected that flows within the sand and gravel aquifer near Callan are being forced to the surface as springs as a result of constriction in the extent of the gravels, and the addition of flow from the deep dolomite aquifer below.

Groundwater gradients are difficult to calculate because of the limited well water level data available. However, assuming that the groundwater supplying the wells comes primarily from flow in the sand and gravels, and therefore has travelled through the sediments, below the river, the topographic gradient along the length of the river is considered to provide a broad indication of the groundwater gradient. The estimated gradient is 0.0014 (1 in 714).

9.11 Hydrochemistry and Water Quality

Data on recent trends in water quality at the Callan source are summarised graphically in Figure 9.2, and the source data can be found in Appendix V.

The following key points have been identified from the data:

- Data from analysis of hardness in five samples indicate a 'very hard' (>350 mg/l $CaCO_3$) calcium-bicarbonate hydrochemical signature. This is typical of most Irish groundwaters, particularly those in limestone regions. Further, levels of magnesium are above 20 mg/l in four out of six analysis available. This supports the suggestion that the spring waters have mixed with waters from the deep magnesium-rich dolomite aquifer.
- Of the parameters examined in the raw[10] groundwater samples taken, only nitrite (in 3 out of 34 available analyses from 1993 to 1998) and faecal coliforms (in nine out of 10 available analyses from 1993 to 2000) were in excess of the European maximum admissible concentration.
- Reported nitrate levels are slightly elevated but are not generally in excess of GSI guide levels and do not appear to have increased significantly between 1983 (14.2 mg/l as NO_3) and 2001 (19.9 mg/l as NO_3).
- With the exception of faecal coliforms, the available analysis of contaminant indicator parameters do not indicate significant problems affecting the source. Most springs are susceptible to bacteriological contamination from surface washings of animal faeces. Where water-logging occurs, as at Callan, the susceptibility is increased. Passing wildfowl may even

[10] *Raw water samples are taken <u>prior to treatment</u>. Assessments are aimed at identifying contamination hazards rather than direct human health issues.*

be the cause. Consequently, it may be that the levels of faecal coliforms identified are not indicative of significant groundwater contamination at the source.

The regional hydrochemistry of the Callan sand and gravel aquifer (**Rg**) and the underlying bedrock aquifers is discussed in Chapter 4 of Volume I.

9.12 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 in Section 9.14.3.

Transmissivities of 200 m^2/day to 250 m^2/day and permeabilities of 30 m/day to 60 m/day were estimated from two pump tests carried out in the unconfined portion of the sand and gravel deposit near Kilmanagh (Naughton, 1978). There is evidence that the southern, confined portion of the aquifer contains more silt and clay overall than the northern portion where these transmissivity estimates were made. Consequently, it is likely that this southern portion has a lower overall permeability than the values given above.

A porosity of 20% is assumed to represent a reasonably conservative value for gravels.

9.13 Conceptual Model

This section provides a qualitative overview of the geological framework, recharge, 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 main aquifers influencing water flowing to the Callan spring are the Kilmanagh sand and gravels and the dolomite aquifer (see Figure 9.1). The sands and gravels stretch from Callan, up the Kilmanagh River valley, to Tullaroan. They are believed to be unconfined between Tullaroan and Kilmanagh and confined by an overlying layer of till between Kilmanagh and Callan. In the vicinity of the Westcourt spring, the deposits are believed to be up to 15 m thick, and 1 km wide, and to be overlain by up to 4 m of confining fine-grained deposits. The dolomite aquifer is believed to be confined by over 500 m of limestone below the spring.
- Most recharge to the sand and gravel aquifer occurs over the unconfined portion, some 7 km north of spring. Very little recharge is believed to occur over the confined portion of the sand and gravel, mainly as a result of a high watertable. Most recharge to the dolomitised aquifer is likely to occur in the vicinity of Galmoy some 30 km north of the spring.
- Though most recharge to the unconfined sand and gravel is likely to discharge to the Kilmanagh River near Kilmanagh, a proportion is expected to flow southwards underneath the confining tills, and discharge at the Callan spring and the three other springs in the vicinity. Flow in the dolomitised aquifer is thought to be forced to surface, through one or more deep faults in the Callan area, by the presence of a faulted barrier of shaley limestone (see Figure 9.1). The addition of these deep flows, in combination with a constriction in the width of the sand and gravel aquifer, is thought to be the reason why several springs occur in the area.
- Recharge rates to the confined portion of the sand and gravel aquifer are thought to be of the order of 30 mm/year. In the unconfined portion further north, it is likely to be closer to 430 mm/year.
- Groundwater gradients within the sand and gravel are thought to be similar to topographic gradients along the river, around 0.0014 (1 in 714) (see Section 9.10).

9.14 Delineation of Source Protection Areas

9.14.1 Introduction

This section delineates the areas around the spring that are believed to contribute groundwater to the spring, and that therefore require protection. The areas are delineated on the basis of the conceptualisation of the groundwater flow pattern as described in Section 9.13.

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 spring.

9.14.2 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 groundwater flow direction and gradient, (b) the aquifer permeability and (c) the recharge in the area. The ZOC was delineated using both analytical modelling and the results of hydrogeological mapping and conceptualisation.

Hydrogeological boundaries taken from hydrogeological mapping and the conceptualisation outlined in Section 9.13 are as follows:

- **Northern boundary:** Northern extent of the entire sand and gravel aquifer, including the unconfined portion as well as the confined portion. This extends up the Kilmanagh River valley to just north of Tullaroan.
- **Southern boundary:** The boundary between the sand and gravel aquifer and the glacial till.
- **Eastern boundary:** The boundary between the sand and gravel aquifer and the glacial till.
- **Western boundary:** The boundary between the sand and gravel aquifer and the glacial till.

These boundaries contain the whole sand and gravel aquifer and are the physical limits within which the ZOC is likely to occur. They encompass an area of 30 km^2.

A water balance can be used to determine whether the delineation of the ZOC could be reasonably reduced to a smaller area within these quite extensive physical limits:

The estimated total recharge to the confined portion of the gravel aquifer is 600,000 m^3/yr (30 mm/yr over 20 km^2). A conservative estimate of spring discharge from the gravel aquifer is 1,300,000 m^3/yr. This is derived from the maximum estimated total discharge from the Callan spring and the estimated discharge from the other springs in the vicinity (estimates taken from GSI records). Note that this figure does not represent the total discharge from the gravel aquifer, which would also comprise baseflow to the Kings River and groundwater abstractions. Nevertheless, three conclusions can be drawn from a comparison of recharge with discharge:

- Recharge to the confined portion of the aquifer near the Callan spring is insufficient to support discharge. It is necessary to include the unconfined portion to the north of Kilmanagh into the ZOC, even though this portion lies several kilometres from the source.
- Given that the recharge estimate from only the confined portion of the gravel aquifer comprises nearly 50% of the discharge estimate, the contribution from the dolomite aquifer is unlikely to be significant in comparison with the contribution from the sand and gravel aquifer as a whole. This is supported by evidence of minor nitrate contamination at the spring, which indicates a significant input of relatively young, shallow groundwaters. In addition, it is probable that groundwaters within the deeper, dolomitised aquifer are several hundred years old, having travelled underneath Slievardagh at depths of over 300 m (see Section 4.14). Consequently, it is

considered unlikely that the recharge area for the deeper dolomite groundwaters requires significant protection in the context of groundwater contamination at the Callan source.

- The total extent of the sand and gravel aquifer should be used as the boundary of the ZOC at the Callan spring.

9.14.3 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 and it is delineated to protect against the effects of potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination.

Estimations of the extent of this area cannot be made by hydrogeological mapping and conceptualisation methods alone. Analytical modelling was therefore used to estimate the extent of this zone upgradient of the spring.

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

$$\textit{Velocity} = \textit{groundwater gradient} \times \textit{permeability} \div \textit{porosity}$$

Using the estimates derived in Sections 9.10 and 9.12 for gradient, permeability, and porosity (0.0014, 60 m/day, and 0.2 respectively), the equation gives a velocity of 0.4 m/day. This could be treated as a 'reasonable worst case estimate'. In other words, though some very rapid flow paths may occur, it is thought that most groundwater will move up to 40 m in 100 days. This has been rounded-up to 50 m and the boundary of the SI has been delineated 50 m upgradient of the source (refer to Map 10).

9.15 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the source protection areas and vulnerability categories – giving a possible total of 8 source protection zones (see the matrix in the table below). In practice, this is done 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 Source Protection area where the groundwater is highly vulnerable to contamination. All of the hydrogeological settings represented by the zones may not be present around any given source. Three groundwater protection zones are present around the Callan source (see Map 10), as shown in the matrix below.

Matrix of Source Protection Zones

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

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

9.16 Land Use and Potential Pollution Sources

Agriculture in the area comprises mainly pasture and some tillage. Callan town lies outside the protection zone for Westcourt spring.

The main hazards within the ZOC are considered to be agricultural: in particular, animal activities at and within the perimeter of the spring site.

9.17 Conclusions and Recommendations

- The Callan spring is located in an extensive sand and gravel aquifer. Groundwater in the zone of contribution is generally considered to be 'highly' vulnerable to contamination.
- 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:
  - chemical and bacteriological analyses of raw water as well as treated water should be carried out regularly. Given some of the raw water quality issues at the source, a monthly frequency has been recommended in Section 7.9. The chemical analyses should include all major ions - calcium, magnesium, sodium, potassium, ammonium, bicarbonate, sulphate, chloride, and nitrate. Analysis of other parameters such as pesticides and hydrocarbons is also recommended;
  - care should be taken in allowing any activities or developments which might significantly increase nitrate levels;
  - the potential hazards in the ZOC should be located and assessed;
  - though the site is fenced off, measures to prevent animal faeces from washing into the spring might be examined. These might include, for example, measures to discourage animal activity at the fence boundary and/or the consideration of drainage ditches to ensure surface waters are drained away from the spring.

10. Glenmore Source

10.1 Introduction

The objectives of this chapter are:

- To delineate source protection zones for the Glenmore Water Supply Scheme.
- To outline the principal hydrogeological characteristics of the Glenmore area.
- To assist Kilkenny 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 spring. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

10.2 Location and Site Description

The location of the Glenmore spring source is shown on Map 8. The well-house for the supply lies in Weatherstown townland some 2 km to the north of Glenmore. Flow from the source is gravity fed into the well-house, where it is chlorinated and then gravity-fed down to Glenmore. The location of the source itself is less obvious than that of the well-house. On the basis of the configuration of pipework to the well-house, Council staff have indicated that the spring is located by the side of the road some 125 m north of the well-house, below a small crescent-shaped, natural cutting in the road-side bank. The source may be associated with a Holy Well spring, which lies less than 100 m downslope and on the opposite side of the road from this cutting.

The well-house is located alongside a small stream, and excess flow from the spring is discharged to the stream via an overflow pipe, 15 m downstream of the well-house and 1 m above the stream bed. Another pipe enters the stream 2 m upstream of the well-house and 0.3 m above the stream bed, but this only discharges when the supply to the village is turned off, or when flow conditions are particularly high.

Reportedly, no protective structures have been built around the spring itself, so it is likely to be vulnerable to infiltration inundation by roadside runoff. The well-house chlorination tank is known to have been inundated by the adjacent stream at least once in the past year.

10.3 Summary of Source Details

	Weatherstown Spring
GSI no.	2611NWW094
Grid ref. (1:25,000)	26539 12460
Townland	Weatherstown
Source type	Spring
Development date	1930's
Owner	Kilkenny County Council
Elevation (ground level)	80 to 85 m OD
Depth to rock	Less than 3 m
Static water level	At surface
Discharge summary:	
(i) average consumption*	20[illegible]d
(ii) measured overflow**	[illegible]/d, 130 m^3/d, 60 m^3/d
(iii) Estimated total discharge***	[illegible] m^3/d to 90 m^3/d

** Figure taken from a report produced by M.C. O'Sullivan Consulting Engineers (1999) for Kilkenny County Council.*
***Measurements were taken by GSI staff on 12/4/00, 31/5/00 and 3/10/00 respectively (refer to Section 10.4.2).*
****The higher of the two values is taken from estimated consumption added to the highest measured overflow. The lower value is taken from the dry weather yield cited in by M.C. O'Sullivan Consulting Engineers (1999).*

10.4 Methodology

10.4.1 Desk Study

Bedrock geology information was compiled from original 1:10560 (six inch) field sheets and from the GSI bedrock report for the area (Tietzsch-Tyler and Sleeman, 1994b). Details of the current abstraction rate were obtained from a report produced by M.C. O'Sullivan Consulting Engineers (1999) for Kilkenny County Council (refer to Section 10.3). Data on private groundwater wells in the area were taken from GSI archives and additional information on the source was obtained from anecdotal information supplied by Kilkenny County Council staff. Data on existing water quality were obtained from the County Council/Health Board (treated waters).

10.4.2 Site Visits and Field Work

- Site visits and fieldwork included walkover surveys undertaken by both the Groundwater (3 days) and Quaternary (1 day) sections of the GSI to further investigate the subsoil and bedrock geology, the hydrogeology, and the vulnerability to contamination.
- A raw water sample was taken on 04/10/00 by GSI staff and was submitted for analysis at the EPA laboratories in Kilkenny in accordance with their sampling and transportation guidelines. Additional samples could not be taken because of restrictions during the Foot and Mouth crisis of 2001.
- Measurements of the overflow from the spring were taken by GSI staff on 12/4/00, 31/5/00 and 3/10/00. The overflow is piped to the adjacent stream and measurements were made by timing the filling of a 13.5 litre vessel from this pipe. Each measurement comprises an average of at least 3 individual readings.

10.4.3 Assessment

Analytical equations and hydrogeological mapping were utilised to delineate protection zones around the source.

10.5 Topography and Surface Hydrology

The Glenmore source is located 3.5 km west of the River Barrow, and 2 km north of Glenmore Village (see Map 8). A small stream flows within 20 m of the source, and it continues down to Glenmore where it joins the Glenmore River and flows into the Barrow 2 km east of Glenmore.

The spring occurs on the floor of a narrow NW-SE trending valley. Where the spring emerges, the valley floor lies at 80 m to 90 m OD and is just under 1 km wide. The stream which occupies the valley originates in steep hills which rise to over 200 m O.D some 1.5 km to the north-west of the spring. These hills form part of the catchment divide between the Nore and the Barrow river basins. Closer to the spring, the watersheds of the valley lie at approximately 100 m OD.

Slopes are approximately 0.1 (1 in 10) on the steeper valley sides in the north of the catchment, and approximately 0.05 (1 in 20) on the valley sides in the vicinity of the Glenmore source.

There is a streamflow gauge on the Glenmore River at Glenmore. Low flows[11] at this station are of the order of 0.023 m^3/sec (EPA, 2001).

10.6 Geology and Aquifers

10.6.1 Bedrock

The main rock types in the vicinity of the Glenmore source are the Oaklands and Ballylane Formations. These formation are described in more detail in Chapters 2 and 4 of Volume I and their distribution in the vicinity of the Glenmore source is shown on Map 8.

In Section 4.6 of Volume I, the Oaklands Formation is classified as a **locally important aquifer** which is **moderately productive only in local zones** (**Ll**), while the Ballylane Formation is classified as a **poor aquifer** which is **generally unproductive except for local zones** (**Pl**). Fracture flow is expected to be dominant in these aquifers. Flows are expected to be concentrated in fractured and weathered zones. Given common weathering patterns, most flow is thought to be relatively shallow; concentrating in the top 10 m to 30 m of the rock profile. More detail on flow characteristics and aquifer classification criteria can be found in Volume I.

The structural geology of both these formations is related. In the Glenmore area, the rocks have been folded into a SW-NE trending syncline (downward fold in the rock mass). The axis of the syncline runs just to the south of the spring, and fracturing is likely to be associated with it. A NE-SW trending fault line is mapped close to the spring. This fault may be associated with more extensive weathering and fracturing and may therefore be a focus for groundwater flow to the spring (refer to Map 8).

The rocks of both formations dip towards the axis of the syncline at between 40° and 80°.

10.6.2 Subsoil

The main subsoil type is glacial till. This material is described in more detail in Chapter 3 of Volume I and its distribution in the vicinity of the Glenmore source is shown on Map 2S.

There are no subsoil materials classified as aquifers in the Glenmore area. The main significance of the subsoil materials, therefore, is in vulnerability and recharge assessments. These issues are described in Sections 10.7 and 10.8.

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[11]*Flow which is equalled or exceeded at least 95% of the time.*

10.7 Groundwater Vulnerability

The concept of vulnerability is discussed in Chapter 5 of Volume I. In essence, however, groundwater vulnerability is dictated by the nature and thickness of the material overlying the main groundwater 'target'. As discussed in Section 10.6, the main groundwater resource occurs within fractured bedrock. Consequently, the target is taken from the top of the bedrock formations, and considerations of groundwater vulnerability concern the permeability of the whole subsoil profile and the depth to bedrock.

The subsoil in the immediate vicinity of the Glenmore source is thought to be generally less than 3 m thick. This interpretation is based on the presence, across the surface water sub-catchment to the north of the source, of at least 11 rock outcroppings (2 of which are in excess of 200 m long). No relevant borehole data is available to the GSI.

At subsoil thicknesses of less than 3 m, bulk permeability becomes less relevant in mapping vulnerability across wide areas (as opposed to specific sites), because the permeability becomes increasingly variable and increasingly influenced by the presence of 'bypass flow' mechanisms such as cracks in the subsoil. Accordingly, on the basis of the general depth to bedrock in the area, a vulnerability classification of 'extreme' has been assigned for the whole sub-catchment to the north of the spring.

The permeability estimations are based on regional-scale evaluations. Depth to rock interpretations are based on the available data cited here. However, permeability and particularly depth to rock can vary over a very small scale. Consequently, the vulnerability mapping provided will not be able to anticipate all the natural variation that occurs in an area. 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. More detail can be found in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

10.8 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 it largely dictates the size of the zone of contribution.

In areas where point recharge from sinking streams, etc, is discounted, the main parameters involved in recharge rate estimation are annual rainfall, annual evapotranspiration, and annual runoff:

- Annual rainfall: 1080 mm, data from Met Éireann average annual (1961-90) rainfall records, measured at Mullinavat Garda Station.
- Annual evapotranspiration losses: 480 mm. This figure ('actual evapotranspiration') was calculated assuming 95% of the country-wide potential evapotranspiration data presented in the "Agroclimatic Atlas of Ireland" (Collins and Cummins, 1996). Local measurements of actual evapotranspiration are not available.
- Potential recharge: 600 mm/year, based on average annual rainfall less estimated evapotranspiration.
- Annual runoff losses: 480 mm/year (80% of potential recharge). This estimation is based on the fact that, due to the poor nature of the aquifer and generally steep slopes, only a small proportion of the potential recharge will enter groundwater. Quantifying the precise proportion which enters groundwater is difficult, and an estimation of 20% has been used, based on work at the Piltown source (refer to Section 12.13). Given the thin subsoils

(thinner subsoils normally allow more groundwater recharge), it is thought that this estimation is conservative and at the lower reasonable limit of groundwater recharge.

These calculations are summarised below[12]:

Average annual rainfall (R)	1080 mm
Estimated A.E.	480 mm
Potential Recharge (R – A.E.)	600 mm
Runoff losses factor (RO)	80%
Estimated Actual Recharge (R-A.E.)*(1-R.O)	120 mm

10.9 Groundwater levels

The GSI database has no records within the surface water sub-catchment upstream of the Glenmore source. However, the fact that the source is a spring suggests water levels are close to ground surface in the vicinity. Further, the generally poor nature of the aquifers in the sub-catchment suggests that that water tables will be generally close to ground levels across most of the area. This is supported by visual evidence of field drainage in the vicinity of the source.

Given the thin subsoils, it is likely that groundwater within the upper, weathered portion of the aquifer is generally unconfined.

10.10 Groundwater Flow Directions and Gradients

In the absence of borehole data, and given the aquifer conditions (refer to Sections 10.6 and 10.9), the water table in the area is assumed to reflect topography, with groundwater flowing south westwards to the spring from the watersheds in Rickardsland and Weatherstown townlands. The Glenmore source, and the associated Holy Well spring, both lie on the eastern side of the stream and it is thought unlikely that significant groundwater flows will pass underneath the stream from the sub-catchment watersheds to the west. It is likely that the spring is formed at the intersection of a large mapped fault (refer to Section 10.6) and the surface water stream. Flows in large fault zones may occur deeper than in the upper weathered zone alone. However, given the generally poor nature of the aquifer, it is assumed that even flows within the fault will not cross underneath the surface watershed in Weatherstown townland.

Groundwater gradients are difficult to calculate because of the limited well water level data available. However, assuming that water levels are close to the ground surface, it is thought that hydraulic gradients will be similar to, but slightly less than, topographic gradients. Accordingly, a hydraulic gradient of 0.05 (1 in 20) is considered to represent a reasonable, if conservative, estimate of hydraulic gradient in the vicinity of the Glenmore source.

10.11 Hydrochemistry and Water Quality

Data on recent trends in water quality at the Glenmore source are summarised graphically in Figure 10.1, and the original data can be found in Appendix V.

The following key points have been identified from the data:

- Three analyses of hardness were available. Results indicate a 'moderately soft' to 'moderately hard' water (91 to 144 mg/l $CaCO_3$). This is considered typical of the non-limestone rocks in the Southern Uplands of Kilkenny; particularly in areas where the subsoil cover is thin. Naturally soft waters are often associated with problems due to low pH, and M.C. O'Sullivan Consulting Engineers (1999) indicate that the water in the source is acidic and likely to attack and tuberculate the cast iron network in the distribution system.

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[12] *Estimations rounded off to two significant figures.*

- Some 34 chemical and 24 bacteriological analyses (one of which was from a raw[13] water sample) have been obtained, and results are depicted in Figure 10.1. The dominant features are elevated nitrate and elevated faecal coliforms. Of the 34 nitrates results, 32 analyses reported concentrations in excess of the guide level of 25 mg/l NO_3, with 6 results close to or in excess of 50 mg/l NO_3. Of the faecal coliforms, most were in excess of 1 count/100 ml. In addition, one of the four available ammonia results is in excess of the guide level of 0.15 mg/l, while all 15 chloride results are close to the guide level of 25 mg/l to 30 mg/l. This combination of results suggests that contamination from organic wastes is occurring in groundwaters feeding the spring. It is likely that the organic wastes comprise domestic wastewater treatment systems (including 'septic tanks') and/or landspreading of animal wastes. In addition, the presence of consistently elevated nitrate concentrations mean that inorganic fertilisers cannot be ruled-out as a contributory hazard.

Faecal coliform and ammonia are usually readily attenuated in the soil/subsoil. Therefore, the occurrence of high ammonia and high faecal coliforms in groundwater would often suggest that contamination is occurring from underground point hazards (such as septic tank systems) rather than from hazards at the ground surface (e.g. landspreading). However, given the generally thin subsoils near the Glenmore source (rock at or close to surface in places), it is likely that the natural attenuation capacity is limited and it is possible that faecal coliforms and ammonia are able to reach groundwater from hazards at the ground surface. In addition, spring sources often have high faecal coliforms as a result of wildfowl activity or surface water inundation. Thus, even though faecal coliforms and ammonia are elevated in some of the available samples, it is not possible to isolate the main organic waste hazard at the Glenmore source using water quality data alone. Further assessments are provided in Section 10.16.

10.12 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 in Section 10.14.3.

The data used in this section are mainly estimations based on our understanding of the likely flow-regimes in the Oaklands and Ballylane aquifer systems. No pump-test data were available in the immediate vicinity of the Glenmore source, but well grant scheme pump tests for each of the formations were used to assist in the assessment. Well 2611NWW092 is situated in the Ballylane Formation, 1.5 km north-west of spring, while well 2611NWW091 is located in the Oaklands Formation, 7 km to the north-east of the spring.

In 2611NWW092, a constant discharge test in 1998 at 22 m^3/day for 6 hours gave a final drawdown of 9.2 m, and a very low specific capacity of 2.4 m^3/day/m. Analysis of the data from this test using the Logan method (Misstear 1998) provided a transmissivity estimate of 5.4 m^2/d.

In 2611NWW091 a discharge test at 30 m^3/day for 4 hours gave a final drawdown of 6.1 m, and a low specific capacity of 4.9 m^3/day/m. Analysis of the data from this test using the Logan method provided a transmissivity estimate of 9 m^2/d.

The estimated bulk permeability of the aquifer feeding groundwater to the Glenmore source is 0.9 m/day. This has been derived by dividing the higher of the two transmissivity estimates (9 m^2/d) by the lower limit of assumed aquifer thickness (10 m). It is thought that this value therefore represents a conservative, but reasonable, estimate of bulk permeability.

Bulk porosity is assumed to be in the order of 0.01. This is at the lower end of the typical range used by the GSI for bedrock aquifers (0.025 to 0.01) and reflects the possibility that the aquifer is not densely fractured near the spring.

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[13] Raw water samples are taken <u>prior to treatment</u>. Assessments are aimed at identifying contamination hazards rather than direct human health issues.

10.13 Conceptual Model

This section provides a qualitative overview of the geological framework, recharge, 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 source at Glenmore is a low yielding spring, discharging a few hundred cubic metres per day. The source lies within the surface water sub-catchment of a small, un-named stream to the north of Glenmore, which drains into the River Barrow.
- The spring occurs at the downstream limit of a poor (Pl) aquifer, and may be associated with a zone where a large, mapped fault intersects the stream.
- Subsoils are dominated by tills which are expected to be less than 3 m thick across most of the surface water sub-catchment upstream of the spring.
- The aquifer is thought to be unconfined in the area and flow to the springs is controlled by fracturing and weathering patterns within the rock mass. Most groundwater flow is thought to be relatively shallow; concentrating in the top 10 m to 30 m of the rock profile and in the mapped fault zone. The flow is therefore likely to follow local variations in topography, but will generally be south westwards.
- Recharge to the spring is likely to originate as rainfall on the eastern half of the surface water sub-catchment upstream of the spring. Given the poor nature of the aquifer, most effective rainfall will divert to surface water and it is assumed that only 20% of the effective rainfall (i.e. 120 mm/year) which falls on the eastern half of the sub-catchment will enter groundwater and flow to the spring.
- The nature of the aquifer is such that groundwater residence times and groundwater flow paths are believed to be short. Even flows within the large mapped fault are not expected to cross underneath surface watersheds, or underneath the stream which runs close to the spring.
- Due to their low bulk permeabilities, groundwater gradients in the aquifer are probably similar to topographic gradients, and are estimated to be up to 0.05 (1 in 20).

10.14 Delineation of Source Protection Areas

10.14.1 Introduction

This section delineates the areas around the source that are believed to contribute groundwater to the source, and that therefore require protection. The areas are delineated on the basis of the conceptualisation of the groundwater flow pattern as described in Section 10.13.

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.

10.14.2 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 groundwater flow direction and gradient, (b) the rock permeability and (c) the recharge in the area. The ZOC is delineated using both analytical modelling and the results of hydrogeological mapping and conceptualisation. Given the limited amount of calibration data available, a full groundwater numerical model was not undertaken.

The larger the total discharge at a source, the larger the ZOC will be in order to balance recharge with discharge. In order to be conservative, therefore, the largest measured discharge (230 m^3/day) was used as the basis for estimating the extent of the ZOC.

Given that groundwater flow in the area is expected to follow topography, the ZOC is likely to coincide, or lie within, the physical constraints of the surface water sub-catchment upstream of the spring. These constraints are outlined below:

- **Northern boundary:** Catchment divide between the Nore and the Barrow in Ballyvoulera townland, approximately 1.5 km north of the Glenmore spring.
- **Southern boundary:** This boundary is downgradient of the spring. In theory, springs will draw no water from areas downgradient of their location. However, irregularities caused by the dominance of fracture flow within the aquifer and by the relationship between surface water and groundwater mean that this may not strictly apply at Glenmore. In order to account for some of these irregularities, the southern boundary has been placed at an arbitrary distance of 100 m downgradient of the spring.
- **Western boundary:** The stream running down the centre of the valley.
- **Eastern boundary:** Watershed running from Ballyvoulera southwards through Weatherstown and into Rickardsland South. This watershed lies 350 m to the east of the spring at its closest point. It has been mapped using a combination of Ordnance Survey contour information, field walkovers, and areal photograph interpretation.

The area defined by the boundaries described above is 0.7 km^2. A water balance should provide a cross-check on whether lands outside the boundaries are supplying groundwater to the spring. Calculations are as follows:

Recharge area required to sustain discharge = *Discharge ÷ average annual depth of recharge.*

Recharge area required to sustain discharge $= (230 \times 365) \div 0.12$

Recharge area required to sustain discharge $= 0.7\ km^2$

Thus, there appears to be a good balance between the recharge area required, and the area which lies within the physical constraints of the surface water sub-catchment upstream of the spring. Though the discharge and recharge figures quoted in these calculations are both estimates, they have both been selected to be conservative in the context of requiring a large area to balance recharge with discharge. The agreement between the water balance and physical constraints is therefore taken to suggest that the physical constraints outlined above provide a reasonable basis for the delineation of the ZOC at the Glenmore source. The ZOC (i.e the extent of the SO, or 'Outer Protection Area') is depicted on Map 10.

10.14.3 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 and it is delineated to protect against the effects of potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination.

Estimations of the extent of this area cannot be made by hydrogeological mapping and conceptualisation methods alone. Analytical modelling was therefore used to estimate the extent of this zone upgradient of the well.

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

$$\textit{Velocity} = \textit{groundwater gradient} \times \textit{permeability} \div \textit{porosity}$$

Using the estimates derived in Sections 10.10 and 10.12 for gradient, permeability, and porosity (0.05, 0.9 m/day, and 0.01 respectively), the equation gives a velocity of 4.5 m/day. This could be treated as a 'reasonable worst case estimate'. In other words, though some very rapid flow paths may occur, it is thought that most groundwater will move up to 450 m in 100 days. Accordingly, the boundary of the SI has been delineated 450 m upgradient of the springs (refer to Map 10).

10.15 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the source protection areas and vulnerability categories – giving a possible total of 8 source protection zones (see the matrix in the table below). In practice, this is done 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 Source Protection area where the groundwater is highly vulnerable to contamination. All of the hydrogeological settings represented by the zones may not be present around any given source. Just two groundwater protection zones are present around the Glenmore source (see Map 10), as shown in the matrix below.

Matrix of Source Protection Zones

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

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

10.16 Land Use and Potential Pollution Sources

Agriculture in the area mainly comprises pasture and there are a number of farms in the area. Glenmore itself is a village of just over 100 people, and with a number of small commercial enterprises, one of which contains a petrol pump.

On the basis of the available water quality analyses, the main hazards within the ZOC are considered to be effluent from on-site wastewater treatment systems (including 'septic tanks'), and agricultural landspreading of organic and inorganic fertiliser. However, the full range of contaminants were not examined and other potential hazards include fuel storage, roadside spillages, pesticide application, and farmyards.

The nitrate concentrations are consistently elevated and merit some additional consideration. Some broad, 'back-of-the-envelope' estimations of the number of domestic wastewater treatment systems required to produce the measured nitrogen loading in the spring are provided below:

- *Typical nitrogen concentration in spring flow: 10 mg/l N*
- *Typical 'background' nitrogen concentration*[14]*: 3 mg/l N*
- *Estimated additional contribution of nitrogen from human activities in the ZOC: 10 – 3 = 7 mg/l N*
- *Minimum estimated total spring flow: 90,000 l/day.*
- *Estimated minimum nitrogen loading in spring: 90,000 × 7 ÷ 1000,000 ≈ 0.6 kg/day N.*
- *Estimated 'natural' nitrogen loading in recharge waters*[15]*: 0.1 mg/l N @ 90,000 l/day → 0.009 kg/day N.*

[14] *Taken as the typical concentration in Piltown spring, which lies in a similar hydrogeological and climatological environment.*

[15] *Loading estimates taken from EPA, 2000. The figures assume no denitrification and subsequent attenuation of nitrogen will occur in the subsurface.*

- *Estimated additional loading from human activities in the ZOC = 0.6 – 0.009 ≈ 0.6 kg/day N.*
- *Assuming all additional loading is derived from septic tanks, the population equivalent of the additional septic tank loading: 0.6 kg/day N @ 50 mg N/l/person @ 180 l effluent/person/day ≈ 70 people.*

In other words, it is estimated that the waste from at least 70 people living in the ZOC would be required to balance all the nitrogen loading observed in the spring waters. The ZOC is estimated to be 0.7 km^2, and 100 people within this area comprises a density of 1 person/hectare. Note that the ZOC crosses the townlands of Weatherstown, Busherstown and Rickardsland South, but does not incorporate Glenmore village itself. Note also that the calculations have used the minimum estimated spring flow (90 m^3/day) and have assumed that all the nitrogen from the septic tanks is converted to nitrate. In practice, some of the nitrogen will not become mobile in the subsurface, and there is evidence that average springflows are greater than 90 m^3/day. Consequently, the population density suggested by these 'back-of-the-envelope' estimations comprises a minimum number required to balance the observed nitrogen concentrations if septic effluent were the only influence on nitrate concentrations at the source.

If the actual population density is significantly lower than 1 person/hectare, the water quality data suggests that agricultural landspreading of organic wastes and inorganic fertilisers will require consideration as a significant influence on nitrate concentrations in the Glenmore spring.

10.17 Conclusions and Recommendations

- The source at Glenmore is a low yielding spring, which is located in a poor aquifer.
- Groundwater below the zone of contribution to the supply is generally 'extremely' vulnerable to contamination. However, future site-specific investigations may indicate that localised patches of lower vulnerability also occur.
- 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:
  - chemical and bacteriological analyses of raw water as well as treated water be carried out regularly. Given some of the raw water quality issues at the source, a monthly frequency has been recommended in Section 7.9. This high frequency is required because of the elevated nitrate and bacterial levels in the source. The chemical analyses should include all major ions - calcium, magnesium, sodium, potassium, ammonium, bicarbonate, sulphate, chloride, and especially nitrate. More occasional analyses of other parameters such as pesticides and hydrocarbons is also recommended;
  - care should be taken in allowing any activities or developments which might significantly increase nitrate levels;
  - the spring should be located and its vulnerability to surface runoff assessed; for example, in the context of animal fouling or chemical spills along the adjacent road. If the spring is intended for long term use, a protective structure would help minimise the risk;
  - the potential hazards in the ZOC should be located and assessed.

11. Paulstown Source

11.1 Introduction

The objectives of this chapter are:

- To delineate source protection zones for the Paulstown Water Supply Scheme.
- To outline the principal hydrogeological characteristics of the Paulstown area.
- To assist Kilkenny 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 springs. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

11.2 Location and Site Description

The location of the Paulstown source is shown on Maps 4N and 8. A number of springs discharge into a small area to form Tobergoorlick pool. The pool is impounded by a small weir over which the excess water discharges.

Adjacent land comprises farmland (pasture during the site visits) and a copse of trees. The pool is fenced off from these features with a barbed wire perimeter. A pump house lies within the compound. Water is drawn directly from an intake in Tobergoorlick pool, before being chlorinated and fluoridated and pumped (continuously) to the water tower reservoir in Castlekelly, which has a capacity of 160 m^3. The supply reportedly serves the towns of Paulstown, Gowran and Goresbridge and their surrounding areas.

11.3 Summary of Source Details

GSI no.	2615SWW107
Grid ref. (1:25,000)	26604 15729
Townlands	Paulstown
Source type	Spring
Development date*	1930's
Owner	Kilkenny County Council
Elevation (ground level)	45.5 to 46 mOD
Depth to rock	Generally < 3 m near the springs
Static water level	Ground level
Discharge summary:	
(i) average consumption*	910 m^3/d
(ii) overflow**	2900 ± 600 m^3/d

**Anecdotal information from Kilkenny County Council*
***A figure of 2900 m3/day was measured on 18/10/00 by GSI staff using a float. In order to compensate for potential errors in the measurement, a 20% error bar has been assigned to this measurement. This range encompasses the overflow estimate of 2500 m^3/ d quoted in K.T.Cullen & Co. Ltd, 1997.*

11.4 Methodology

11.4.1 Desk Study

Bedrock geology information was compiled from original 1:10560 (six inch) field sheets and from the GSI bedrock report for the area (Tietzsch-Tyler *et al*, 1994a). Details of the current abstraction rate were obtained from Kilkenny County Council. Data on private groundwater wells in the area were taken from GSI archives and additional information on the source was obtained from a report produced by M.C. O'Sullivan Consulting Engineers (1999) for Kilkenny County Council. Data on existing water quality were taken from the EPA (raw waters) and the County Council/Health Board (treated waters).

11.4.2 Site Visits and Field Work

- Site visits and fieldwork included walkover surveys undertaken by both the Groundwater (3 days) and Quaternary (1 day) sections of the GSI to further investigate the subsoil and bedrock geology, the hydrogeology, and the vulnerability to contamination.
- Spring overflow measurements were taken by the GSI on 18/10/00. No calibrated weir exists and flows were estimated using a timed float method.
- A raw water sample was taken on 4/10/2000 by GSI staff and was submitted for analysis at the EPA laboratories in Kilkenny in accordance with their sampling and transportation guidelines.

11.4.3 Assessment

Analytical equations and hydrogeological mapping were utilised to delineate protection zones around the source.

11.5 Topography and Surface Hydrology

The Paulstown source is located 2 km due south of Paulstown village (Maps 4N and 8).

The source is located on the western side of the River Barrow valley. Baunreagh hill on the Castlecomer Plateau forms the regional watershed on the west bank, rising approximately 260 m above the level of the source. Slopes on the valley sides are in the order of 0.08, and decrease over a short interval to approximately 0.008 on the valley floor. The low topography of valley floor in the vicinity of the source is broken by a ridge (termed the 'Butlersgrove ridge' in this document), located just downstream of the source. This ridge runs north east to south west and rises approximately 30 m above the level of the source.

The spring overflow joins the Acore stream, which joins the Mountfelim stream just downstream of the spring and then the Barrow approximately 3 km to the south east. Toberkeagh pool, a spring lying approximately 0.8 km north of the source, also joins the Acore River. A gap occurs in the Butlergrove ridge just downstream of the Paulstown springs. This gap constitutes a focal point in the surface drainage network of the area - all the surface drainage within a band extending some 2 km to the north and 4.5 km south of the source drains through this feature.

Natural surface water drainage densities are high on the slopes of the plateau, but decrease significantly on the valley floor. This change coincides with the karstic phenomenon of sinking streams. During site visits on the 9/8/01 the Acore stream was observed to begin to lose water once it flowed off the Castelcomer Plateau and onto the valley floor. It dried-up completely between the main Waterford road and the area around the Paulstown source. The Paulstown source itself continued to flow, but the Toberkeagh spring, though similar in surface area to the Paultsown source, was dry. This spring lies at a slightly higher altitude than the Paulstown source and local residents have indicated that it is often dry in the summer months. The Mountfelim stream demonstrated a similar pattern to the Acore stream during the site visit. Though the stream did not completely dry-up in any stretch of the channel, the flow was visibly reduced on the valley floor in comparison with the Castlecomer Plateau.

11.6 Geology and Aquifers

11.6.1 Bedrock

The main rock types in the vicinity of the Paulstown source comprise limestones on the valley floor and shales, siltstones, and sandstones on the slopes of the Castelcomer Plateau. These formations are described in more detail in Chapter 2 of Volume I and their distribution in the vicinity of the Paulstown source is shown in Figure 11.1 and on Map 8.

The source itself lies at the boundary between a karstic and a shaley limestone aquifer. Clean, karstic limestones (Ballyadams and Clogrennan Formations) underlie the valley floor upstream of the source. These limestones have been classed as regionally important karst limestones (**Rk**) in Chapter 4 of Volume I. Regionally, flows are expected to be highly variable both in space and time, concentrating in discreet fissure zones within the top 75 m of the rock profile. Given this depth, flow direction may not always correspond with topographic slope or surface water catchment divides. Locally, groundwater flow through the aquifer may be influenced by the following bedrock features:

- A band of dolomitised limestone is mapped running south west - north east near the spring. Dolomitisation often enhances rock permeability (refer to Chapter 4 of Volume I).
- Folding and faulting extends in a north west – south east trend. Fracture zones are also likely to follow this orientation. No faults are mapped in the immediate vicinity of the spring, but a major fault is mapped on the Castlecomer Plateau running north west – south east along the course of the Mountfelim stream (refer to Map 1N). It may be that this fault follows the Mountfelim stream onto the valley floor, perhaps coinciding with the gap in the 'Butlergrove Ridge' which lies near the spring (Figure 11.1).
- Bulk aquifer thickness may be reduced along the base of the Castelcomer Plateau (particularly where this area coincides with thick, low permeability subsoils). This zone will have been exposed to the effects of weathering and limestone dissolution over a shorter period of geologic time than areas further from the plateau.

Muddy limestones (Butlersgrove Formation) lie just downstream of the Paulstown spring. They have been classed as 'locally important bedrock aquifers which are moderately productive only in local zones' (**Ll**). Fracture flow is expected to be dominant. Regionally, flows are expected to be concentrated in fractured and weathered zones. Given common weathering patterns, most flow is thought to be relatively shallow; concentrating in the top 10 m to 30 m of the rock profile. Flow direction will therefore usually correspond with topographic slope and surface water catchment divides. More detail on flow characteristics and aquifer classification criteria can be found in Chapter 4 of Volume I.

Shales, siltstones and sandstones underlie the Castelcomer Plateau. The rocks closest to the base of the Plateau have been classified as poor - 'bedrock aquifers which are generally unproductive' (**Pu**). Higher up the slopes, the aquifer classification of the rocks varies between 'bedrock aquifers which are generally unproductive except for local zones' (**Pl**), 'Generally unproductive' (**Pu**), and 'Locally Important (**Lm**)'. In most of these rocks, flows are expected to be relatively shallow; concentrating in the top 10 m to 30 m of the rock profile. With the exception of the Lm aquifer, flow direction will therefore usually correspond with topographic slope and surface water catchment divides. More detail on flow characteristics and aquifer classification criteria can be found in Chapter 4 of Volume I.

All these rocks dip north westwards at angles of 8° to 15° (Figure 11.1).

11.6.2 Subsoil

The main subsoil type in the Paulstown area is till. This material is described in more detail in Chapter 3 of Volume I and its distribution in the vicinity of the Paulstown source is shown on Map 2N.

There are no subsoil materials classified as aquifers in the Paulstown area. The main significance of the subsoil materials, therefore, is in vulnerability and recharge assessments. These issues are described in Chapter 5 of Volume I and in Sections 11.7 and 11.8.

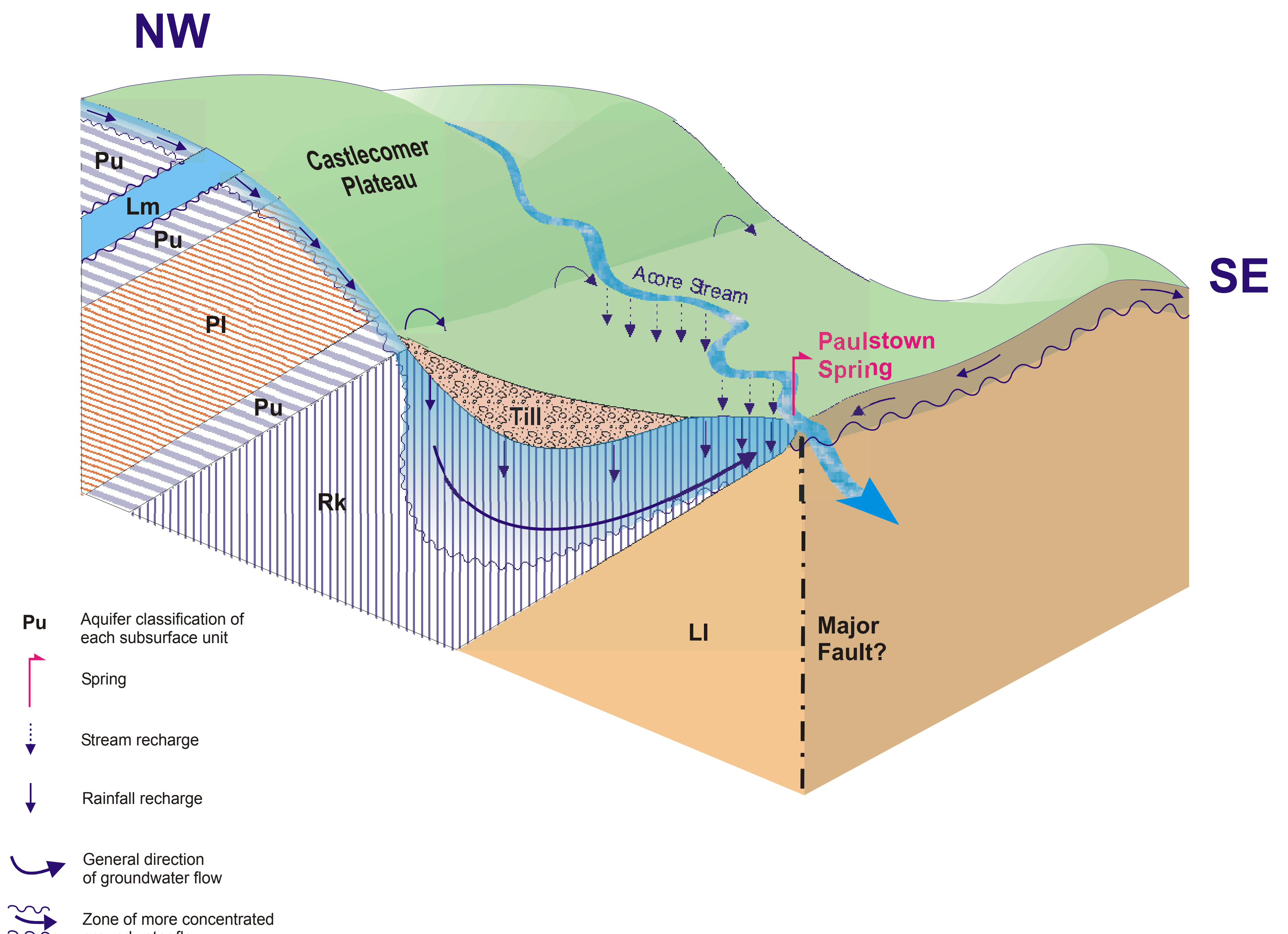

Figure 11.1 Schematic Hydrogeology of the Paulstown Source in Cross Section

11.7 Groundwater Vulnerability

11.7.1 Introduction

The concept of vulnerability is discussed in Chapter 5 of Volume I. In essence, groundwater vulnerability is dictated by the nature and thickness of the material overlying the main groundwater 'target' and by the presence of features (such as karstic sinkholes) which may allow contaminants to bypass the overlying material. As discussed in Section 11.6, the main groundwater resource at the Paulstown source occurs within fractured and karstified bedrock. Consequently, the target is taken from the top of the bedrock formations and considerations of groundwater vulnerability concern the permeability of the whole subsoil profile, the depth to bedrock, and the presence of karst features on the karst limestone aquifer.

11.7.2 Permeability

A generalised subdivision of Kilkenny into three broad permeability types ('high', 'moderate' and 'low') is provided in Chapter 5 of Volume I. The tills in the vicinity of the Paulstown springs have been classed into the 'moderate' permeability category, and are thought to be characteristic of the moderate permeability tills which occur across most of the Kilkenny lowlands.

11.7.3 Depth to rock

The basic depth to rock data on which vulnerability assessments have been made is presented on Map 3N. The data on this map come from drilling records housed in the GSI databases and detailed field mapping carried out in the 1800's. On the basis of available data, three broad areas can be identified in the vicinity of the Paulstown springs:

Location of area	Depth to rock	Summary of available data
Underlying the springs and extending in a north east to south west band between Kilmacahill and Woodquarter.	Generally less than 3 m.	3 boreholes: 0 m - 2 m to rock. At least 23 rock outcrops in evidence, several of which are in excess of 150 m long.
North east to south west band at the foot of the Plateau running from Ballyquirk to Jordanstown.	Generally more than 5 m	7 boreholes: 6 m – over 23 m to rock.
On the slopes of the Plateau, west of a line from Ballinvally to Kellymount.	Generally less than 5 m	Over 20 boreholes: 2 m - 6 m to rock (5 m to 10 m in a small area around Castle Hill). Large number of rock outcrops in evidence.

11.7.4 Karst features

As described in Section 11.5, both the Mountfelim and Acore streams are thought to lose water through the base of their channels as they cross the karst limestone aquifer. Contaminants within surface water are likely to be able to reach the limestone aquifer in a concentrated line and with minimal attenuation below these stretches. Groundwater vulnerability in Ireland is at its most extreme below swallow holes and sinking streams.

11.7.5 Summary

The factors of depth to rock and subsoil permeability combine to give three broad bands of vulnerability running north east to south west across the area upstream of the Paulstown springs. The springs themselves lie on a band where the rock aquifers (i.e. the target) are very close to surface and groundwater vulnerability is considered to be generally extreme. This is also the case on the side of the Castlecomer Plateau (though there is a small area of moderate vulnerability near Castle Hill). In between these two bands of extreme vulnerability lies a band of thicker subsoil and generally high to moderate vulnerability, running along the base of the Castlecomer Plateau from Ballyquirk in the south west to Shankill in the north east. All three bands are cross-cut by zones of extreme vulnerability extending 30 m on either side of the Mountfelim and Acore streams as they pass over the karstic aquifer. Maps of interpreted vulnerability in the area are presented on Map 6N (small scale) and Map 8 (large scale).

The permeability estimations are based on regional-scale evaluations. Depth to rock interpretations are based on the available data cited here. However, permeability and particularly depth to rock can vary over a very small scale. Consequently, the vulnerability mapping provided will not be able to anticipate all the natural variation that occurs in an area. 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. More detail can be found in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

11.8 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 'direct', aerial inputs from effective rainfall less runoff losses. The estimation of recharge is usually critical in source protection delineation as it largely dictates the size of the zone of contribution (i.e. the catchment of the source). However, in the case of the Paulstown springs, total recharge is complicated by the additional influence of 'indirect' recharge from sinking streams (refer to Section 11.13).

Direct rainfall recharge:

- Annual rainfall on the limestone lowland: 830 mm (Met Eireann average annual (1961-90), average of rainfall measured at Paulstown Castle).
- Annual evapotranspiration (A.E.) losses: 480 mm. This figure was calculated by assuming that 'actual evapotranspiration' can be approximated as 95% of annual the countrywide potential evapotranspiration data presented in the "Agroclimatic Atlas of Ireland" (Collins and Cummins, 1996).
- Potential recharge: 350 mm/year, based on average annual rainfall less estimated evapotranspiration.
- Annual runoff losses: At least 20% (70 mm/year). This is a typical figure used by the GSI in areas where the till cover is thin. In areas of thicker subsoil, steeper slopes, or poorer aquifers, the proportion lost will be greater.

These calculations are summarised below[16]:

Average annual rainfall on the limestone lowland (R)	830 mm
Estimated A.E.	480 mm
Potential Recharge (R – A.E.)	350 mm
Runoff losses factor (RO)	≥20%
Estimated Actual Recharge (R-A.E.)*(1-R.O)	≤280 mm

Indirect recharge from streams: No estimation can be made as it is not known if river recharge occurs outside the summer months. However, based on available hydrochemical evidence from the limestones (refer to Section 11.11), it seems likely that river recharge will be a smaller component than direct rainfall recharge over the karstic limestones.

[16] Estimations used in this report have generally been rounded off to two significant figures

11.9 Groundwater levels

There is a certain amount of groundwater level data available for the Paulstown/Gowran area. The data set comprises information collected as part of well surveys carried out in August 1971 and July 1973 by GSI staff, and data from the well database held at the GSI. Results are summarised in Figure 11.2. The data suggest that the karstic aquifer varies from confined to unconfined depending on the depth to rock.

11.10 Groundwater Flow Directions and Gradients

Generally, groundwater is expected to follow broad topographic trends, flowing south eastwards from the base of the Castlecomer Plateau towards the River Barrow. Detailed flow patterns are likely to vary from this broad pattern, particularly on the karst limestone aquifer.

The water level information summarised in Figure 11.2 suggests that the overall flow pattern in the karstic aquifer follows the regional topographic trend but that there is also a significant north eastward component of flow to the Paulstown springs. It may be that this component follows a higher permeability pathway associated with the mapped band of dolomitisation within the aquifer. The water levels also highlight a zone of concentrated discharge in the vicinity of the Paulstown springs and the springs at Toberkeagh. This discharge zone may have formed as a result of the combination of certain geological features described in Section 11.6.1:

- Two higher permeability zones are thought to merge in the vicinity of the discharge zone and flow volumes may therefore increase in the area to an extent where the aquifer can no longer contain the waters underground.
- A generally lower permeability zone occurs downstream of the springs and is associated with the presence of the less productive, muddy, Bultersgrove limestone aquifer. This generally lower permeability aquifer may serve to hinder downstream movement of groundwater, forcing discharge to the surface. This feature is depicted in Figure 11.1.

In addition to groundwater flow from the karstic aquifer, a component is expected to reach the springs from the poorer aquifers of the Castlecomer Plateau. This is thought to occur via a complex mechanism comprising local groundwater discharge to streams on the Plateau sides, followed by surface water flow in the Mountfelim and Acore streams, and then recharge back to groundwater when the streams cross the karstic aquifer (Figure 11.1). Given that the Acore stream sinks completely in the summer, but that the Mountfelim stream is thought to only partially lose its flow in most summers, it is thought that the groundwater contribution from the Acore catchment will be the greater of the two on the Castlecomer Plateau. The line of small springs along the base of the Plateau (depicted in Figures 11.1 and 11.2) suggest that direct groundwater crossover between the rocks of the Castelcomer Plateau and the valley floor is minimal.

Note that the water level information provided in Figure 11.2 cannot be used to give a precise determination of flow direction beneath specific sites.

Groundwater gradients close to the slopes of the Castlecomer Plateau are in the order of 0.018. On the basis of data and interpretations in Figure 11.2, gradients along the north east – south west feature on the valley floor are in the order of 0.004.

11.11 Hydrochemistry and Water Quality

Data on recent trends in water quality at the Paulstown source are summarised graphically in Figure 11.3, and the source data can be found in Appendix V.

The following key points have been identified from the data:

- The results of the eight analyses of hardness available suggest that the groundwater is 'hard' to 'very hard' (292-377 mg/l $CaCO_3$). This is typical of most Irish groundwaters, particularly those in limestone regions.

- Faecal coliforms were in excess of the European maximum admissible concentration for drinking water (MAC) [17] in most of the eighteen available raw water analyses of discharge from the springs.
- Of the parameters examined in the eight available raw groundwater analyses, faecal coliforms, chloride, the potassium:sodium ratio, and nitrate are all regularly in excess of GSI guide levels. This combination of parameters, found in a spring located in an extreme vulnerability setting suggests that one or more farmyard point hazards are contributing to the contamination at the springs.
- Note, however, that the size of the spring discharge suggests that one farmyard is unlikely to be the sole cause of the water quality problems identified. It may be that several farmyards are contributing, and/or that landspreading of organic and inorganic wastes, on-site wastewater treatment systems, livestock activity along the sinking streams, and sewer leakages (from Paulstown) could also be contributing.

Comparative field readings of temperature/conductivity from the streams and the Paulstown source were taken by GSI staff on 9/8/01:

- Paulstown springs: Conductivity 646 µS/cm. Temperature 11.1°C.
- Acore stream: (3 readings): Conductivity 148 to 196 µS/cm. Temperature 12.3 to 12.9 °C.
- Mountfelim stream: (2 readings): Conductivity 177 to 178 µS/cm. Temperature 12.2 to 12.7 °C.

The main point to note from these data is that there is a clear difference between temperature/conductivity in the streams and in the spring. A similar pattern was identified by K.T. Cullen & Co. in 1997. This suggests that the proportion of indirect stream recharge is relatively minor compared to direct rainfall recharge over the karstic limestone.

11.12 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 in Section 11.14.3.

No pumping test data is available for the Paulstown springs. Data are available, however, for the Durrow public supply in County Laois. This supply draws water from the same karstic aquifer and lies some 33 km to the north east. A transmissivity of approximately 2900 m²/d was estimated from testing at Durrow (summarised in Fitzsimons and Wright, 2000). Assuming an effective aquifer thickness of 75 m (refer to Section 11.6.1), a bulk permeability of 39 m/d has been estimated from this transmissivity.

A porosity of 0.01 is assumed as being applicable to this aquifer. This is at the lower end of the typical range used by the GSI for bedrock aquifers (0.025 to 0.01) and reflects the belief that most flow will occur in discrete, karstic fissures and conduits.

Permeability and porosity estimates have not been made for the Butlergrove limestone aquifer or the aquifers of the Castlecomer Plateau. The Butlergrove limestones lie downstream of the springs and groundwater flow is unlikely to pass through this aquifer to the spring over significant distances. Groundwater is not thought to cross directly between the aquifers of the Castelcomer Plateau and the karst aquifer that feeds the Paulstown springs (refer to Section 11.10). Consequently, aquifer permeability and flow rates under the Plateau are not thought to influence the extent of the inner source protection area around the springs.

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[17] *Raw water samples are taken prior to treatment. Assessments are aimed at identifying contamination hazards rather than direct human health issues.*

11.13 Conceptual Model

This section provides a qualitative overview of the geological framework, recharge, 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. A summary of the conceptual model is depicted in Figure 11.1.

- The spring source at Paulstown has a high yield. It lies within the surface water sub-catchment of the Mountfelim and Acore streams, which drain south eastwards into the River Barrow.
- The spring occurs at the downstream limit of a karstic limestone (Rk) aquifer, and originates where groundwater flowing within the karstic aquifer is forced to the surface when it flows up against a less productive muddy limestone aquifer (Ll). The rocks of the Castelcomer Plateau are generally Pl and Pu aquifers and lie at the upstream limit of the surface water sub-catchment within which the source lies.
- Subsoils are dominated by glacial tills. They vary in thickness and permeability, being thicker at the base of the Castelcomer Plateau and thinner in the vicinity of the springs and on the Plateau itself.
- Flow to the springs occurs through at least two main mechanisms:
  - *Limestone lowlands:* Much of the effective rainfall will percolate downwards to groundwater and then flow to the Paulstown springs from the south west, from the west, and from the north west. Areas in the south west where the karstic aquifer is dolomitised are thought to provide a higher permeability pathway than elsewhere in the vicinity of the springs. Flows within this pathway may have travelled over 4 km from the south east to reach the spring, and are probably prevented from moving towards the Barrow River over this distance by the presence of the generally lower permeability Butlersgrove limestone aquifer. Given the configuration of adjacent surface water sub-catchments, it is considered unlikely that significant quantities of groundwater reach the springs from the sub-catchment to the north of the Acore stream, or from the Gowran River sub-catchment to the south.
  - *Castlecomer Plateau:* A smaller proportion of effective rainfall will percolate to groundwater in this area. This groundwater will follow short, localised flowpaths and discharge to the Mountfelim and Acore streams and to the small springs which lie along the base of the Plateau. As the streams flow off the Plateau and onto the karstic aquifer, a proportion of streamflow will sink back down into groundwater before flowing to the springs. Most of this river recharge will occur from the Acore catchment to the north of the springs, rather than from the Mountfelim catchment to the north west.

11.14 Delineation of Source Protection Areas

11.14.1 Introduction

This section delineates the areas around the well that are believed to contribute groundwater to the well, and that therefore require protection. The areas are delineated on the basis of the conceptualisation of the groundwater flow pattern as described in Section 11.13.

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 spring.

11.14.2 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 abstraction from long-term recharge. The ZOC is controlled primarily by (a) the abstraction rate, (b) the groundwater flow direction and gradient, (c) the rock permeability and (d) the recharge in the area. The ZOC is delineated using both analytical modelling and the results of hydrogeological mapping and conceptualisation.

The highest measured discharge at the Tobergoorlick pool - estimated from readings in October 2000 - was 4500 m^3/d, of which Kilkenny County Council use an estimated 910 m^3/d.

The shape and boundaries of the ZOC were determined primarily on the basis of the conceptual model outlined in Section 11.13. The model envisages that flow to the springs occurs from both the aquifers of the Castlecomer Plateau and the karstic lowlands, and that different flow mechanisms are throughout to occur in these aquifers. Consequently, different ZOC delineation approaches were adopted for the aquifers of the Castlecomer Plateau and the karstic lowlands:

- *Castelcomer Plateau:* In the Acore sub-catchment, all surface and groundwater flow from the Plateau recharges groundwater upstream of the Paulstown springs at certain times of the year. Consequently, the whole of this sub-catchment has been incorporated within the ZOC of the Paulstown springs. In the Mountfelim sub-catchment, only a portion of surface and groundwater flow from the Plateau recharges groundwater upstream of the Paulstown springs at certain times of the year. Consequently, it is considered over-conservative to incorporate the whole of the Mountfelim sub-catchment within the ZOC of the Paulstown springs. Instead, a nominal strip 15 m on either side of the channel is included.
- *Karstic Lowlands:* Key nodes were identified on the basis of the conceptual model of flow to the well. The boundary of the ZOC was delineated by joining these nodes with a line running perpendicular to the interpreted groundwater contours depicted in Figure 11.2. The location of each node (labelled 'A' to 'H') is identified in Figure 11.2. In broad terms, the nodes have been located so as to incorporate that portion of the Acore surface water sub-catchment which lies upstream of the springs, along with an additional portion of the karstic aquifer which extends south westwards to the boundary of the Gowran River catchment. The location of each node is described in more detail below:
  - *Node 'A':* Intersection of the Acore surface water sub-catchment with the upstream limit of the karstic aquifer.
  - *Node 'B':* Downstream limit (relative to the Paulstown springs) of the boundary of the Acore surface water sub-catchment.
  - *Nodes 'C' and 'D':* 300 m across gradient (and to the south) of the Paultsown springs. The ZOC has been delineated such that no point within 300 m upgradient or across gradient (as defined by the interpreted groundwater contours) of the springs lies outside the boundary of the ZOC. This limit has been set to try to incorporate some of the uncertainties inherent in karst aquifers. It is based on DELG/EPA/GSI (1999) which recommends that a limit of 300 m be used in sources where limited data are available.
  - *Node 'E':* A highpoint, in terms of topography and interpreted groundwater levels, on the 'Butlergrove ridge'. On the basis of the interpreted groundwater contours, groundwater to the east of this node is expected to flow away from the source and towards the River Barrow.
  - *Nodes 'F', 'G', and 'H':* These points define the northern boundary of the Gowran River surface water sub-catchment. Groundwater flows to the spring are not expected to cross this sub-catchment boundary.

An actual recharge estimate was derived in Section 11.8. This estimate applied to direct rainfall recharge (i.e. stream recharge was not included) in the areas close to the Paulstown springs where the karstic aquifer was within 3 m of the surface. The portion of this area which lies within the ZOC delineated above is approximately 7 km^2. Assuming an average recharge of 280 mm/year, this area alone can provide an average of approximately 5400 m^3/day to the springs and to the Mountfelim/Acore streams downstream of the springs. Given that this estimation does not include direct recharge elsewhere over the karstic limestone aquifer upstream of the springs, nor does it include estimates of stream recharge, it seems likely that the ZOC area delineated above is more than sufficient to supply the water demand of the springs.

11.14.3 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 to protect against the effects of potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination.

Estimations of the extent of this area cannot be made by hydrogeological mapping and conceptualisation methods alone. Analytical modelling was therefore used to estimate the extent of this zone upgradient of the spring.

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

$$Velocity = groundwater\ gradient \times permeability \div porosity$$

Using the estimates derived in Sections 11.10 and 11.12 for gradient, permeability, and porosity (0.018, 39 m/day, and 0.01 respectively), the equation gives a velocity of 70 m/day. In other words, though some more rapid flow paths may occur, it is thought that most groundwater will move up to 700 m in 100 days. However, the karstic aquifer does not extend as far as 700 m upgradient of the Paulstown spring and direct crossovers of groundwater are not expected with the aquifers of the Plateau. Accordingly, the SI has been set to encompass the whole of the limestone aquifer within the ZOC. The SI also includes the area of the Plateau encompassed by the buffers for the Acore and Mountfelim streams. The SI area is presented in Map 10.

11.15 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the source protection areas and vulnerability categories – giving a possible total of 8 source protection zones (see the matrix in the table below). In practice, this is done 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 Source Protection area where the groundwater is highly vulnerable to contamination. All of the hydrogeological settings represented by the zones may not be present around any given source. Six groundwater protection zones are present around the Paulstown source (Map 10), as shown in the matrix below.

Matrix of Source Protection Zones

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

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

11.16 Land Use and Potential Pollution Sources

The predominant land use within the Paulstown source ZOC is agricultural, which mainly consists of grassland/pastureland but there is also some tillage.

There is evidence that the spring is being contaminated by organic wastes from a farmyard point hazard and from intensive landspreading of organic and inorganic fertiliser (Section 11.11). Potentially contributing hazard types within the ZOC are considered to be effluent from on-site wastewater treatment systems (including 'septic tanks'), leakages from the mains sewers around Paulstown, and livestock activity along the channel of the sinking streams. Note that, during the site visit, there was some evidence of animal remains along the Acore stream upgradient of the source. Given that this stream sinks underground at certain times of the year, activities such as this are likely to contribute contamination directly to the springs.

Other activities which could pose a threat, or which may be contributing to current contaminant levels are fuel storage, roadside spillages close to the sinking streams, and pesticide application.

Note that no detailed assessment of individual hazards was carried out as part of this study, and that chemical parameters associated with some of the activities described above (e.g. fuel oil) were not examined.

11.17 Conclusions and Recommendations

- The Tobergoorlick springs at Paulstown lie on a regionally important karstic aquifer (Rk). Groundwater below the zone of contribution to the supply ranges from generally 'extremely' vulnerable to generally 'moderately' vulnerable to contamination. Future site-specific investigations may indicate that localised variations in certain areas also occur.
- 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:
  - chemical and bacteriological analyses of raw water be continued by the EPA and be carried out as frequently as possible. Given some of the raw water quality issues at the source, a monthly frequency has been recommended in Section 7.9. The chemical analyses should include all major ions - calcium, magnesium, sodium, potassium, ammonium, bicarbonate, sulphate, chloride, and especially nitrate. More occasional analyses of other parameters such as pesticides and hydrocarbons is also recommended;
  - the potential hazards in the ZOC should be located and assessed;
  - mains sewer integrity in the vicinity of Paulstown be checked on a regular basis;
  - care should be taken in allowing any activities or developments which might significantly increase nitrate levels;
  - a zone of increased hazard surveillance and land use contingency measures might be considered on each side of the Mountfelim and Acore streams; for example, in relation to livestock activity along the stream channels and in relation to emergency response measures in the event of chemical spillages from roadway accidents.
  - the weir structure in the containing pool be rebuilt and that measurements of discharge be made on a regular basis (perhaps in collaboration with the EPA or OPW).

12. Piltown / Fiddown Source

12.1 Introduction

The objectives of this chapter are:

- To delineate source protection zones for the Piltown/Fiddown Water Supply Scheme.
- To outline the principal hydrogeological characteristics of the Templeorum area.
- To assist Kilkenny County Council in protecting the water supply from contamination.

The protection zones are part of the Groundwater Protection Scheme for County Kilkenny and have been delineated to help prioritise certain areas around the source in terms of pollution risk to the spring. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

12.2 Location and Site Description

Five springs supply public drinking water for the towns of Fiddown and Piltown and the village of Templeorum. They are located in the townlands of Templeorum and Raheen. At the end of the summer, water is sometimes taken from the nearby stream to augment the spring supply.

The location of the springs and stream supplying the Piltown/Fiddown source is shown on Maps 4 and 8. The springs lie in a wooded area at the bottom of a small, steep sided valley. For the purposes of this report, the small stream which occupies this valley will be called the 'Templeorum stream.'

The area owned by Kilkenny County Council, within which the springs are located, is fenced off with wire and barbed wire. Each spring has been deepened and the water now collects in a concrete sump approximately 1 m in diameter. Each sump is covered with a concrete slab, and access is by a metal manhole cover, which is kept locked. Water from the five springs (and periodically from the stream) is fed into a central sump and from here the water is gravity-fed to a plant house in Jamestown where it is fluoridated and chlorinated.

12.3 Summary of Source Details

GSI no.	2311NEW069
Grid ref. (1:25,000)	24774 12553
Townlands	Templeorum and Raheen
Source type	Springs (five), augmented by surface water
Development date*	1930's
Owner	Kilkenny County Council
Elevation (ground level)	80 m OD to 92 m OD.
Depth to rock	<1 m to 3 m
Static water level	Ground level
Discharge summary:	
(i) average consumption**	780 m^3/d
(ii) average overflow*	None

**Anecdotal information from Kilkenny County Council*
***Information taken from consumption data from 1999 to 2000 provided by Kilkenny County Council*

12.4 Methodology

12.4.1 Desk Study

Bedrock geology information was compiled from original 1:10560 (six inch) field sheets and from the GSI bedrock report for the area (Sleeman and McConnell, 1995). Details of the current abstraction rate were obtained from Kilkenny County Council. Data on private groundwater wells in the area were taken from GSI archives and additional information on the source was obtained from a report produced by M.C. O'Sullivan Consulting Engineers (1999) for Kilkenny County Council.

12.4.2 Site Visits and Field Work

- Site visits and fieldwork included walkover surveys undertaken by both the Groundwater (3 days) and Quaternary (1 day) sections of the GSI to further investigate the subsoil and bedrock geology, the hydrogeology, and the vulnerability to contamination.
- Raw water samples were taken on 03/10/00 and 28/06/01 by GSI staff and were submitted for analysis at the EPA laboratories in Kilkenny in accordance with their sampling and transportation guidelines.

12.4.3 Assessment

Analytical equations and hydrogeological mapping were utilised to delineate protection zones around the source.

12.5 Topography and Surface Hydrology

The springs of the Piltown/Fiddown source are located between 300-400 m south of the church in Templeorum at an elevation of approximately 90 m. The springs can be found on either side of a stream that rises in the uplands to the north of Templeorum village. The Templeorum stream flows southwards down the slopes of the Southern Kilkenny Uplands for a distance of 2.3 km before reaching the low-lying, generally flat land at the River Suir.

The springs occur on both sides of, and close to, the stream at a point where the slopes suddenly steepen from 0.05 upstream to 0.07 downstream. The width of the valley also becomes constricted at the springs, reducing from approximately 500 m upstream to approximately 100 m downstream.

The local watersheds of the Templeorum stream lie up to 110 m above the level of the springs and occur approximately 2.3 km to the east and 0.5 km to the west of the springs. Both watersheds run approximately north south and converge to a point approximately 2 km north of the springs. Slopes on the valley sides are typically in the order of 0.05 to 0.1.

12.6 Geology and Aquifers

12.6.1 Bedrock

The main bedrock types in the vicinity of the Piltown/Fiddown source comprise the Carrigmaclea Formation and the Kiltorcan Formation. These formations are described in more detail in Chapter 2 of Volume I and their distribution in the vicinity of the Piltown/Fiddown source is shown on Map 8.

The Carrigmaclea Formation underlies the Templeorum surface water catchment upstream of the springs. It consists of a sequence of quartz-cobble conglomerates, pebbly sandstones and cross-stratified sandstones. The formation has been classed as a locally important bedrock aquifer which is moderately productive only in local zones (**Ll**). Fracture flow is expected to be dominant. Flows are expected to be concentrated in fractured and weathered zones. Given common weathering patterns, most flow is thought to be relatively shallow; concentrating in the top 10 m to 30 m of the rock profile. More detail on flow characteristics and aquifer classification criteria can be found in Chapter 4 of Volume I.

The boundary between the Carrigmaclea and the lower units of the Kiltorcan Formation is mapped some 200 m to 300 m to the south of the springs. The Kiltorcan Formation as a whole is a regionally important aquifer, but lower permeability shales, mudstones and siltstones are predominant close to the boundary with the Carrigmaclea Formation (Daly, 1994). The presence of shales, mudstones and siltstones may explain the sudden change in topography to the south of the springs.

The springs are located on the southern limb of a large 'anticline' (upward fold in the rock mass). Bedrock units dip gently at 5^o to 20^o southwards. Associated with this fold is a large north-south trending fault, mapped some 400 m from the springs. Other, similar faults may also occur within the Templeorum sub-catchment, but have not yet been identified. The main significance of the fold structure is that the Carrigmaclea Formation will occur below the springs to considerable depths underground and that this formation, in conjunction with north-south trending fractures, will be the main influence on groundwater flow to the springs.

12.6.2 Subsoil

The main subsoil type in the surrounding area is till. However, bedrock is close to the surface (generally less than 3 m) over much of the surface water catchment of the Templeorum stream. The till is described in more detail in Chapter 3 of Volume I and its distribution in the vicinity of the Piltown/Fiddown source is shown on Map 2S.

There are no subsoil materials classified as aquifers in the Templeorum area. The main significance of the subsoil material, therefore, is in vulnerability and recharge assessments. These issues are described in Sections 12.7 and 12.8.

12.7 Groundwater Vulnerability

The concept of vulnerability is discussed in Chapter 5 of Volume I. In essence, groundwater vulnerability is dictated by the nature and thickness of the material overlying the main groundwater 'target'. As discussed in Section 12.6, the main groundwater resource at the Piltown springs occurs within fractured bedrock. Consequently, the target is taken from the top of the bedrock formation and considerations of groundwater vulnerability concern the permeability of the whole subsoil profile and the depth to bedrock.

The subsoil in the immediate vicinity of the springs is thought to be between 1 m and 3 m thick. This thickness persists along the river valley. Once away from the valley floor, the till thins and over the remainder of the zone of contribution the bedrock is mapped as being close to the ground surface; generally within 1 m of ground level. This interpretation is based on the presence, across the surface water catchment to the north of the springs, of at least 12 rock outcroppings (4 of which are in excess of 200 m long) and 2 boreholes with reported depths to rock of 1 m to 2 m.

At subsoil thicknesses of less than 3 m, bulk permeability becomes less relevant in mapping vulnerability across wide areas (as opposed to specific sites), because subsoil permeability becomes increasingly variable and increasingly influenced by the presence of 'bypass flow' mechanisms such as cracks in the subsoil. Accordingly, on the basis of the general depth to bedrock in the area, a vulnerability classification of 'extreme' has been assigned for the whole Templeorum sub-catchment.

The permeability estimations are based on regional-scale evaluations. Depth to rock interpretations are based on the available data cited here. However, permeability and particularly depth to rock can vary over a very small scale. Consequently, the vulnerability mapping provided will not be able to anticipate all the natural variation that occurs in an area. 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. More detail can be found in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

12.8 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 it largely dictates the size of the zone of contribution.

In areas where point recharge from sinking streams, etc, is discounted, the main parameters involved in recharge rate estimation are annual rainfall, annual evapotranspiration, and annual runoff:

- Annual rainfall: 1080 mm, data from Met Éireann average annual (1961-90) rainfall records, measured at Mullinavat Garda Station.
- Annual evapotranspiration losses: 480 mm. Potential evaporation (P.E.) is estimated to be 500 mm yr^{-1} (Met Éireann, 1996). Actual evapotranspiration (A.E.) is assumed to be 95 % of P.E. (Daly, 1994).
- Potential recharge: 600 mm/year, based on average annual rainfall less estimated evapotranspiration.

12.9 Groundwater levels

There are few groundwater level data available for the area around the source. There are, however, water level data from August 1971 (GSI well records) for 3 domestic wells in Ashtown and Oldcourt townlands in the surface water catchment upgradient of the springs. In addition, the springs themselves provide groundwater level information. Available data are summarised below:

Distance upstream of springs	**Water Levels measured in August 1971**			**Distance to Templeorum Stream.**
	m below ground	m OD	m above stream.	
0 km (springs)	0 m	90 mOD	0 m to 18 m.	50 m to 210 m
1.1 km	10.2 m	161 mOD	0.5 m	70 m
1.6 km	7.2 m	191 mOD	23 m	370 m
2 km	23.5	182 mOD	22 m	850 m

Though the data are sparse, there is a suggestion that:

- The aquifer is unconfined over most of the sub-catchment to the north of the springs.
- Groundwater can discharge both into the stream and into the springs.
- Net groundwater flow directions are unlikely to be northwards.
- Thickest unsaturated zones occur at higher elevations and most recharge is likely to occur towards the head of the surface water sub-catchment.

12.10 Groundwater Flow Direction and Gradients

The aquifer on which the surface water sub-catchment lies is not regarded as being highly productive (refer to Section 12.6.1). As such, the water table in the area is generally assumed to be a slightly subdued reflection of topography. The overall flow direction will therefore vary within the sub—catchment, but is expected to be generally southwards. This is inference supported by available water level data.

Given that the springs occur on both sides of the valley floor and at a constriction in the valley sides, and given that groundwater flow within the aquifer is expected to concentrate at shallow depths, it is likely that;

- most groundwater will be forced to the surface and discharge into either the springs or surface water upstream of the springs, and that
- groundwater flow to the springs will occur from both the eastern and western sides of the valley.

Groundwater gradients are difficult to calculate because of the limited water level data available for wells in the Carrigmaclea Formation near the springs, and because gradients will vary locally with topography. However, assuming that groundwater will generally flow along very short flowpaths of a few tens or hundreds of metres, gradients of 0.003, 0.03, and 0.06 have been estimated between the wells identified in Section 12.9 and the nearest portion of the stream. These gradients compare with topographic gradients of 0.05 (on the valley floor) to 0.1 (on the valley sides).

On the basis of a comparison of topographic and water level information, a figure of 0.05 has been taken as a typical (but 'reasonably conservative') groundwater gradient below the Templeorum surface water sub-catchment upstream of the springs.

12.11 Hydrochemistry and Water Quality

Data on recent trends in water quality at the Piltown source are summarised graphically in Figure 12.1, and the source data can be found in Appendix V.

The following key points have been identified from the data:

- Only one analysis of hardness was available. The groundwater sample indicates a 'moderately soft water' of 53 mg/l $CaCO_3$. This is considered typical of the non-limestone rocks in the Southern Uplands of Kilkenny; particularly in areas where the subsoil cover is thin. Naturally soft waters are often associated with problems due to low pH, and M.C. O'Sullivan Consulting Engineers (1999) indicate that the water in the source is acidic and likely to attack and tuberculate the cast iron network in the distribution system.
- Of the two available <u>raw</u> water analyses of combined discharge from the springs, faecal coliforms were in excess of the European maximum admissible concentration for drinking water (MAC).[18]
- Aside from coliforms, no other indicators of agricultural or domestic groundwater contamination were reported above GSI guide levels in the available samples. Note, however, that nitrate levels, typically in the order of 13 mg/l, were reported at 20 mg/l in the most recent sample analysis available. Though below indicator guide levels, this most recent result is slightly elevated and would be worthy of note <u>if</u> it proved to be part of a rising trend in nitrate concentrations.

A sample of the stream water was taken on the 28/6/01. Results are presented in Table 12.1. The main feature to note is that there are large differences in the amount of coliforms, ammonium and chloride between groundwater and surface water samples, but that concentrations of most other parameters are very similar. The similarities suggest that groundwater residence times within the aquifer are very short (more likely to be a few months than a few tens of years) and/or that there is a close hydraulic connection between surface water and groundwater in the sub-catchment updradient of the springs. The lower concentrations of coliforms and ammonium in the groundwater sample might reflect the partial protection afforded by the thin subsoils. However, chloride is not readily attenuated by subsoils, and the elevated chloride concentration in the stream (if correct) suggests that organic wastes are being discharged directly to the stream. It may be that these wastes are the source of the bacteria and ammonium found in the surface water sample.

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[18] Raw water samples are taken <u>prior to treatment</u>. Assessments are aimed at identifying contamination hazards rather than direct human health issues.

Table 12.1: Selected EPA Laboratory Analyses at the Piltown/Fiddown Source

Parameter	Results of Laboratory Analyses of *Untreated* Water Samples	
	Sample from combined spring discharge (28/6/01)	Sample taken from the stream in the vicinity of the springs. (28/6/01)
Temperature °C (field[19])	11.4 °C	13.7 °C
Conductivity µS/cm (lab,field)	198, 176	198, 188
pH (lab, field)	6.6, 6.2	7, 7.3
Alkalinity (mg/l HCO_3)	37	38
Calcium (mg/l)	19	20
Magnesium (mg/l)	5.9	5.5
Chloride (mg/l)	14	882
Sulphate (mg/l SO_4)	9.6	8
Sodium (mg/l)	9.3	8.4
Potassium (mg/l)	2.6	2.6
Nitrate (mg/l NO_3)[20]	19.9	15.1
Ammonium (mg/l NH_4)	0.006	0.014
Iron (mg/l)	<0.05	<0.05
Manganese (mg/l)	0.003	0.002
Faecal coliforms per 100 ml	7	1120
Total coliforms per 100 ml	172	>2419

12.12 Aquifer Parameters

In unconfined aquifers where the influence on gradients of seasonal variations in recharge is expected to be limited, 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 in Section 12.14.3.

No tests of permeability and porosity have been undertaken in the sub-catchment upgradient of the spring. Some data is available, however, for well 2311NEW068, which is approximately 1.8 km to the south-east of the springs and is located in the Carrigmaclea Formation. Pumping test data from this well gave a specific capacity of 5 m^3/d/m, a transmissivity of 7 m^2/d and a permeability of 0.7 m/d. These local-scale estimates tend to agree with regional-scale aquifer permeability and specific capacity estimates of 1 m/day and 2 m^3/d/m to 10 m^3/d/m respectively (from Daly 1992). Accordingly, a typical permeability of 0.7 to 1 m/day has been assumed for the aquifer upgradient of the springs.

A porosity of 0.01 is assumed as being applicable to this aquifer. This is at the lower limit of the typical range used by the GSI for bedrock aquifers (0.025 to 0.01) and reflects the possibility that the aquifer is not densely fractured near the springs.

12.13 Conceptual Model

This section provides a qualitative overview of the geological framework, recharge, flow and discharge patterns across the aquifer contributing groundwater to the source. It represents a summary

[19] *Field measurements undertaken by GSI staff.*
[20] *Parameter reported as Total Oxidised Nitrogen. GSI has assumed nitrate is the only significant contributor of oxidised nitrogen.*

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 springs lie at the base of a steep slope and at the point where the valley becomes more constrained downstream. Their location is believed to be topographically controlled, although this topography may be itself controlled by changes in rock type and by faulting.
- The springs and the Templeorum surface water sub-catchment upstream of the springs overlie the 'Locally important' (Ll) Carrigmaclea sandstones aquifer. Subsoils are dominated by tills which are expected to be less than 3 m thick across most of the area upstream of the springs.
- The aquifer is unconfined in the area, and flow to the springs is controlled by fracturing and weathering patterns within the rock mass. As a consequence, the potential for contaminant attenuation within the bedrock will be limited and flows will be locally variable both in terms of velocity and orientation. Most groundwater flow is thought to be relatively shallow; concentrating in the top 10 m to 30 m of the rock profile. The flow is therefore likely to follow local variations in topography, but will generally be southwards.
- Recharge is likely to occur across both sides of the Templeorum sub-catchment upstream of the springs.
- The nature of the aquifer, and of water quality in the spring and stream is such that groundwater residence times and groundwater flow paths are believed to be short. Flows would not usually be expected to cross underneath surface watersheds, and the distance between recharge and discharge areas is unlikely to exceed a few hundred metres.
- Most groundwater flow within the Templeorum surface water sub-catchment upstream of the springs is likely to discharge to surface water at, or upstream of, the springs. The proportion of groundwater flow leaving the sub-catchment below the springs is thought to be insignificant. No long term streamflow data is available for the Templeorum sub-catchment, However, very broad estimates can be made on the basis of estimated potential recharge (i.e. soil moisture excess) and estimates of the area of the sub-catchment. If the estimates of potential recharge in Section 12.8 were broadly correct, the average combined surface water and springflow at the mouth of the Templeorum sub-catchment would be in the order of 5300 m^3/day. Assuming an average daily total discharge of 780 m^3/day at the springs, this would suggest that springflow accounts for approximately 15% of the total flow from the sub-catchment, and that the proportion of effective rainfall infiltrating to groundwater is at least 15%.

12.14 Delineation of Source Protection Areas

12.14.1 Introduction

This section delineates the area around the source that is believed 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 12.13.

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.

12.14.2 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 abstraction rate, (b) the recharge in the area (c) the groundwater flow direction and gradient, (d) the rock permeability. The ZOC was delineated using the results of hydrogeological mapping and flow system conceptualisation.

The average abstraction rate for the Piltown/Fiddown source was calculated using monthly abstraction records from January 1999 to December 2000 obtained from Kilkenny County Council. The abstraction rates were relatively constant, ranging from 763 m^3/day to 846 m^3/day, with an average of 780 m^3/d.

Given that groundwater flow in the area is expected to follow topography, the ZOC is likely to coincide, or lie within, the physical constraints of the Templeorum surface water sub-catchment upstream of the springs. These constraints are outlined below:

- **Northern boundary**: This is the area of the intersection between the eastern and western watersheds of the Templeorum surface water sub-catchment.
- **Southern boundary:** This boundary is downgradient of the springs. In theory, springs will draw no water from areas downgradient of their location. However, irregularities caused by the dominance of fracture flow within the aquifer and by the relationship between surface water and groundwater mean that this may not strictly apply at the Piltown/Fiddown source. In order to account for some of these irregularities, the southern boundary has been placed at an arbitrary distance of 100 m downgradient of the springs.
- **Western boundary:** Groundwater is thought to flow to the springs from both sides of the Templeorum sub-catchment. The western boundary is defined by the surface water divide of the Templeorum stream. Given that groundwater in the catchment is thought to flow generally southwards, only the portion of this watershed which lies to the north of the springs has been included. This portion has been linked to the southern boundary by drawing a line between the two boundaries which intersects the intervening topographic contours at right angles. It has been assumed that groundwater on the watershed will broadly follow the same pattern.
- **Eastern boundary:** This boundary is defined by the watershed dividing the Templeorum stream and its neighbour to the east. Again, only the portion of this watershed which lies to the north of the springs has been included, and this portion has been linked to the southern boundary by drawing a line between the two boundaries which intersects the intervening topographic contours at right angles.

The area constrained by these limits is approximately 3.2 km^2 . The ZOC is taken as comprising the whole of the area constrained within these boundaries and is depicted on Map 10.

12.14.3 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 to help planners minimise the risk to groundwater from potentially contaminating activities which may have an immediate influence on water quality at the source; particularly those related to microbial contamination.

Estimations of the extent of this area could not be made by hydrogeological mapping and conceptualisation methods alone. Analytical modelling was used to estimate groundwater flow velocities and the extent of the Inner Protection Area upgradient of the spring. Subject to certain assumptions and conditions, Darcy's Law can be used to approximate groundwater flow velocities, as follows:

$$\text{Velocity} = \text{groundwater gradient} \times \text{permeability} \div \text{porosity}$$

Using the estimates derived in Sections 12.10 and 0 for gradient, permeability, and porosity (0.05, 0.7 - 1 m/day, and 0.01 respectively), the equation gives a velocity of 3 m/day. This can be treated as a 'reasonable worst case estimate'. In other words, though some very rapid flow paths may occur, it is thought that most groundwater will move up to 300 m in 100 days. Accordingly, the boundary of the SI has been delineated 300 m upgradient of the springs (Map 8).

12.15 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the source protection areas and vulnerability categories – giving a possible total of 8 source protection zones (see the matrix in the table below). In practice, superimposing the vulnerability map on the source protection area map does this. Each zone is represented by a code, e.g. **SI/H**, which represents an Inner Source Protection area where the groundwater is highly vulnerable to contamination. All of the hydrogeological settings represented by the zones may not be present around any given source. Just two groundwater protection zones are present around the Piltown/Fiddown source, as shown in the matrix below.

Matrix of Source Protection Zones for Piltown/Fiddown source

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

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

12.16 Land Use and Potential Pollution Sources

The main land use in the area is agricultural, comprising pasture with some tillage. Templeorum is a small village of 150 people and lies within the ZOC of the spring. The village is reportedly not sewered.

The main hazards within the ZOC are considered to be effluent from on-site wastewater treatment systems (including 'septic tanks'), agricultural landspreading of organic and inorganic fertiliser, and direct discharges of wastes to surface water. Other potential hazards include fuel storage, roadside spillages, pesticide application, and farmyards.

Though the nitrate concentrations in the springs have generally been quite low, the most recent analysis available reported a slightly elevated concentration of 20 mg/l. Given that the catchment is small, with limited potential for dilution of contaminants, the total loading of nitrogen from the village effluent may become significant. Some broad, 'back-of-the-envelope' estimations of the septic nitrate loading from domestic wastewater treatment systems in comparison with the measured nitrate loading are provided below:

- *Estimated average water flow in catchment: 5,300,000 litres/day (proportion of springflow is estimated at 15% of this total).*
- *Estimated nitrogen loading from wastewater systems[21]:0.009 kg/day/person @ 150 people → 1.4 kg/day N.*
- *Estimated 'natural' nitrogen loading: 0.1 mg/l N @ 5,300,000 litres/day → 0.5 kg/day N.*
- *Estimated total wastewater and 'natural' nitrogen loading: 1.4 + 0.5 ≈ 1.9 kg/day N.*
- *Measured nitrogen concentration in catchment runoff[22]: 3.4 mg/l N in the stream and 4.5 mg/l N in the springs.*

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[21] *Loading estimates taken from EPA, 2000. The figures assume no denitrification and subsequent attenuation of nitrogen will occur in the subsurface.*

[22] *From EPA laboratory analyses. Refer to Table 12.1.*

- *Estimated nitrogen loading in catchment runoff: 5,300,000 × ((3.4 × 0.85) + (4.5 × 0.15)) ≈ 19 kg/day N.*

Though the estimations are very approximate, it seems that the domestic wastewater effluent from 150 people (~ 2 kg/day N), combined with the natural loading from rainwater, is insufficient to account for the total nitrogen loading in surface and groundwaters leaving the sub-catchment (~ 20 kg/day N). One conclusion which could be drawn is that, if nitrogen concentrations require remedial action in the future, hazards other than domestic wastewater treatment systems (e.g. landspreading of organic and inorganic fertiliser, and direct discharges to surface water) may need to be targeted.

12.17 Conclusions and Recommendations

- The springs at Piltown/Fiddown lie on a locally important aquifer (Ll).
- Groundwater in the area of the zone of contribution to the supply is generally 'extremely' vulnerable to contamination. However, future site-specific investigations may indicate that localised patches of lower vulnerability also occur.
- 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.
- The spring supply is augmented with surface water in the summer. Existing treatment methods are focussed on bacteria and may not be sufficient in the event of chemical spillages into the stream.
- It is recommended that:
  - chemical and bacteriological analyses of raw water as well as treated water be carried out regularly. Given some of the raw water quality issues at the source, a monthly frequency has been recommended in Section 7.9. The chemical analyses should include all major ions - calcium, magnesium, sodium, potassium, ammonium, bicarbonate, sulphate, chloride, and especially nitrate. More occasional analyses of other parameters such as pesticides and hydrocarbons is also recommended;
  - the potential hazards in the ZOC should be located and assessed;
  - the use of borehole supplies be examined to minimise requirements for surface water augmentation. The aquifer is categorised as 'Ll' and, as such, is expected to be moderately productive only in local zones, like the one exploited by Thomastown wells (refer to Section 13). Away from these local zones, yields from individual wells are not expected to exceed a few tens of cubic metres per day and adequate supplies would probably require the development of a small wellfield. Consequently, exploratory drilling would benefit from some preparatory studies (perhaps including a geophysical survey) into the potential existence of productive zones in the Templeorum sub-catchment and, in the context of a wellfield, into the potential area of land and number of wells required;
  - there is some evidence of direct discharges to surface water. If the stream water is to continue to be used to augment supply, a zone of land use restrictions might be considered on each side of the stream for the purposes of protecting surface water.
  - planning permission for new developments in the ZOC be considered in the context of the additional nitrogen and phosphorous loading from septic effluent.

13. Thomastown Source

13.1 Introduction

The objectives of this chapter are:

- To delineate source protection zones for the Thomastown Water Supply Scheme.
- To outline the principal hydrogeological characteristics of the Thomastown area.
- To assist Kilkenny 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. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

13.2 Location and Site Description

Two wells situated in the townland of Grenan, make up the public drinking water source for Thomastown. Their location is shown on Map 8 and Map 4S. The more northerly well is known as Well 9, or the GAA Grounds well, while the southerly one is known as Well 5, or the Nore Creamery well.

Both wells have separate pump-houses, and both are located outside them. Well 9 is located 35 m to the south east of the pump-house, while Well 5 is situated 9 m south of its pump-house. Both pump-houses have the same dimensions: floored with concrete 0.15 m above the surrounding ground level, 4.6 m wide by 4.6 m deep. Both pump-houses also have tarmac laid all around them and are securely fenced off from the road. Well 5 is contained within this fencing, but Well 9 is not.

Both wells are situated on the west side of the River Nore, above the flood-plain level. Although the two well heads are below ground surface, they appear to be sealed-off and protected from surface runoff. According to County Council staff, neither well has been inundated during recent floods. The discharge from both wells is pumped to a plant house less than 0.5 km to the west, where it is chlorinated and fluoridated before being stored in the adjacent reservoir. The two wells are pumped one hour on, one hour off, 24 hours a day.

13.3 Summary of Source Details

	Well 5, Nore Creamery	**Well 9, GAA Grounds**
GSI no.	2313NEW234	2313NEW236
Grid ref. (1:25,000)	25900 14094	25904 14146
Townland	Grenan	Grenan
Source type	Borehole	Borehole
Drilled	January 1991	December 1990
Owner	Kilkenny County Council	Kilkenny County Council
Elevation (ground level)	20.4 m O.D.	16.2 m O.D.
Depth	67 m	102 m
Depth of casing	63 m	90 m
Diameter	250 mm (10")	300 mm (12")
Depth to rock	12 m	12 m
Static water level	14.4 m O.D. (6.0 m b.g.l.) on 12/02/91	15.5 m O.D. (0.7 m b.g.l.) on 13/02/91
Pumping water level	7.8 m O.D. (12.6 m b.g.l.) on 09/07/01	7.5 m O.D. (8.7 m b.g.l.) on 09/07/01
Maximum drawdown	[illegible]7 m	7.97 m[illegible]
Consumption	[illegible]) m^3/d	[illegible] m[illegible]
Pumping test summary:		
(i) abstraction rate	2232-2246 m^3/d*	*Not available*
(ii) specific capacity	260 $m^3/d/m$	
(iii) transmissivity	[illegible] to 1000 m^2/d	

* *Well 5 was tested at various rates in February 1991, the longest test abstracting on average 2240 m^3/d and lasting 10 days.*

13.4 Methodology

13.4.1 Desk Study

Bedrock geology information was compiled from original 1:10560 (six inch) field sheets and from the GSI bedrock report for the area (Tietzsch-Tyler *et al*, 1994a). Details of the current abstraction rate were obtained from Kilkenny County Council. Drilling and pumping test data for the supply wells were obtained from Brian P. Connor, the consultant involved with their development, while data on private groundwater wells in the area was taken from GSI archives and an unpublished groundwater supply scheme feasibility report prepared by the GSI (Daly, 1984). Historical water quality data was provided the EPA and the County Council.

13.4.2 Site Visits and Field Work

Site visits and fieldwork included walkover surveys undertaken by both the Groundwater (1 day) and Quaternary (1 day) sections of the GSI to further investigate the subsoil and bedrock geology, the hydrogeology and the vulnerability to contamination. Two raw water samples were taken by the GSI on 02/10/2000 and 25/04/2001, and analysed by EPA laboratories in Kilkenny to assess possible sources of contamination at the wells.

13.4.3 Assessment

Analytical equations and hydrogeological mapping were utilised to delineate protection zones around the source.

13.5 Topography and Surface Hydrology

Both wells are located less than 1 km south of Thomastown. Well 5 is located 140 m west of the River Nore, while well 9 is located 340 m west of the river (Map 8).

The Nore flows generally south eastwards and forms a broad meander at Thomastown, which encircles the wells in all directions except the south west. This meander occupies the base of a flat, 500 m wide valley which rises sharply on either side. The southern watershed of the Nore rises to an altitude of 252 m O.D., at a distance of 8 km from the wells. The eastern watershed rises to an altitude of 365 m O.D., at a distance of 6.5 km from the wells.

Slopes on the valley bottom are generally in the order of 0.01 (1 in 100), and up to 0.35 (1 in 3) on the valley sides.

There are streamflow gauges on the Nore River at Brownsbarn Bridge, 3.5 km downstream of Thomastown, and at Mount Juliet, 4 km upstream. Low flows[23] at Mount Juliet are in the order of 4 m^3/sec, while those at Brownsbarn are in the order of 4.3 m^3/sec (EPA, 2001).

The natural stream density is low, even on the valley floor. Aside from the Nore itself, only one stream is found in the vicinity of the wells.

13.6 Geology and Aquifers

13.6.1 Bedrock

The main rock types in the vicinity of the Thomastown source are the Maulin Slate, the Carrigmaclea Sandstone and the Kiltorcan Sandstone Formations. Both supply wells are thought to draw most of their water from the Carrigmaclea sandstones. This is shown in cross-section in Figure 13.1, and in plan view in Map 8. These formation are described in more detail in Chapter 2 of Volume I. Aquifer classifications are discussed in Chapter 4 of Volume I.

The Carrigmaclea Formation comprises sandstones and has been classified as a **locally important aquifer** which is **moderately productive only in local zones** (**Ll**). Drilling information from six wells in the vicinity of the supply wells suggests that the main water strikes in the Carrigmaclea sandstones in this area occur in two zones:

- *Within the weathered zone in the top fifteen meters of the bedrock profile*: Initial strikes of 15,000 to 30,000 gph (1640 to 3270 m^3/day) were encountered in this zone in three of the six holes.
- *Close to the contact between the Carrigmaclea sandstone and the underlying Maulin shale, at depths of 60 to 90 m below ground:* A zone of conglomeratic rocks is sometimes associated with this contact and was encountered in three of the six holes drilled. Strikes of over 20,000 gph (2180 m^3/day) were encountered in this material in a test borehole close to production well 9, and over 18,000 gph (1960 m^3/day) in production well 5. No strikes were recorded in the third hole which encountered this material; another test hole for production well 9.

In addition to these two intervals of concentrated groundwater flows, it is apparent from the six well logs that water strikes can occur across the whole thickness of the Carrigmaclea sandstones in the valley floor area. Strikes of 1000 to 1500 gph (110 to 160 m^3/day) were encountered between the upper weathered zone and the basal conglomerate material in four of the six holes in the vicinity of the supply wells. Note also that strikes of 2000 to 2300 gph (220 to 250 m^3/day) were estimated in a hole that penetrated the underlying Maulin Formation slates.

The Kiltorcan Formation, which overlies the Carrigmaclea Formation to the north of the supply wells, has been classified as a **regionally important** fissured bedrock aquifer (**Rf**). The Maulin Formation

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[23] *Flow which is equalled or exceeded at least 95% of the time.*

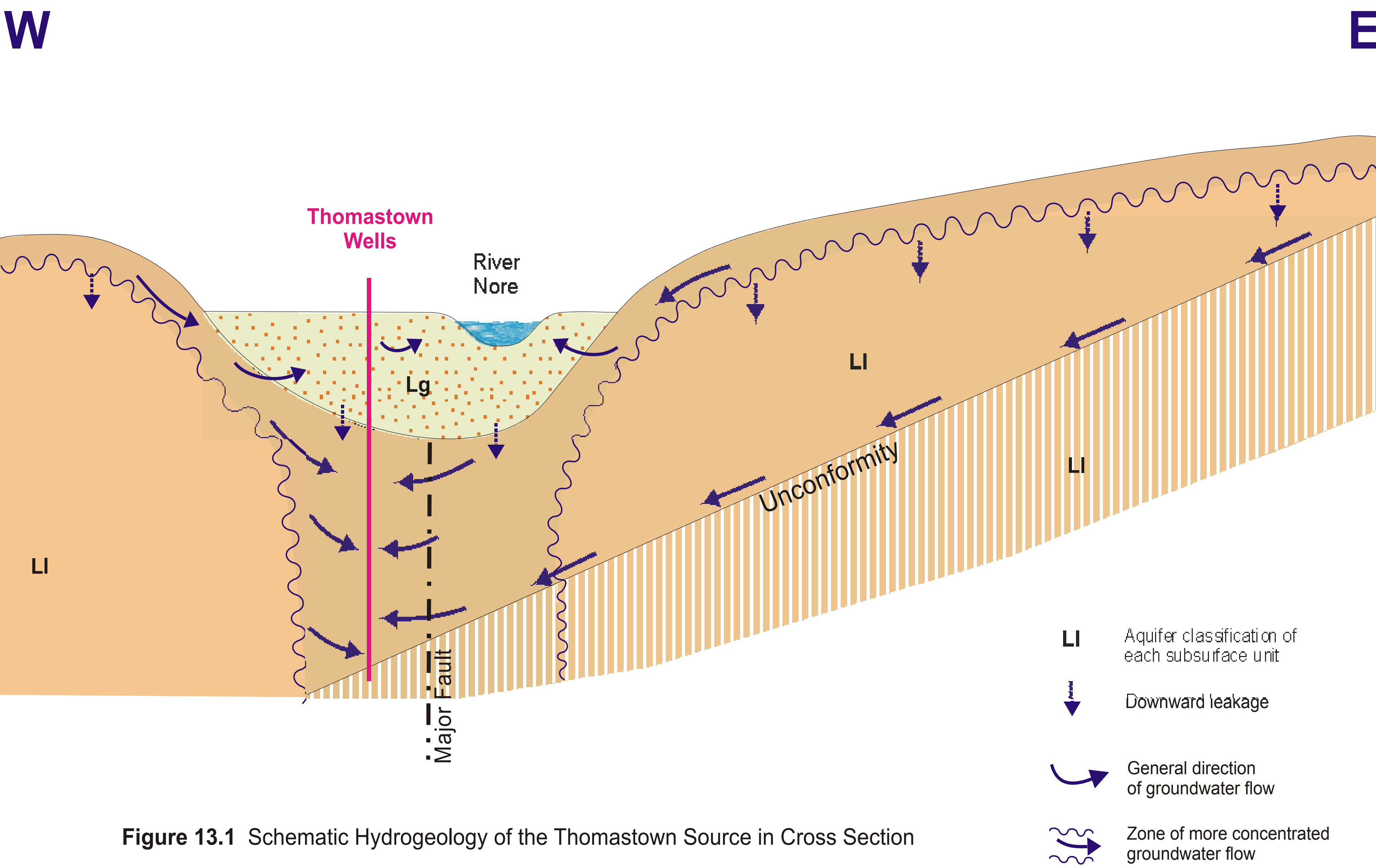

Figure 13.1 Schematic Hydrogeology of the Thomastown Source in Cross Section

underlies the Carrigmaclea sandstones at the wells. It consists of metamorphic rock, and has been classified as a **locally important aquifer** which is **moderately productive only in local zones** (**Ll**).

All three formations have been affected by a north to south trending fault (Map 8 and Map 1S), which appears to have resulted in 400 m of displacement and which is likely to act as a focus for groundwater flow.

The Nore catchment around the source lies on the south-eastern side of a large syncline (downward fold in the rock mass). As a consequence, the rocks dip at 3° to 10° north-westwards into the valley (Figure 13.1).

13.6.2 Subsoil

The main subsoil types are gravel, till and alluvium. These materials are described in more detail in Chapter 3 of Volume I and their distribution in the vicinity of the Thomastown source is shown on Map 2S.

As described in Chapter 4 of Volume I, gravels occur along the Nore valley and are classified as a **Locally important** gravel aquifer (**Lg**). Prior to 1991 the town's water supply was from an infiltration gallery situated in these gravels on the banks of the Nore at Stamps-Park 1 km west of the supply wells. Well records in the area show the gravel to be between 9 and 12 m thick on the valley floor (under the meander which partially encircles the supply wells) but thinning rapidly to less than 3 m at the edge of the Nore floodplain, and further downstream where the river valley narrows.

The till deposits are found on the valley sides, where they form a thin covering which rarely exceeds 3 m. The alluvial deposits are recent, and are found at points along the river bank where flooding is common. Neither deposit is considered to have aquifer potential. Their main significance is in vulnerability and recharge assessments. These issues are described in Sections 13.7 and 13.8.

13.7 Groundwater Vulnerability

13.7.1 Introduction

The concept of vulnerability is discussed in Chapter 5 of Volume I. In essence, however, groundwater vulnerability is dictated by the nature and thickness of the material overlying the main groundwater 'target'. As discussed in Section 13.6, two groundwater targets occur, one in fractured bedrock and the other in the overlying sands and gravels. Where the sand and gravel aquifer occurs at the surface, the overall vulnerability will be dictated by the vulnerability of groundwater within this aquifer. On the valley sides where the sand and gravel aquifer is absent, vulnerability will be dictated by the overall subsoil permeability and by the depth to bedrock.

13.7.2 Vulnerability in Areas where the Sand and Gravel Aquifer Occurs

Water level information for the six wells in the vicinity of the supply wells indicate that the water table is between 2 and 2.6 m below ground level on the flood plain, and 5.6 to 6.7 m on the lower valley sides.

In unconfined situations, the vulnerability of a sand and gravel aquifer is dictated by the thickness of the unsaturated zone. Where the unsaturated zone is less than 3 m from the land surface, the vulnerability of the aquifer is considered to be 'extreme'. Although the available water level information indicates that in some cases, the water table is less than 3 m from the land surface, it is regarded as generally 'high' rather than 'extreme' vulnerability due to the presence of a silty alluvial layer at the surface. This alluvial layer should serve to somewhat reduce the vulnerability of the groundwater.

13.7.3 Vulnerability in Areas where the Sand and Gravel Aquifer is Absent

In these areas, situated on the valley sides overlooking the site, the groundwater vulnerability is determined by the permeability and thickness of the tills overlying the bedrock.

A large number of outcrops occur on the valley sides and subsoils are thought to be generally less than 3 m thick. At subsoil thicknesses of less than 3 m, bulk permeability becomes less relevant in mapping vulnerability across wide areas (as opposed to specific sites), because permeability becomes increasingly variable and increasingly influenced by the presence of 'bypass flow' mechanisms such as cracks in the subsoil. Accordingly, on the basis of the general depth to bedrock on the valley sides, a vulnerability classification of 'extreme' has been assigned.

13.7.4 Summary

Groundwater vulnerability is generally 'high' on the valley floor and generally 'extreme' on the valley sides.

Note that the permeability estimations are based on regional-scale evaluations, while depth to rock and water level interpretations are based on the available data cited here. However, permeability, water level and particularly depth to rock can vary over a very small scale. As such, the vulnerability mapping provided will not be able to anticipate all the natural variation that occurs in an area. 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. More detail can be found in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

13.8 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 it largely dictates the size of the zone of contribution.

In areas where point recharge from sinking streams, etc, is discounted, the main parameters involved in recharge rate estimation are annual rainfall, annual evapotranspiration, and annual runoff [24]:

- Annual rainfall: 930 mm (Met Eireann average annual (1961-90) rainfall measured at Kilmurry House in Thomastown.
- Annual actual evapotranspiration (A.E.) losses: 460 mm. This figure ('actual evapotranspiration') was calculated assuming 95% of the country-wide potential evapotranspiration data presented in the "Agroclimatic Atlas of Ireland" (Collins and Cummins, 1996). Local measurements of actual evapotranspiration are not available.
- Potential recharge: 470 mm/year, based on average annual rainfall less estimated evapotranspiration.
- Annual runoff losses: 90 mm/year. (20% of potential recharge). This is a typical figure used by the GSI in areas where the till cover is thin, and where drainage densities are low. Note, however, that drilling evidence indicates that groundwater flows occur at a number of depths. The total groundwater recharge will be distributed across these depths. Recharge to the lower levels will therefore be a small fraction of the estimated total groundwater recharge.

[24] *Estimations used in this report have generally been rounded off to two significant figures*

These calculations are summarised below:

Average annual rainfall (R)	930 mm
Estimated A.E.	460 mm
Potential Recharge (R – A.E.)	470 mm
Runoff losses (RO)	20%
Estimated recharge to upper groundwater flow zones (R-A.E.) x (1-R.O)	380 mm

13.9 Groundwater levels

Measurement of water levels was not directly possible at the 2 wells, but auto-recorder levels were obtained from the County Council. Typical results were as follows:

Date	Level in River (m OD)*		Pumping **	Level in Pumping Well 5 (m OD)	Level in Pumping Well 9 (m OD)
	Mount Juliet	Brownsbarn			
12/03/97	21.7	7.9	Pump off	14.6	16.4
			Pump on	8.1	7.5
09/07/01	21.4	7.5	Pump off	11.9	15.0
			Pump on	7.8	7.5

**Data from OPW. Brownsbarn lies 6.8 km downstream (measured along the river channel) while Mount Juliet lies 5.4 km upstream.*

***It should be noted that both wells are pumped 24 hours a day on a one hour off, one hour on basis.*

13.10 Groundwater Flow Directions and Gradients

A diagrammatic representation of the various components of flow is presented in Figure 13.1.

Due to the range of aquifer types in the Thomastown area, the groundwater flow directions are somewhat complex. Information from the logs of the supply wells suggest that flows occur within the subsoil gravels, and across the whole profile of the Carrigmaclea sandstone aquifer. In the gravels along the river and the top few tens of meters of weathered rock, water is likely to follow relatively short flowpaths, recharging in the hills to the west and east of the Nore, before discharging into the river. Thus, the water table in the area is assumed to be controlled by topography, with a good hydraulic connection between the river and the groundwater (see Figure 13.1).

The deeper component of groundwater flow at the base of the Carrigmaclea sandstones is likely to be controlled primarily by the dip of the rocks, with a proportion of flow drawn from the western side of the Nore valley and towards the supply wells (refer to Figure 13.1).

Gradients on the valley sides have been estimated at 0.01 from water level data collected during development of the supply scheme in the 1980's. However, less data are available for the valley floor, and groundwater gradients in this area are difficult to calculate because different gradients are likely in the different flow systems. Nevertheless, it is clear from permeability and topography data that gradients on the valley floor will be much lower than those on the valley sides. The gradient of the river channel between Mount Juliet and Brownsbarn is 0.001 (refer to Section 13.9) and this is likely to represent a lower limit for the groundwater gradient. A figure of 0.005 (in between the river gradient and the groundwater gradient on the valley sides) has been selected as generally representative of groundwater gradients on the valley floor.

Note that gradients close to the pumping wells are likely to increase.

13.11 Hydrochemistry and Water Quality

Data on recent trends in water quality at the Thomastown wells are summarised graphically in Figures 13.2 and 13.3, and the source data can also be found in Appendix V.

The following key points have been identified from the data:

- Data from analysis in eight samples from the two supply wells indicate a 'moderately hard' to 'very hard' (>350-151 mg/l $CaCO_3$) calcium-bicarbonate hydrochemical signature. Daly, 1994 reports that these levels of hardness are common in sandstones in Kilkenny where they are overlain by thick subsoils.
- For Well 5 (Nore Creamery), only total coliforms exceeded the European maximum admissible concentration. This occurred at low levels (8 counts/100 ml) in one of the three raw water[25] analyses available. Note that small concentrations of total coliforms can originate in the natural environment and are not necessarily proof that faecal contamination has occurred.
- For Well 9 (GAA grounds), in the five analyses available, manganese (one occasion in 1993), lead (one occasion in 1993), and faecal coliforms (two occasions in October 2000) exceeded the European maximum admissible concentration. Note that the levels of faecal coliforms were low (1 count / 100 ml) and may have originated from the sample vessel or sample handling.
- In terms of the remaining contaminant indicators studied, levels of nitrate, phosphate and chloride were close to GSI guide limits in Well 9 (GAA grounds). It is likely, therefore, that the waters are affected by releases of organic waste and/or inorganic fertiliser such as agricultural landspreading, or seepage from sewerage systems.
- Given the presence of casing at depths of 63 m and 90 m in the supply wells (refer to section 13.3) it is unlikely that contaminants are being introduced down the side of the well bore. Consequently, the contaminant indicators suggest that, within the aquifer itself, surface water and/or shallow groundwaters are mixing with the deeper groundwaters which supply the wells.

The regional hydrochemistry of the Maulin (**Ll**), Carrigmaclea (**Ll**) and Kiltorcan (**Rf**) aquifer systems is discussed in Chapter 4 of Volume I.

13.12 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. The data used in this section are based on pumping tests undertaken by the consultant Brian P. Connor in February 1991 (results provided by Brian P. Connor).

Well 5 (Nore creamery): A constant discharge test in February 1991 at 2240 m^3/day for 10 days gave a final drawdown of 8.62 m, and a specific capacity of 260 m^3/day/m. Water levels in a well just 2 m from Well 5 were observed throughout the discharge and subsequent recovery. Analysis of the drawdown in both the pumping and observation wells provided a transmissivity estimate of approximately 1000 m^2/d. The well penetrates through the whole saturated thickness of the aquifer (from 12 m below ground to 67 m below ground). An overall bulk permeability of 18 m/day has been derived from the transmissivity and saturated thickness estimates.

Specific capacity estimates are available for six wells (including Well 5) in the Carrigmaclea sandstones in Grenan and Dangan townlands. Estimates ranged from 16 to 260 m^3/day/m, and exceeded 190 m^3/day/m in three of the six wells. These specific capacities are generally significantly higher that the levels normally associated with the Carrigmaclea sandstones and it may be that the

[25] *Raw water samples are taken <u>prior to treatment</u>. Assessments are aimed at identifying contamination hazards rather than direct human health issues.*

fault described in Section 13.6 has increased specific capacities and transmissivities in the vicinity of the valley floor. Consequently, though the transmissivity derived from data for Well 5 is much higher than would normally be expected for Carrigmaclea sandstones, it is thought to represent a realistic 'worst case' (in terms of the need for groundwater protection) for the formation in the vicinity of the fault. Transmissivities on the valley sides are expected to be generally lower, probably by at least an order of magnitude.

Storativity values estimated from this 1991 pump test data are in the order of 1.6×10^{-3}.

Pump test data have not currently been made available for well 9 (GAA grounds).

A porosity of 0.025 has been assumed for the aquifer on the valley floor. This is at the upper end of the typical range used by the GSI for bedrock aquifers (0.025 to 0.01) and reflects the belief that the aquifer is densely fractured in the vicinity of the fault zone which runs along the valley floor.

13.13 Conceptual Model

This section provides a qualitative overview of the geological framework, recharge, 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 depicted schematically in Figure 13.1

- The supply wells are drilled into fractured sandstones of the Carrigmaclea Formation. Water strikes occurred at intervals across the whole thickness of this formation during drilling of the two supply wells, but were largest in the upper weathered portion (top 5 to 15 m of the rock) and at the unconformity at the base of the formation (60 to 90 m below ground). Transmissivity and specific capacity data in the vicinity suggests that the transmissivity of the sandstones is significantly enhanced (1000 m^2/d) on the valley floor in the vicinity of the wells. This is probably related to increased fracturing near a large fault.
- In the Nore valley, the bedrock units are overlain by gravel, which is greater than 10 m thick at the centre of the valley, thinning rapidly to less than 3 m close to the valley sides. There is evidence that this material is very free-draining and highly permeable, and prior to the development of the two wells, it was the source of water in Thomastown. The valley sides are mainly covered by tills of less than 3 m thickness. Surface drainage indicators suggest that the valley sides are also free-draining.
- Shallow groundwater flows occur in the gravel aquifer and the weathered portion of the sandstone aquifer. They are controlled by topography/gravity and by the high permeability pathway orientated along the north-south fault on the valley floor. Consequently, most shallow groundwater flows will be derived from the Nore valley sides to the west and south of the wells and will generally migrate towards the river perpendicular to the topographic contours. Recharge rates to the shallow portion of the aquifer are thought to be of the order of 380 mm/year.
- The deeper flows to the wells are concentrated in a geological unconformity at the base of the sandstone aquifer. They are controlled by topography/gravity and by the geological orientation of the base of the sandstone aquifer. This flow pathway is predominantly recharged vertically from shallow flow systems closer to the surface, but also horizontally from the area where the base of the aquifer comes to surface. The mixing of shallow and deep water is supported by the presence of slightly elevated levels of phosphate, nitrate and chloride in the production wells. Consequently, the recharge area for deep groundwater flows will include the recharge area for the shallow flows, but will also extend across to the valley sides to the east of the river where the base of the sandstone aquifer comes to surface. Groundwater close to the base of the aquifer will generally flow perpendicular to the dip of the geological unconformity.
- Gradients within the shallow groundwater component are in the order of 0.01 on the valley sides and assumed to be in the order of 0.005 on the valley floor.

13.14 Delineation of Source Protection Areas

13.14.1 Introduction

This section delineates the areas around the wells that are believed to contribute groundwater to the wells, and that therefore require protection. The areas are delineated on the basis of the conceptualisation of the groundwater flow pattern as described in Section 13.13 and shown in Figure 13.1.

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 wells.

13.14.2 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 pumping rate, (b) the groundwater flow direction and gradient, (c) the rock permeability and (d) the recharge in the area. The ZOC is delineated using both analytical modelling and the results of hydrogeological mapping and conceptualisation. Given the limited amount of calibration data available, a full groundwater numerical model was not undertaken.

In order to provide a reasonable, but conservative, estimate of the size of the ZOC, a high abstraction estimate of 2,780 m^3/day (1,014,700 m^3/year) was used. This figure was derived from the 1991 pumping test estimate of maximum yield from the Nore Creamery well (2250 m^3/day) and the maximum recorded daily discharge from the GAA grounds well[26] (530 m^3/day).

The boundaries of the analytical model were taken from hydrogeological mapping and the conceptualisation outlined in Section 13.13, and were as follows:

- **Northern boundary:** Nore river.
- **Southern boundary:** Ridge at Knockard - at point where the dip of the unconformity at the base of the Carrigmaclea sandstone swings away from the supply wells.
- **Western boundary:** Grenan ridge, surface water catchment for this stretch of the Nore.
- **Eastern boundary:** That portion of the unconformity between the Maulin and the Carrigmaclea Formations which dips towards the supply wells from the eastern side of the Nore valley. An additional buffer of 30 m was added upslope of the unconformity to allow for surface drains which may supply recharge waters to the unconformity.

These boundaries delineate the physical limits within which the ZOC is likely to occur, and cover an area of 5.7 km^2.

Note that the limits extend onto the far side of the Nore and it is unusual for a ZOC to cross under rivers of this size. The reasons are outlined in Section 13.13, but a water balance can also be used to examine whether the inclusion of the area to the east of the Nore is over-conservative:

West bank recharge rate estimate:	*380 mm/year*
Area of west bank included within the physical constraints:	*2.3 km^2*
Average annual volume of recharge from the west bank:	*2,300,000 $\times$ 0.38 = 874,000 m^3/year*
Volume of recharge required to sustain abstraction at Thomastown:	*1,014,700 m^3/year*
Shortfall in required recharge:	*140,700 m^3/year.*

In other words, recharge to the west bank under-estimates the total recharge volume required to balance abstraction by 140,700 m^3/year. This represents a minimum shortfall as the water balance

[26] *Pumping tests data for this well was not provided by the consultants.*

assumes that all groundwater recharge to the west bank will be drawn into the wells and that none will discharge directly to the river.

The area of the eastern bank contained within the physical constraints is 3.4 km^2. Over this area, the shortfall volume equates to a recharge rate of at least 40 mm/year, or more than 11% of the recharge rate estimate described in Section 13.8. Although most groundwater recharge from the eastern bank will discharge to the Nore without reaching the Thomastown wells, it is thought that the amount migrating to deeper levels and crossing under the Nore will be at least 10% and will therefore be sufficient to balance the shortfall in recharge from the western bank.

In summary:

- The recharge on both the western and eastern banks of the Nore are required to balance the abstraction at Thomastown wells, particularly if the rate of abstraction is to be increased in future years.
- The physical constraints are not overly conservative and appear to be generally appropriate to utilise as the boundary of the ZOC.

The ZOC boundary is depicted in Map 10.

13.14.3 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 and it is delineated to protect against the effects of potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination.

Estimations of the extent of this area cannot be made by hydrogeological mapping and conceptualisation methods alone. Analytical modelling was therefore used to estimate the extent of this zone upgradient of the two wells.

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

$$Velocity = groundwater\ gradient \times permeability \div porosity$$

A permeability of 18 m/day and a porosity of 0.025 was used (refer to Section 13.12). Given that the source comprises pumping wells in a high permeability zone, the natural gradient described in Section 13.10 is likely to increase closer to the wells. The increasing groundwater gradient moving closer to the pumping wells was estimated using the 'Theim' equation and groundwater velocities were predicted accordingly. In essence, though some more rapid flow paths may occur, it is predicted that most groundwater will move up to 400 m towards the wells in 100 days. Accordingly, the boundary of the SI has been delineated in a radius 400 m from each of the wells (refer to Map 10). Where the radii from each well intersect, the intersection has been smoothed-off.

13.15 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the source protection areas and vulnerability categories – giving a possible total of 8 source protection zones (see the matrix in the table below). In practice, this is done 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. All of the hydrogeological settings represented by the zones may not be present around any given source. 4 groundwater protection zones are present around the Thomastown source (see Map 10), as shown in the matrix below.

Matrix of Source Protection Zones

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*

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

13.16 Land Use and Potential Pollution Sources

Agriculture in the area comprises mainly pasture. Thomastown itself is a town of over 3,000 people, with a number of small commercial enterprises, including two petrol service stations. Much of the development lies on the opposite bank of the Nore, but housing and small industrial enterprises occur 40-50 m upgradient of the supply wells. The housing is sewered.

There is no evidence of significant contamination in the wells. There is, however, evidence that inorganic fertilisers and/or organic wastes have influenced water quality to some degree at the GAA Grounds well. Based on general land use, these influences may be linked to sewer leakage from the nearby housing.

13.17 Conclusions and Recommendations

- Wells 5 and 9 are excellent yielding wells, which draw from a mixture of deep, old groundwater and shallow, young groundwater.
- Most of the area in the ZOC is 'highly' to 'extremely' vulnerable to contamination.
- 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:
  - chemical and bacteriological analyses of raw water should be carried out regularly, in addition to analysis of treated samples. Given the raw water quality issues at Well 9 (GAA Grounds), a quarterly frequency has been recommended in Section 7.9. The chemical analyses should include all major ions - calcium, magnesium, sodium, potassium, ammonium, bicarbonate, sulphate, chloride, and especially nitrate. More occasional analyses of other parameters such as pesticides and hydrocarbons is also recommended. In order to detect separate contamination hazards at each well, it is recommended that the two wells be sampled separately;
  - given the proximity of commercial and industrial enterprises close to the wells, analysis of parameters specific to operations at these enterprises (e.g. oils and hydrocarbons) might be appropriate;
  - care should be taken in allowing any activities or developments which might significantly increase nitrate levels;
  - the potential hazards in the ZOC should be located and assessed, particularly in relation to agricultural activities, handling of wastes by commercial activities close to the supplies, and sewer integrity.

14. Urlingford/Johnstown Source

14.1 Introduction

The objectives of this chapter are:

- To delineate source protection zones for the Urlingford/Johnstown Water Supply Scheme.
- To outline the principal hydrogeological characteristics of the Urlingford/Johnstown area.
- To assist Kilkenny 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 source. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

14.2 Location and Site Description

Two springs 1.5 km east of Urlingford make up the public drinking water source for Urlingford and Johnstown. The location of the springs is shown on Map 8 and Map 4N. The springs are located in the townland of Borrismore; one in pasture land (2315NWW204), and the other by the side of the road (2315NWW124).

Spring 2315NWW124 lies just beside the R693 and the Borrismore Stream. It is enclosed in a concrete sump which is 5.5 m by 6.5 m, the top being set 1.6 m above the stream level, almost flush with the road. Reportedly, the stream inundates the spring during higher flows.

Spring 2315NWW204 reportedly lies some 370 m south of the R693 road, but is inaccessible to County Council staff and their representatives. It is unknown whether any protective structures have been built, but it may also be susceptible to inundation from surface drainage.

Discharge from both springs flows under gravity along pipes to a sump at the Borrismore pump-house, 1.7 km to the north-west. Here it is chlorinated and fluoridated before being pumped to a water tower further north in Warrenstown.

14.3 Summary of Source Details

	Spring 2315NWW124	**Spring 2315NWW204**
GSI no.	2315NWW124	2315NWW204
Grid ref.	23007 16355	23018 16324
Townland	Borrismore	Borrismore
Source type	Spring	Spring
Development date	1950's	1950's
Owner	Kilkenny County Council	Kilkenny County Council
Elevation (ground level)*	[illegible] m OD	130 m OD
Depth to rock	[illegible]ably less than 3 m	Probably less than 3 m
Static water level	surface	surface
Discharge summary:		
(i) consumption**	**Average:** [illegible] m³/d **Maximum:** 966 m³/d **Minimum:** 644 m³/d *	
(ii) average overflow***	Minimal	

** Estimated.*
*** County Council records from 1998 to 2001*
****County Council staff have indicated that occasions when the springs overflow are rare, and that generally usage matches discharge.*

14.4 Methodology

14.4.1 Desk Study

Bedrock geology information was compiled from original 1:10560 (six inch) field sheets and from the GSI bedrock report for the area (Archer *et. al*, 1996). Details of the current abstraction rate were obtained from Kilkenny County Council. Data on private groundwater wells in the area was taken from GSI archives. Chemistry data was obtained from EPA and County Council records. Water levels were from GSI records.

14.4.2 Site Visits and Field Work

Site visits and fieldwork included walkover surveys undertaken by both the Groundwater (0.5 day) and Quaternary (1 day) sections of the GSI to further investigate the subsoil and bedrock geology, the hydrogeology and the vulnerability to contamination. Two water samples were taken by the GSI on 04/10/2000 and 26/04/2001, and were submitted for analysis at the EPA laboratories in Kilkenny in accordance with their sampling and transportation guidelines.

14.4.3 Assessment

Analytical equations and hydrogeological mapping were utilised to delineate protection zones around the source.

14.5 Topography and Surface Hydrology

The Urlingford/Johnstown source is located 1.5 km east of Urlingford and almost 3 km south of Johnstown (see Maps 4N and 8). The Borrismore Stream flows past both springs, 100 m west of 2315NWW204 and immediately west of 2315NWW124. This stream originates just 1.5 km to the east of the springs, and flows around in a loop to join the River Goul 4.5 km to the north-west. The Goul is part of the Erkina River sub-catchment of the Nore Basin.

The two springs and the stream occur in gently undulating land, varying in elevation from 140 m O.D. to 120 m O.D. The stream valley is wide and low, and the Stream meanders in broad loops, frequently overflowing its banks during the winter. This gently undulating terrain continues westwards for some distance into Tipperary, but ends just 3 km to the north-east of the springs, against the steep slopes of the Slieveardagh Hills. These hills form the northern boundary to the Borrismore Stream catchment.

The valley has very gentle variable slopes of about 0.02 (1 in 50) around the supply springs, steepening to 0.15 (1 in 6) in the hills to the north-east.

There is a streamflow gauge on the Borrismore Stream, installed by the GSI and monitored in the 1970's. Low flows at this station are particularly low, and it was dry in the summer of 1976. The maximum recorded winter flow was 0.52 m^3/sec.

The drainage density in the immediate area of the springs is low. The other main river in the area is the Nuenna River, which rises 4.5 km to the south-east of the Urlingford springs.

Note that karst features occur 1 km to the east of the springs, but they lie on the far side of a surface watershed and on a different aquifer to the Urlingford springs. They are not thought to be relevant in the context of groundwater flow to the springs.

14.6 Geology and Aquifers

14.6.1 Bedrock

The main rock types below the Urlingford/Johnstown source are the Aghmacart and Durrow limestone Formations. The Ballyadams limestone Formation underlies the area to the east of the springs. These formations are described in more detail in Chapters 2 and 4 of Volume I and their distribution in the vicinity of the Urlingford/Johnstown springs is shown on Map 8. The springs are located in the Durrow Formation.

The Aghmacart and the Durrow Formations both consist of shaley limestones and are both classified as **locally important aquifers** which are **moderately productive only in local zones** (**Ll**). Fracture flow is expected to be dominant. Flows are expected to be concentrated in fractured and weathered zones. Given common weathering patterns, most flow is thought to be relatively shallow; concentrating in the top 10 m to 30 m of the rock profile. More detail on flow characteristics and aquifer classification criteria can be found in Chapter 4 of Volume I.

The Ballyadams Formation consists of clean limestone which have been extensively karstified. Springs, swallow holes, a turlough and collapse features can all be found in the areas where this rock-types occurs, and the groundwater flow regime is expected to demonstrate karstic characteristics. The Ballyadams has been classified as a **regionally important karst aquifer** (**Rk^d**) (see Chapter 4, Volume I).

All these formations have been affected by faulting. Faulting and associated fracturing are likely to be a focus for groundwater flow.

The springs occur towards the centre of an anticline (upward fold in the rock mass). In the immediate vicinity of the springs, the Durrow and Aghmacart Formations dip at about 14° south eastwards. This means that the regionally important karstic aquifer dips away from the springs and is unlikely to play a direct role in influencing groundwater flow to the springs.

14.6.2 Subsoil

The main subsoil types in the area are gravel, alluvium, and glacial till. These materials are described in more detail in Chapter 3 of Volume I and their distribution in the vicinity of the Urlingford/Johnstown springs is shown on Map 2N.

Gravel deposits underlie the spring and are the most widespread subsoil in the area, and further east along the Nuenna River, they are classed as a **Locally important** gravel (**Lg**) aquifer (see Section 4.18.4 of Volume I). In the area around the Urlingford springs, however, they rarely exceed 5 m in thickness and are too thin to be regarded as an aquifer. The alluvial deposits occur in thin strips along the Borrismore Stream. Thin tills are mapped to the west of the springs, near Urlingford. There are no subsoil materials classified as aquifers in the Urlingford/Johnstown area and the main significance of the subsoil materials is in vulnerability and recharge assessments. These issues are described in Sections 14.7 and 14.8.

14.7 Groundwater Vulnerability

14.7.1 Introduction

The concept of vulnerability is discussed in Chapter 4 of Volume I. In essence, however, groundwater vulnerability is dictated by the nature and thickness of the material overlying the main groundwater 'target'. As discussed in Section 14.6, the main groundwater resource occurs within fractured bedrock. Consequently, the target is taken from the top of the bedrock formations, and considerations of groundwater vulnerability concern the permeability of the whole subsoil profile and the depth to bedrock.

14.7.2 Permeability

A generalised subdivision of Kilkenny into three broad permeability types (high, moderate and low) is provided in Chapter 5 of Volume I. The sands and gravels around the spring supplies are thought to be generally high permeability, and are regarded as part of the Nuenna River sand and gravel region (refer to Chapter 5, Volume I). The alluvium is regarded as generally moderate permeability, as is the till.

14.7.3 Depth-to-rock

The variation in depth to rock in the vicinity of the Urlingford/Johnstown springs is presented on Map 3N. The data on this map come from drilling records housed in the GSI databases and detailed field mapping carried out in the 1900's.

In summary, the subsoils in the immediate vicinity of the springs are thought to be thin or absent, rarely exceeding 3 m in thickness. Three individual outcrops are in evidence, along with one borehole record which indicates a depth to rock of 2 m. The Borrismore Stream is small, and the alluvial deposits are unlikely to exceed 1 m in thickness. To the east of the springs, the depth to rock is thought to gradually increase to 3 to 10 m. However, depths are variable, with rock outcrops in evidence, and at least one borehole record indicating a depth to rock of 14 m. These variations are located over the Ballyadams limestones, and are typical of karstic rock.

14.7.4 Summary

The vulnerability categories in the vicinity of the Urlingford/Johnstown supply springs are shown on Map 9. In areas where the subsoils are likely to be less than 3 m thick, a vulnerability rating of generally 'extreme' has been applied. In areas to the east, where the gravel deposits are believed to be greater than 3 m thick, their likely high permeability means that a vulnerability rating of generally 'high' has been assigned.

The permeability estimations are based on regional-scale evaluations. Depth to rock interpretations are based on the available data cited here. However, permeability and particularly depth to rock can vary over a very small scale. As such, the vulnerability mapping provided will not be able to anticipate all the natural variation that occurs in an area. 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. More detail can be found in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

14.8 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 it largely dictates the size of the zone of contribution.

In areas where point recharge from sinking streams, etc, is discounted, the main parameters involved in recharge rate estimation are annual rainfall, annual evapotranspiration, and annual runoff[27]:

- Annual rainfall: 880 mm (Met Eireann average annual (1961-90), average of rainfall measured at Urlingford and Johnstown).
- Annual actual evapotranspiration (A.E.) losses: 450 mm. This figure ('actual evapotranspiration') was calculated assuming 95% of the country-wide potential evapotranspiration data presented in the "Agroclimatic Atlas of Ireland" (Collins and Cummins, 1996). Local measurements of actual evapotranspiration are not available.
- Potential recharge: 430 mm/year, based on average annual rainfall less estimated evapotranspiration.
- Annual runoff losses: 20% of potential recharge (90 mm/year). This is a typical figure used by the GSI in areas where the till cover is thin, and where drainage densities are low.

[27] *Estimations used in this report have generally been rounded off to two significant figures*

These calculations are summarised below:

Average annual rainfall (R)	880 mm
Estimated A.E.	450 mm
Potential Recharge (R – A.E.)	430 mm
Runoff losses factor (RO)	20%
Estimated Actual Recharge (R-A.E.) x (1-R.O)	340 mm

14.9 Groundwater levels

Groundwater level monitoring was carried out by the GSI on 43 observation wells in the karstic Ballyadams aquifer to the east of the springs, from 1974 to 1976 (Cawley, 1990). The same level of research was not extended to the Durrow Formation, but water levels are available for four wells in the area. All these levels were obtained during late summer, from wells penetrating the Durrow Formation, and should reflect low groundwater levels. They indicate that the watertable in the aquifer is generally quite shallow, probably between 5 m and 10 m below ground level. The distribution of levels is presented on Map 8. The distribution suggests that there is a groundwater low in the vicinity of the supply springs, with a groundwater high following the slight topographic ridge that runs north-south along the geological contact between the Durrow **'Ll'** aquifer and the Ballyadams karstic aquifer. This, coupled with the fact that water levels appear to be quite shallow, suggests that the slight topographic ridge forms the eastern limit of the catchment area ('zone of contribution') of the springs and that the karstic aquifer has little influence on the flow regime at the springs. The Borrismore stream originates in the Loughans turlough on the karst aquifer and dries-up in the summer, while the Urlingford supply springs reportedly do not dry-up. This provides supporting information to suggest that the flow regime feeding the springs is not karstic.

14.10 Groundwater Flow Directions and Gradients

It is inferred from water level data (Section 14.9) that groundwater flow in the vicinity of the supply springs follows local topography. Two north-south trending low ridges occur 700 m to the east and west of the springs. Groundwater flow is expected to move from these ridges and towards the springs and to the Borrismore Stream. The stream is likely to act as a partial cut-off drain to flows from the west and most flow to the springs is expected to occur from the eastern ridge. Note that groundwater flows within the karstic limestones further east are expected to follow quite different patterns, but they are not expected to contribute a significant portion of the flow to the supply springs.

Assuming that shallow groundwater flow predominates in this shaley limestone aquifer, the groundwater gradients have been estimated from topographic data and limited water level data to range from 0.004 (1 in 250) to 0.02 (1 in 50).

14.11 Hydrochemistry and Water Quality

Data on recent trends in water quality at the Urlingford springs are summarised graphically in Figure 14.1, and the source data can be found in Appendix V.

The following key points have been identified from the data:

- Data from analysis of hardness in four samples indicate a 'very hard' (>350 mg/l $CaCO_3$) calcium-bicarbonate hydrochemical signature.
- Of the parameters examined in the eight available raw groundwater analyses, faecal coliforms, potassium, the potassium:sodium ratio, and nitrate are all regularly in excess of GSI guide levels. This combination of parameters, found in springs located in an extreme vulnerability setting suggests that one or more farmyard point hazards are contributing to the contamination at the springs.

The regional hydrochemistry of the Durrow (**Ll**) Aghmacart (**Ll**) and Ballyadams (**Rk**) aquifer systems are discussed in Chapter 4 of Volume I.

14.12 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.

The data used in this section are mainly estimations based on our understanding of the likely flow-regime in the Durrow aquifer system. No pump test data were available in the immediate vicinity of the Urlingford springs, but pump test records for a well belonging to the Glanbia well-field in Ballyragget were used to assist in the assessment. Well 2317SWW455 is situated in the Durrow Formation, about 16 km north-east of the springs, and was tested by KTC consultancy (Cullen, 1990).

A constant discharge test in November 1989 at 320 m^3/day for 54 hours gave a final drawdown of 8 m, and a specific capacity of 40 m^3/day/m. Analysis of the data from this test using the Jacob method provided a transmissivity estimate of 15 m^2/d.

Using a conservative aquifer thickness estimate of 10 m, a permeability of 1.5 m/day has been derived from the transmissivity estimate.

A porosity of 0.01 has been assumed for the Durrow '**Ll'** aquifer on the valley floor. This is at the lower end of the typical range used by the GSI for bedrock aquifers (0.025 to 0.01) and reflects the belief that fracturing is not particularly dense in this portion of the aquifer.

14.13 Conceptual Model

This section provides a qualitative overview of the geological framework, recharge, 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 Urlingford springs lie in the shaley limestones of the Durrow Formation, which are classed as a **locally important aquifer** (**Ll**). Shaley limestones of the Aghmacart Formation (also **Ll**) occur 400 m to the west and dip under the springs at a depth of approximately 100 m. Flow in all these aquifers will generally concentrate along faults and fractures and within the upper, weathered zones.
- Subsoils consist predominantly of gravels less than 5 m in thickness in most places. Some alluvium is mapped along the Borrismore Stream, while thin tills are mapped to the west of the area. The subsoils are not considered aquifers and groundwater vulnerability in the bedrock aquifers is expected to increase from generally 'high' to generally 'extreme' moving westwards towards the springs.
- Water level data suggest that groundwater within the aquifer feeding the springs is mostly unconfined and follows local topographic divides.
- Transmissivities are low and the water table appears to be quite shallow. Consequently, most recharge is expected to occur locally, and most occur at shallow depths and follow short flowpaths within the Durrow Formation limestones.
- Groundwater flow to the springs is expected to come from the slight topographic ridge that occurs 700 m to the east.
- Where the Borrismore Stream flows across the Durrow Formation, it is considered to be in hydraulic continuity with groundwater, and is likely to act as a partial cut-off drain to flow from the west. However, the stream is small and some groundwater flow may move under the stream from the west. Consequently, the western half of the topographic catchment is also considered a possible source of recharge.
- The Durrow limestone is overlain by a karstic aquifer to the north-east, but flow to the springs is not believed to be significantly influenced by karstic flows from this area.

- Due to the likely low permeability of the Durrow Formation, groundwater gradients are probably similar to topographic gradients, and are estimated to range from 0.004 (1 in 250) to 0.02 (1 in 50).

14.14 Delineation of Source Protection Areas

14.14.1 Introduction

This section delineates the areas around the Urlingford/Johnstown springs that are believed to contribute groundwater to the springs flows, and that therefore require protection. The areas are delineated on the basis of the conceptualisation of the groundwater flow pattern as described in Section 14.13.

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.

14.14.2 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 groundwater flow direction and gradient, (b) the rock permeability and (c) the recharge in the area. The ZOC is delineated using both analytical modelling and the results of hydrogeological mapping and conceptualisation. Given the limited amount of calibration data available, a full groundwater numerical model was not undertaken.

In order to provide a reasonable, but conservative, estimate of the size of the ZOC, a high abstraction of 1455 m^3/day (531,100 m^3/year) was used. This represents the highest recorded combined discharge of 970 m^3/day multiplied by an additional safety factor of 1.5. This conservative discharge figure was used because topography is not well defined in the area, and, as such, the delineation of the ZOC is subject to more uncertainty than in sources like Piltown or Graiguenamanagh.

The boundaries of the analytical model were taken from hydrogeological mapping and the conceptualisation outlined in Section 14.13, and were as follows:

- **Northern boundary:** 100 m down-gradient of spring 2315NWW124.
- **Eastern boundary:** Ridge of higher ground extending northwards from Belle Vue House.
- **Western boundary:** Ridge of higher ground extending northwards from Tincashel townland and into Borrisbeg townland.
- **Southern boundary:** Line joining the eastern and western boundaries at their closest point.

These boundaries delineate the physical limits within which the ZOC is likely to occur and are shown on Map 10.

The area defined by these boundaries described above is approximately 2.3 km^2. Most flow to the springs is expected to originate from the portion of this area to the east of the Borrismore Stream. This portion comprises 1.2 km^2. However, water balance estimations suggest that the actual ZOC of the springs needs to be approximately 1.6 km^2 to supply sufficient rainfall recharge to support the spring flows as follows:

Recharge area required to sustain discharge = Discharge ÷ average annual depth of recharge.

Recharge area required to sustain discharge $= (1455 \times 365) \div 0.34$

Recharge area required to sustain discharge $= 1.6\ km^2$

This suggests that the portion to the west of the Borrismore stream is also required.

In summary, the physical limits defined above are considered appropriate to delineate the extent of the Outer Protection Area (ZOC).

14.14.3 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 and it is delineated to protect against the effects of potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination.

Estimations of the extent of this area cannot be made by hydrogeological mapping and conceptualisation methods alone. Analytical modelling was therefore used to estimate the extent of this zone upgradient of the springs.

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

$$\text{Velocity} = \text{groundwater gradient} \times \text{permeability} \div \text{porosity}$$

Using the estimates derived in Sections 14.12 and 14.10 for gradient, permeability, and porosity (0.02, 1.5 m/day, and 0.01 respectively), the equation gives a velocity of 3 m/day. This could be treated as a 'reasonable worst case estimate'. In other words, though some more rapid flow paths may occur, it is thought that most groundwater will move up to 300 m in 100 days. Accordingly, the boundary of the SI has been delineated 300 m upgradient of the springs (refer to Map 10).

14.15 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the source protection areas and vulnerability categories – giving a possible total of 8 source protection zones (see the matrix in the table below). In practice, this is done 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 Source Protection area where the groundwater is highly vulnerable to contamination. All of the hydrogeological settings represented by the zones may not be present around any given source. Just three groundwater protection zones are present around the Urlingford/Johnstown source (see Map 10), as shown in the matrix below.

Matrix of Source Protection Zones

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

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

14.16 Land Use and Potential Pollution Sources

Agriculture in the area comprises pasture and tillage.

No detailed hazard survey was carried out as part of this study, but, on the basis of the water quality and vulnerability assessments (see Section 14.11), the main hazards within the ZOC are considered to be farmyard point sources.

Other potential hazards include landspreading, domestic wastewater treatment systems, application of inorganic fertilisers and pesticides, inundation of contaminants from the stream, and possible spillages along the road passing the springs. Note also that the track leading past spring 2315NWW124 to the Borrismore Stream appears to be frequently used as a dumping ground. Toxic chemicals (e.g. fuel oil) dumped here could reach the spring.

The nitrate concentrations are consistently elevated and merit some additional consideration. Some broad, 'back-of-the-envelope' estimations of the number of domestic wastewater treatment systems required to produce the measured nitrogen loading in the springs are provided below:

- *Typical nitrogen concentration in spring flow: 9 mg/l N*
- *Typical 'background' nitrogen concentration[28]: 5.5 mg/l N*
- *Estimated additional contribution of nitrogen from human activities in the ZOC: 9 – 5.5 = 3.5 mg/l N*
- *Minimum estimated total spring flow: 644,000 l/day.*
- *Estimated minimum nitrogen loading in spring:* $644,000 \times 3.5 \div 1000,000 \approx 2.3$ *kg/day N.*
- *Estimated 'natural' nitrogen loading in recharge waters[29]: 0.1 mg/l N @ 644,000 l/day* $\rightarrow$ *0.06 kg/day N.*
- *Estimated additional loading from human activities in the ZOC =* $2.3 - 0.06 \approx 2.3$ *kg/day N.*
- *Assuming all additional loading is derived from septic tanks, the population equivalent of the additional septic tank loading: 2.3 kg/day N @ 50 mg N/l/person @ 180 l effluent/person* $\approx$ *250 people.*

In other words, it is estimated that the waste from at least 250 people living in the ZOC would be required to balance all the nitrogen loading observed in the spring waters. Note that the calculations have used the minimum estimated spring flow (644 m^3/day) and have assumed that all the nitrogen from the septic tanks is converted to nitrate. In practice, some of the nitrogen will not become mobile in the subsurface, and average springflows are greater than 644 m^3/day. As such, the population equivalent suggested by these 'back-of-the-envelope' estimations comprises a minimum number required to balance the observed nitrogen concentrations if septic effluent were the only influence on nitrate concentrations at the source. It is unlikely that this number of people live and use septic systems within the ZOC and, as such, the estimations provide evidence that other sources of nitrogen (such as farmyards) are contributing to the nitrate problem at the springs.

14.17 Conclusions and Recommendations

- The two springs serving the Urlingford/Johnstown water supply scheme are both intermediate yielding springs, which are located in a locally important shaley limestone aquifer.
- The area around the supply is 'highly' to 'extremely' vulnerable to contamination and both springs are potentially vulnerable to inundation by the Borrismore stream.
- 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:
    - chemical and bacteriological analyses of raw water should be carried out monthly (refer to Section 7.9), in addition to analysis of treated samples. The chemical analyses should include all major ions - calcium, magnesium, sodium, potassium, ammonium, bicarbonate,

[28] *Taken as the typical concentration in Clomantagh spring, which lies 6 km to the east in a similar hydrogeological and climatological environment.*

[29] *Loading estimates taken from EPA, 2000. The figures assume no denitrification and subsequent attenuation of nitrogen will occur in the subsurface.*

sulphate, chloride, and nitrate. More occasional analyses of other parameters such as pesticides and hydrocarbons is also recommended;

- care should be taken in allowing any activities or developments which might significantly increase nitrate levels;
- the potential hazards in the ZOC should be located and assessed;
- dumping around the spring close to the road be discouraged as much as possible.

15. Graiguenamanagh

15.1 Introduction

The objectives of this chapter are:

- To delineate source protection zones for the Ballyogan springs (part of the Graiguenamanagh Water Supply Scheme).
- To assist Kilkenny 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 springs. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

15.2 Location and Site Description

According to a site location map sent to the GSI on 18th April 2002, the source comprises four springs, forming a line 230 m long in Ballyogan townland. The springs all lie close to the 170 m contour on the flanks of Brandon Hill, some 1.4 km north east of its peak.

M'C O'Sullivan Consulting Engineers (1999) indicate that the spring waters are integrated with waters from a surface water intake on the Duiske River, some 1.2 km west of Graiguenamanagh to form the supply for Graiguenamanagh town. They indicate that the combined surface water and groundwater output comprises 529 m^3/day.

No information is available on the sanitary protection measures at the springs. Examples of typical sanitary protection measures include fences and constructions to provide protection from wildfowl, livestock, and surface water inundation.

15.3 Summary of Source Details

GSI no.	2613NWW119
Grid ref.	270600, 141300
Townland	Ballyogan
Source type	4 springs
Development date	Unknown
Owner	Kilkenny County Council
Elevation (ground level)*	170 m OD
Depth to rock	Rock generally close to surface
Static water level	At surface
Discharge summary:	Unknown

* *Estimated from Ordnance Survey contours*

15.4 Methodology

Examination of spring flows, water quality, aquifer parameters, etc, was beyond the scope of the study. Protection zones were delineated on the basis of an examination of Ordnance Survey topographic maps and aerial photographs alone. As a consequence, the basis for the protection zones is more limited than for the other public supplies in this report. This may not be a significant limitation in the case of the Ballyogan springs, because the springs are located on the side of a mountain, and protection zones in steep topographic areas would normally be based primarily on topographic features; even in the context of a more comprehensive study.

15.5 Topography and Surface Hydrology

The springs lie on the flanks of Brandon Hill within the catchment of the River Barrow (western side). The peak of Brandon Hill forms part of the regional catchment divide between the Nore and the Barrow. Upgradient of the spring, slopes are in the order of 0.25 (1 in 4), with the peak of Brandon Hill at 515 m OD. Downgradient of the springs, elevations reduce to less than 10 m OD at the Barrow River itself, which lies some 1.4 km to the north east of the springs.

There is no evidence from the Ordnance Survey 1:50,000 or 1:10,560 maps of surface water features on Brandon Hill upslope of the springs.

The Ordnance Survey contours define two minor watersheds running towards the Barrow River from the peak of Brandon Hill. These watersheds lie on either side of the Ballyogan springs, with one running 0.7 km to the north west and one running 0.5 km to the south of the springs. The aerial photographs suggest that these two minor watersheds define a pronounced, triangular-shaped bowl which is open on its north eastern side. The springs occur at the open, north eastern side of the bowl.

In the absence of groundwater level and flow data, it is assumed that this bowl controls groundwater flow to the springs and its boundaries have been used to define the source protection areas in later sections of this chapter.

15.6 Geology and Aquifers

15.6.1 Bedrock

The springs are mapped close to the boundary with two slightly different types of granite. The granites in Kilkenny are all classified as a **poor aquifer** which is **generally unproductive except for local zones** (**Pl**). Fracture flow is expected to be dominant and flows are expected to be concentrated in fractured and weathered zones. Given common weathering patterns, most flow is thought to be relatively shallow; concentrating in the top 10 m to 30 m of the rock profile. As a consequence, groundwater flow is expected to follow topography quite closely.

The boundary between the two types of granite may form a focus for slightly more intense weathering and, as a consequence, may act as a subsurface channel for groundwater flow. More detail on flow characteristics and aquifer classification criteria can be found in Chapter 4 of Volume I.

The granites will have been subject to a variety of different tectonic stresses, resulting in faulting and fracturing. The southern boundary of a ‘shear zone’ (band of major structural deformation) is mapped close to the location of the spring. The shear zone may be associated with increased rock fracturing and this feature might also be a focus for groundwater flow within the topographic bowl described in Section 15.5.

15.6.2 Subsoil

The area is mapped in Map 2S as ‘rock close to surface’. Subsoil materials are considered to be very thin or absent. There are no subsoil materials classified as aquifers in the area. The main significance of the subsoil materials, therefore, is in vulnerability assessments.

15.7 Groundwater Vulnerability

The concept of vulnerability is discussed in Chapter 5 of Volume I. In essence, groundwater vulnerability is dictated by the nature and thickness of the material overlying the main groundwater ‘target’. As discussed in Section 15.6, the main groundwater resource occurs within fractured granite bedrock. Consequently, the target is taken from the top of the granite, and considerations of groundwater vulnerability concern the permeability of the whole subsoil profile and the depth to bedrock.

The subsoil in the immediate vicinity of the source is thought to be generally absent or very thin. This interpretation is based on the presence, uplsope of the springs, of over 20 rock outcroppings (most of which are in excess of 200 m long). No borehole data is available to the GSI in this area.

At subsoil thicknesses of less than 3 m, bulk permeability becomes less relevant in mapping vulnerability across wide areas (as opposed to specific sites), because it becomes increasingly variable and increasingly influenced by the presence of 'bypass flow' mechanisms such as cracks in the subsoil. Accordingly, on the basis of the general depth to bedrock in the area, a vulnerability classification of 'extreme' has been assigned for the whole area upslope of the springs.

Depth to rock interpretations are based on the available data cited here. However, depth to rock can vary over a very small scale. As such, the vulnerability mapping provided will not be able to anticipate all the natural variation that occurs in an area. 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. More detail can be found in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

15.8 Rainfall, Evaporation and Recharge

The term 'recharge' refers to the amount of water replenishing the groundwater flow system. The estimation of recharge is often used in source protection delineation in order to assess if the potential catchment of the source (as defined by geological, topographic and hydrogeological constraints) is equivalent to the are required to support the discharge at the source with rainfall recharge.

However, because no measurements of discharge at the springs are available to the GSI, a water balance cannot be undertaken and the estimation of recharge is therefore not relevant in this instance.

15.9 Groundwater levels

The GSI database has no records within the surface water sub-catchment upstream of the springs.

15.10 Groundwater Flow Directions and Gradients

In the absence of borehole data or site visits, and given the aquifer conditions, the water table in the area is assumed to reflect topography, with groundwater flowing towards the spring from the watersheds to the north west and to the south and from the peak of Brandon Hill.

Hydraulic gradients are probably similar, if slightly less than, topographic gradients.

15.11 Hydrochemistry and Water Quality

No water quality data for the springs are currently available to the GSI.

15.12 Aquifer Parameters

No data are available.

15.13 Conceptual Model

This section provides a qualitative overview of the geological framework, recharge, 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 Ballyogan springs are fed by groundwaters flowing within the granites of Brandon Hill, which constitute a poor aquifer. The springs lie within the surface water catchment of the River Barrow, which lies to the east of the springs.
- Subsoils are thought to be generally absent or thin.
- Based on a regional conceptualisation of flow within the granite aquifer, groundwater flow to the springs is thought to be controlled by topography and by fracturing and weathering patterns within the rock mass. Most groundwater flow is thought to be relatively shallow; concentrating in the top 10 m to 30 m of the rock profile. The flow is therefore likely to follow local variations in topography, moving towards the springs from the Peak of Brandon Hill and from the minor watersheds to the north, south and west of the springs.
- Recharge to the springs is likely to originate as rainfall falling within the triangular-shaped topographic bowl which encloses the springs on the eastern flank of Brandon Hill.

15.14 Delineation of Source Protection Areas

15.14.1 Introduction

This section delineates the areas around the source that are believed to contribute groundwater to the source, and that therefore require protection. The areas are delineated on the basis of the conceptualisation of the groundwater flow pattern as described in Section 15.13.

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.

15.14.2 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 normally delineated using inferences of (a) the groundwater flow direction and gradient, (b) the rock permeability and (c) the recharge in the area.

In the case of the Ballyogan springs, information on groundwater gradients, bedrock permeability, etc is not available, and the conceptualisation is such that groundwater is expected to follow topography quite closely. Consequently, the ZOC for this source is assumed to coincide with the triangular-shaped topographic bowl which encloses the springs on the eastern flank of Brandon Hill. The boundaries of this bowl are described in Section 15.5 and depicted in Map 10.

15.14.3 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 and it is delineated to protect against the effects of potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination.

Given the limited amount of information available at the source, the Inner Protection Area has been delimited by a line drawn 300 m upslope of all four springs at the source (refer to Map 10). A distance of 300 m is recommended in DELG/EPA/GSI (1999) for areas where no data are available.

15.15 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the source protection areas and vulnerability categories – giving a possible total of 8 source protection zones (see the matrix in the table below). In practice, this is done by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code, e.g. **SI/E**, which represents an Inner Source Protection area where the groundwater is highly vulnerable to contamination. All of the hydrogeological settings represented by the zones may not be present around any given source. Just two groundwater protection zones are present around the source (refer to Map 10), as shown in the matrix below:

Matrix of Source Protection Zones

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

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

15.16 Land Use and Potential Pollution Sources

Assessments of spring water quality and existing potential hazards were outside the scope the study at the Ballyogan source. However, some examples of potential hazards in upland environments are; sheep dip disposal, livestock activity close to a supply, animal carcasses close to a supply, waste and hydrocarbon effluent from tourism developments, extractive industry, and fly tipping.

15.17 Conclusions and Recommendations

- The groundwater source for the Graiguenamanagh supply scheme is a spring, which is located in a poor aquifer on the eastern flank of Brandon Hill.
- Groundwater below the zone of contribution to the supply is generally 'extremely' vulnerable to contamination.
- 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:
    - chemical and bacteriological analyses of raw water as well as treated water be carried out regularly. The springs should be sampled and analysed separately from the surface water intake component of the public supply scheme. Sampling might be quite frequent initially (perhaps monthly), being reduced to perhaps quarterly if there is no evidence of contamination. The chemical analyses should include all major ions - calcium, magnesium, sodium, potassium, ammonium, bicarbonate, sulphate, chloride, and nitrate. More occasional analyses of other parameters such as pesticides and hydrocarbons is also recommended;
    - vulnerability to surface runoff be assessed. If necessary, a protective structure should be constructed over the spring;
    - the potential hazards in the ZOC be located and assessed.

16. Group Scheme, Domestic and Industrial Groundwater Supplies

Available raw water quality data for most of the public groundwater supplies, the larger group schemes and selected industrial and domestic groundwater sources are presented in Appendix VI, and discussed in Chapter 7.

The mapping of specific protection areas for sources in County Kilkenny other than those public supplies listed in Sections 8 to 15 was outside the scope of the Groundwater Protection Scheme work. This means that only the risk to these specific receptors is defined in the maps and digital GIS datasets produced for the Kilkenny Protection Scheme.

Any remaining public groundwater supplies and some of the larger group scheme and industrial supplies may merit source protection zone delineation in the future; particularly if major developments are planned close-by.

For domestic and smaller farm supplies, the existing groundwater protection responses for on-site wastewater treatment systems, IPC landspreading, and landfills are intended to provide adequate protection in relation to these specific activities. Additional protection responses for activities such as underground hydrocarbon storage and farmyards are planned for the near future.

The protection response measures for on-site wastewater treatment systems for single houses (including 'septic tanks') provides an example of how domestic wells are accounted-for. The recommended measures for these systems require the mapping of aquifer category, vulnerability, and source protection zones for public groundwater supplies. All these elements are supplied in the vicinity of those sources considered in the Kilkenny Groundwater Protection Scheme. In addition, however, the response measures require that consideration be given to smaller wells. Depending on groundwater vulnerability and subsoil 'T test' results, the measures provide specific guidance on the appropriate minimum distance between the percolation area and neighbouring wells and the EPA guidelines specify that the proximity of existing wells has to be checked on-site (EPA, 2000).

In summary,

- Source protection zones have not yet been mapped for the group scheme and industrial groundwater supplies in County Kilkenny.
- Protection for domestic wells and smaller farm supplies is provided-for under the existing groundwater protection responses for on-site wastewater treatment systems, landfills and IPC landspreading. Additional protection responses are planned for the near future.
- Site-specific developments which have the potential to contaminate groundwater will usually require site-specific checking of the proximity of nearby receptors such as domestic drinking water wells.

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AppendixIV:Discusion of the Key Indicators of Domestic and Agricultural Contamination of Groundwater

Appendix IV: 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.

TABLE A1

Recommended Parameters		
Appearance	Calcium (Ca)	Nitrate (NO_3)*
Sediment	Magnesium (Mg)	Ammonia (NH_4 and NH_3)*
pH (lab)	Sodium (Na)	Iron (Fe)*
Electrical Conductivity (EC)*	Potassium (K)*	Manganese (Mn)*
Total Hardness	Chloride Cl)*	
General coliform	Sulphate (SO_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 (NO_2)*	TOC *	Lead (Pb)
B.O.D.*	Boron (B) *	Other metals
Dissolved Oxygen *	Cadmium (Cd)	
*** good indicators of contamination**		

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; entertoviruses 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 Hagedorn 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 streptocci 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 NO_3 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 not 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** mg/l	**EU MAC** 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 ⇨ organic waste source nearby (except in karst areas), usually either a septic tank system or farmyard.
E. coli absent ⇨ 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 ⇨ either inorganic fertiliser or organic waste source; check other parameters.
Ammonia > 0.15 mg/l ⇨ source is nearby organic waste; fertiliser is not an issue.
Potassium (K) > 5.0 mg/l ⇨ source is probably organic waste.
K/Na ratio > 0.4 (0.3, in many areas) ⇨ Farmyard waste rather than septic tank effluent is the source. If < 0.3, no conclusion is possible.
Chloride > 30 mg/l ⇨ 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.

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Appendix V:Laboratory analytical results

EPA Regional Water Laboratory, Kilkenny. Monitoring Data for County Kilkenny Groundwaters 1993 to 1999.

Source	Sampling Date	Sampling Time	To	Ref No	Sampling Location	Taken By	Lab No	EPARef	Stn Grid Ref	Water Supply	Public/Group/Private	Temperature	Odour 1/2/3	Colour Hazen	pH	Conductivity µS/cm	Turbidity NTU	TOC mg/l C	Ammonia mg/l N
Spring at Paulstown Castle	29/04/1992	11:38:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle		1648	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	9.1	1	5	7.3	623			0.03
Spring at Paulstown Castle	01/07/1992	15:55:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle		2681	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	11.4	1	5	7.4	640			0.02
Spring at Paulstown Castle	20/08/1992	15:15:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle		3737	KIK46	S 660 570	Gowran/Goresbr./P-town	Public		1	5	7.2	600			0.02
Spring at Paulstown Castle	18/11/1992	13:29:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle		5086	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	9.8	2	5	7.4	623			0.02
Spring at Paulstown Castle	10/03/1993	16:00:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle		1017	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	9.6	1	5	7.3	660			0.01
Borehole at Castlecomer Yarns	02/06/1993		Kilkenny Co. Co.	KK00300	Tap in yard at Castlecomer Yarns	J. Keohane	2269		25360 17330	Castlecomer Yarns	Private		1	15	7.5	570	1	< 1	0.01
Spring at Paulstown Castle	02/06/1993		Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle	J. Keohane	2270	KIK46	S 660 570	Gowran/Goresbr./P-town	Public		1	5	7.2	696	0.4	5.7	0.01
Borehole at Rathcash	02/06/1993		Kilkenny Co. Co.	KK02000	Joe Pykes house, Rathcash, Clara.	J. Keohane	2271	KIK55	25870 15510	Rathcash	Group		1	5	7.3	682	0.2	< 1	0.01
Springs at Bausheenmore	02/06/1993		Kilkenny Co. Co.	KK00500	At source (springs at Bausheenmore)	J. Keohane	2272	KIK39	25520 14690		Private		1	5	7.3	814	0.35	0.9	0.01
Spring at Westcourt	02/06/1993		Kilkenny Co. Co.	KK00800	Spring at Earlsland, Westcourt, Callan	J. Keohane	2273	KIK91	S 407 442	Callan	Public		1	5	7.3	718	0.2	0.5	0.01
Borehole at Galmoy	03/06/1993	11:25:00	Kilkenny Co. Co.	KK00200	Leahy's House, Galmoy	P.Mullins	2292	KIK17	23020 17120	Galmoy	Group	10	1	5	7.4	790	0.2	< 1	0.01
Galmoy 35	03/06/1993	11:47:00	Kilkenny Co. Co.		M. Phelan	P.Mullins	2293				Private	10	1	5	7.4	792	0.15	< 1	0.01
Galmoy 37	03/06/1993	12:02:00	Kilkenny Co. Co.		Mr. Tom Maher's House	P.Mullins	2294				Private	11	1	5	7.4	769	0.2		0.01
Galmoy 25	03/06/1993	12:15:00	Kilkenny Co. Co.		Hennessy's at House	P.Mullins	2295				Private	10	1	5	7.3	894	0.25	0.2	0.01
Galmoy 202	03/06/1993	12:55:00	Kilkenny Co. Co.		Phelans	P.Mullins	2296				Private	11	1	5	7.4	755	0.3	< 1	0.01
Borehole at Bawnmore	03/06/1993	16:00:00	Kilkenny Co. Co.	KK00100	Phelan's house, Bawnmore	P.Mullins	2297	KIK50	22580 16610	Bawnmore	Group	12	1	5	7.3	820	0.2	0.14	0.01
Spring at Clomantagh	10/06/1993	11:40:00	Kilkenny Co. Co.	KK00900	Beside Nuenna river, 50m SE of road	P.Mullins+J.Keohane	2395		23520 16320		Private		1	5	7.3	664	0.3		0.01
Spring at Clomantagh	10/06/1993	11:50:00	Kilkenny Co. Co.	KK00900	Beside Nuenna river, 50m SE of road	P.Mullins+J.Keohane	2396		23520 16320		Private		1	5	7.3	677	0.35		0.01
Borehole at Dunmore	10/06/1993	12:28:00	Kilkenny Co. Co.	KK00700	C. Murray,s house, Dunmore.	P.Mullins+J.Keohane	2397		24910 16200	Dunmore	Group		1	5	7.4	676	0.2		0.01
Spring Toberpatrick Urlingford	15/06/1993	10:45:00	Kilkenny Co. Co.	KK01500	In chamber at source	C. Murray	2417	KIK34	23000 16350	Urlingford/Johnstown	Public		1	5	7.2	781	0.3	1.6	0.01
Borehole at Kilmanagh	15/06/1993	12:00:00	Kilkenny Co. Co.	KK01400	In pumphouse	C. Murray	2418	KIK45	23930 15250	Kilmanagh/Ballycuddihy	Group		1	5	7.5	659	0.3		0.01
Borehole at Dunmore S/G	15/06/1993	14:30:00	Kilkenny Co. Co.	KK01000	Canteen at Dunmore Sand & Gravel	C. Murray	2419	KIK53	25000 16020	Dunmore Sand & Gravel	Private		1	5	7.4	643	1.2	0.4	0.01
Borehole at Kilkenny Mart	15/06/1993	15:00:00	Kilkenny Co. Co.	KK01300	Cattle holding shed	C. Murray	2420		25070 15670	Kilkenny Mart	Private		1	5	7.6	691	0.2	0.4	0.01
Borehole at Windgap	01/07/1993		Kilkenny Co. Co.	KK01900	Overflow from borehole	C. Murray	2769		24200 13580	Farm supply	Private		1	5	7.2	382	1.5		0.37
Spring at Paulstown Castle	05/08/1993	15:55:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle		3294	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	11.6	1	5	7.3	680			0.01
Galmoy	08/11/1993	11:15:00	Kilkenny Co. Co.		Leahy's House (A 82)	P.Mullins	4754			Galmoy	Group	8	1	5	7.3	806	0.09		0.01
Galmoy	08/11/1993	11:45:00	Kilkenny Co. Co.		Parochial House	P.Mullins	4755			Galmoy	Private	9	1	5	7.3	725	0.09		0.01
Galmoy	08/11/1993	12:20:00	Kilkenny Co. Co.		Phelans, original (A 35)	P.Mullins	4756			Galmoy	Private	8	1	5	7.1	996	0.21		0.01
Galmoy	08/11/1993	12:40:00	Kilkenny Co. Co.		Brophy's (A 25)	P.Mullins	4757			Galmoy	Private	9	1	5	7.4	849	0.15		
Galmoy	08/11/1993	13:50:00	Kilkenny Co. Co.		Phelans (A 24)	P.Mullins	4758			Galmoy	Private	9	1	5	7.4	874	0.19		< 0.01
Galmoy	08/11/1993	13:55:00	Kilkenny Co. Co.		Hennessy's	P.Mullins	4759			Galmoy	Private	9							
Galmoy	08/11/1993	14:44:00	Kilkenny Co. Co.		Gannons (A 36)	P.Mullins	4760			Galmoy	Private	9	1	5	7.3	864	0.13		< 0.01
Galmoy	08/11/1993	14:52:00	Kilkenny Co. Co.		Maher's (A 37)	P.Mullins	4761			Galmoy	Private	9	1	5	7.3	816	0.14		< 0.01
Borehole at Bawnmore	08/11/1993	15:15:00	Kilkenny Co. Co.	KK00100	Phelan's house, Bawnmore	P.Mullins	4762	KIK50	22580 16610	Bawnmore	Group	9	1	5	7.3	829	0.1		< 0.01
Galmoy	08/11/1993	15:45:00	Kilkenny Co. Co.		Dan Phelan (A 202)	P.Mullins	4763			Galmoy	Private	9	1	5	7.3	739	0.07		< 0.01
Spring Toberpatrick Urlingford	09/11/1993	11:45:00	Kilkenny Co. Co.	KK01500	In chamber at source	P. Mullins	4776	KIK34	23000 16350	Urlingford/Johnstown	Public	10	2	< 5	7.3	808	0.22		0.01
Borehole at Castlecomer Yarns	09/11/1993	12:35:00	Kilkenny Co. Co.	KK00300	Tap in yard at Castlecomer Yarns	P. Mullins	4777		25360 17330	Castlecomer Yarns	Private	10	2	5	7.6	568	3.5		0.01
Spring at Paulstown Castle	09/11/1993	14:40:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle	P. Mullins	4778	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	11	2	< 5	7.4	648	0.24		0.01
Borehole at Clara	09/11/1993	15:15:00	Kilkenny Co. Co.	KK00400	At pumphouse	P. Mullins	4779	KIK41	25770 15530	Clara	Group	10	1	< 5	7.4	677	0.17	67.3	0.01
Spring at Westcourt	09/11/1993	16:00:00	Kilkenny Co. Co.	KK00800	Spring at Earlsland, Westcourt, Callan	P. Mullins	4780	KIK91	S 407 442	Callan	Public	10	1	< 5	7.3	722	0.21		0.01
Borehole at Dunmore	10/11/1993	10:30:00	Kilkenny Co. Co.	KK00700	C. Murray,s house, Dunmore.	C.Murray	4796		24910 16200	Dunmore	Group	8.4	1	5	7.5	702	0.1		0.01
Borehole at Dunmore S/G	10/11/1993	10:55:00	Kilkenny Co. Co.	KK01000	Canteen at Dunmore Sand & Gravel	C.Murray	4797	KIK53	25000 16020	Dunmore Sand & Gravel	Private	8.1	1	< 5	7.6	635	0.7		0.01
Borehole at Kilkenny Mart	10/11/1993	11:15:00	Kilkenny Co. Co.	KK01300	Cattle holding shed	C.Murray	4798		25070 15670	Kilkenny Mart	Private	4.9	2	< 5	8	690	0.14		0.01
Borehole at Kilmanagh	10/11/1993	12:22:00	Kilkenny Co. Co.	KK01400	In pumphouse	C.Murray	4799	KIK45	23930 15250	Kilmanagh/Ballycuddihy	Group	10	2	< 5	7.7	644	0.33		0.01
Springs at Bausheenmore	10/11/1993	14:30:00	Kilkenny Co. Co.	KK00500	At source (springs at Bausheenmore)	C.Murray	4800	KIK39	25520 14690		Private	10.2	1	< 5	7.4	812	0.23		0.01
Borehole No.9, Thomastown	10/11/1993	15:10:00	Kilkenny Co. Co.	KK01600	At pumphouse	C.Murray	4801	KIK32	25890 14160	Thomastown	Public	11	2	< 5	7.4	798	0.15		0.01
Borehole at Windgap	10/11/1993	15:50:00	Kilkenny Co. Co.	KK01900	Overflow from borehole	C.Murray	4802		24200 13580	Farm supply	Private	10.8	1	< 5	7.5	375	0.32		0.01
Borehole at Avonmore Dairy	11/11/1993	11:30:00	Kilkenny Co. Co.	KK01200	Holding tank on roof	C.Murray	4803			Avonmore Kilkenny City	Private		2	5	7.8	621	0.11		0.01
Rathcash, Clifden,Co. Kilkenny	08/12/1993	09:45:00	Kilkenny Co. Co.		Joe Pykes	J.Keohane	5212			Rathcash	Group		1	5	7.4	711	0.17		< 0.01
Spring at Paulstown Castle	10/11/1994	11:25:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle		5072	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	9.8	1	5	7.1	680			0.08
Graigue, Callan.	12/01/1995		Kilkenny Co. Co.		James Robinsons well	James Robinson	212			Proposed Supply for James Robinson	Private			< 5	7.6	528	14		
Spring at Paulstown Castle	23/01/1995	15:45:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle		255	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	9.5		5		680			0.01
Spring at Paulstown Castle	16/10/1995	15:23:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle		4410	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	11.8	1	5	7.3	595			< 0.01
Borehole at Castlecomer Yarns	08/01/1996	11:10:00	Kilkenny Co. Co.	KK00300	Tap in yard at Castlecomer Yarns	C. Murray	74		25360 17330	Castlecomer Yarns	Private	11.6	2	20	7.4	583	5.5	2	< 0.01
Borehole at Dunmore	08/01/1996	11:30:00	Kilkenny Co. Co.	KK00700	C. Murray,s house, Dunmore.	C. Murray	75		24910 16200	Dunmore	Group	8	1	5	7.3	615	0.2	3.4	< 0.01
Borehole at Dunmore S/G	08/01/1996	12:00:00	Kilkenny Co. Co.	KK01000	Canteen at Dunmore Sand & Gravel	C. Murray	76	KIK53	25000 16020	Dunmore Sand & Gravel	Private	10.1	2	5	7.7	627	1.6	2.2	< 0.01
Borehole at Kilkenny Mart	08/01/1996	12:15:00	Kilkenny Co. Co.	KK01300	Cattle holding shed	C. Murray	77		25070 15670	Kilkenny Mart	Private	9.5	1	5	7.9	690	0.2	2.4	< 0.01
Borehole at Clara	08/01/1996	12:55:00	Kilkenny Co. Co.	KK00400	At pumphouse	C. Murray	78	KIK41	25770 15530	Clara	Group	11	1	5	7.3	696	0.2	4.5	< 0.01
Borehole at Rathcash	08/01/1996	13:10:00	Kilkenny Co. Co.	KK02000	Joe Pykes house, Rathcash, Clara.	C. Murray	79	KIK55	25870 15510	Rathcash	Group	8.7	2	5	7.4	708	0.1		< 0.01
Spring at Paulstown Castle	08/01/1996	14:40:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle	C. Murray	80	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	10.6	1	5	7.2	623		5.5	< 0.01
Spring at Clomantagh	09/01/1996	10:40:00	Kilkenny Co. Co.	KK00900	Beside Nuenna river, 50m SE of road	C. Murray	89		23520 16320		Private	9.8	1	60	7.3	467	38		0.026
Spring Toberpatrick Urlingford	09/01/1996	11:05:00	Kilkenny Co. Co.	KK01500	In chamber at source	C. Murray	90	KIK34	23000 16350	Urlingford/Johnstown	Public	9.7	1	5	7.3	712	1.7	8	< 0.01
Borehole at Bawnmore	09/01/1996	11:30:00	Kilkenny Co. Co.	KK00100	Phelan's house, Bawnmore	C. Murray	91	KIK50	22580 16610	Bawnmore	Group	8.5	1	5	7.2	835	0.1	3	< 0.01

EPA Regional Water Laboratory, Kilkenny. Monitoring Data for County Kilkenny Groundwaters 1993 to 1999.

Source	Sampling Date	Sampling Time	o-Phosphate mg/l P	Nitrate mg/l N	Nitrite mg/l N	Chloride mg/l Cl	Ca Hardness mg/l CaCO3	Alkalinity mg/l CaCO3	TCS	Total Coliforms per 100 ml	FCS	Fecal Coliforms per 100 ml	Sulphate mg/l SO4	Dry Residue mg/l	Sus_ Solids mg/l	Magnesium mg/l Mg	Total Hardness mg/l CaCO3	Sodium mg/l Na	Potassium mg/l K	Aluminium mg/l Al	Iron mg/l Fe	Manganese mg/l Mn	Copper mg/l Cu	Zinc mg/l Zn	Chromium mg/l Cr	Lead mg/l Pb
Spring at Paulstown Castle	29/04/1992	11:38:00	0.04	6		29				78		44	2		5						< 0.05	< 0.02	< 0.03	< 0.01		
Spring at Paulstown Castle	01/07/1992	15:55:00	0.01	5		28				13		999			5						< 0.04	< 0.02	< 0.03	0.01		
Spring at Paulstown Castle	20/08/1992	15:15:00	0.02	4.3		28									5											
Spring at Paulstown Castle	18/11/1992	13:29:00	0.03	4.6		28				340		280			5											
Spring at Paulstown Castle	10/03/1993	16:00:00	0.02	6.8		38				20		5			5						0.011	0.009	< 0.001	0.015		
Borehole at Castlecomer Yarns	02/06/1993		0.05	0.1	0.006	20				999		999	7			23.8	242	33.1	1.4		9.2	0.797		0.017	< 0.001	< 0.001
Spring at Paulstown Castle	02/06/1993		0.06	8.2	0.005	30		305		999		999	< 1			12.3	355	9.1	3.2		0.051	0.006	< 0.001	< 0.005	< 0.001	< 0.001
Borehole at Rathcash	02/06/1993		0.08	7.2	0.001	24		317		15		1				22.3	359	8.4	1.5		0.033	0.004	< 0.001	0.02	< 0.001	< 0.001
Springs at Bausheenmore	02/06/1993		0.08	6.1	0.006	41		401		999		999	< 1			33.3	425	9.3	4.3		0.077	0.017	< 0.001	0.018	< 0.001	< 0.001
Spring at Westcourt	02/06/1993		0.05	3.8	0.002	24		370		64		21	< 1			27.8	383	9.8	1.2		0.012	< 0.005	< 0.001	< 0.005	< 0.001	< 0.001
Borehole at Galmoy	03/06/1993	11:25:00	0.01	9.4	0.002	29		350		999		999	4			83.2	399	17.1	2.7	0.027	0.026	< 0.005	0.063	0.036	< 0.001	0.011
Galmoy 35	03/06/1993	11:47:00	0.01	10	0.003	28		350		999		999	9			96.8	393	22.8	6.5	0.006	0.022	< 0.005	0.079	0.021	< 0.001	0.001
Galmoy 37	03/06/1993	12:02:00	0.01	5.7	0.002	21		379		999		999	3			84.8	393	20.2	2.2	0.02	0.015	< 0.005	0.111	0.05	< 0.001	0.005
Galmoy 25	03/06/1993	12:15:00	0.007	12	0.003	22		383		275		28	25			80	433	37.9	11.7	0.009	0.036	< 0.005	0.439	0.278	< 0.001	0.016
Galmoy 202	03/06/1993	12:55:00	0.005	5.7	0.003	22		359		20		18	7			58.8	375	26.2	10	0.019	0.021	0.012	0.151	0.027	< 0.001	< 0.001
Borehole at Bawnmore	03/06/1993	16:00:00	0.01	6	0.002	26		398		1		1	8			102	419	21.8	5.4	0.005	0.015	< 0.005	0.068	0.03	< 0.001	< 0.001
Spring at Clomantagh	10/06/1993	11:40:00	0.007	6.1	0.004	22		297		230			< 1			14.1	359	7.5	1.6		0.032	0.009	< 0.001	< 0.005	< 0.001	0.003
Spring at Clomantagh	10/06/1993	11:50:00	0.02	6.5	0.003	23		318		162			< 1			14.3	369	7.6	1.6		0.037	0.008	0.001	< 0.005	< 0.001	< 0.001
Borehole at Dunmore	10/06/1993	12:28:00	0.004	14	0.001	27		251		999		999	2			7.5	354	8.3	0.8		0.031	< 0.005	0.009	< 0.005	< 0.001	< 0.001
Spring Toberpatrick Urlingford	15/06/1993	10:45:00	0.01	7.6	0.005	27		383		34		15	8			22.2	400	9.1	4.7				0.004			< 0.001
Borehole at Kilmanagh	15/06/1993	12:00:00	0.01	4.5	0.001	19		328		175		116	7			18.9	345	8.5	1.1			0.009				< 0.001
Borehole at Dunmore S/G	15/06/1993	14:30:00	0.01	0.2	0.006	18		313		999		999	24			19.3	333	11.3	1				0.039			< 0.001
Borehole at Kilkenny Mar	15/06/1993	15:00:00	0.01	6.3	0.002	18		296		43		20	32			20.8	355	11	1.5				0.03			< 0.001
Borehole at Windgap	01/07/1993		0.02	1.6	0.001	14		137		999		999	< 1		Not Vis.	20	177	6.9	1.1		0.17	0.014		0.01		
Spring at Paulstown Castle	05/08/1993	15:55:00	0.02	6		27				85					5						0.019	< 0.005		0.025		
Galmoy	08/11/1993	11:15:00	< 0.01	10.2		34	309	389					8			30.6	435	8.6	1.1		0.041	< 0.005	< 0.001	0.031	0.0005	< 0.001
Galmoy	08/11/1993	11:45:00	< 0.01	4.4		20	247	378		999		999	11			35.9	395	11.5	1.7		0.03	< 0.005	< 0.001	0.021	0.0004	< 0.001
Galmoy	08/11/1993	12:20:00	< 0.01	5.3		59	384	470		6		999	10			27.4	497	18.6	10.3		0.036	< 0.005	0.006	0.034	0.0004	0.003
Galmoy	08/11/1993	12:40:00	0.003	7.2	0.01	24	300	437		24		999	14			38.1	457	12.7	1.8		0.055	0.002	< 0.001	0.062	0.0005	< 0.001
Galmoy	08/11/1993	13:50:00	0.004	15.1		34.6	288	387		999		999	14			38.7	448	13.4	9		0.032	< 0.005	0.014	0.178	0.0005	< 0.001
Galmoy	08/11/1993	13:55:00								50		7														
Galmoy	08/11/1993	14:44:00	0.008	12.7		28.7	342	415		100		2	8			24.5	443	13.9	9.1		0.044	0.016	< 0.001	0.681	0.0003	< 0.001
Galmoy	08/11/1993	14:52:00	0.007	8.8		26	309	416		999		999	7			32.4	443	8.6	1.4		0.051	< 0.005	0.002	0.026	0.0004	< 0.001
Borehole at Bawnmore	08/11/1993	15:15:00	< 0.01	6		27.6	315	434		1		1	9			33.6	454	9	2.2		0.025	< 0.005	0.005	0.015	0.0004	< 0.001
Galmoy	08/11/1993	15:45:00	0.006	6.4		18.3	305	389		999		999	6			22.6	398	8.7	2.7		0.038	< 0.005	0.008	0.017	0.0004	< 0.001
Spring Toberpatrick Urlingford	09/11/1993	11:45:00	0.01	8.5		27		395		100		21	8				403									
Borehole at Castlecomer Yarns	09/11/1993	12:35:00	0.01	0.2		19		278		1		999	12				229									
Spring at Paulstown Castle	09/11/1993	14:40:00	0.01	5.8		26		296		33		18	8				314									
Borehole at Clara	09/11/1993	15:15:00	0.01	6.8		21		325		167		2	8				340									
Spring at Westcourt	09/11/1993	16:00:00	0.01	4.3		24		370		4		3	5				368									
Borehole at Dunmore	10/11/1993	10:30:00	0.01	13.6		22		296		999		999	< 1			7.3	320	9.2	0.8		0.041	< 0.005	0.001	0.035		< 0.001
Borehole at Dunmore S/G	10/11/1993	10:55:00	0.01	0.1		17		297		84		27	12			17.5	300	12	0.9		0.106	0.229	0.003	0.043		< 0.001
Borehole at Kilkenny Mar	10/11/1993	11:15:00	0.01	6.6		18		307		8		6	19			19	324	12	1.3		0.087	0.013	0.003	0.487		< 0.001
Borehole at Kilmanagh	10/11/1993	12:22:00	0.01	5		19		293		8		2	< 1			16.2	300	9.3	0.9		< 0.005	0.001	0.001	0.06		< 0.001
Springs at Bausheenmore	10/11/1993	14:30:00	0.01	6.5		30				100		100	< 1			34	381	10.1	3.5		0.009	0.001	< 0.001	0.052		< 0.001
Borehole No.9, Thomastown	10/11/1993	15:10:00	0.02	7.3		41				999		999	2			25.4	350	18	3.5		0.017	0.002	0.002	0.565		0.001
Borehole at Windgap	10/11/1993	15:50:00	0.02	1.7		12		173		9		5	2			17	173	8	1		0.016	0.001	< 0.001	0.075		< 0.001
Borehole at Avonmore Dairy	11/11/1993	11:30:00	0.3	6.5		31		230		999		999	15			10.6	265	16.9	6.7		0.04	0.003	0.002	0.178		< 0.001
Rathcash, Clifden,Co. Kilkenny	08/12/1993	09:45:00	0.011	6	0.001	23		334		999		999	8			27.8	358	8.5	1.2		0.01	0.006	0.004	0.084		0.003
Spring at Paulstown Castle	10/11/1994	11:25:00	< 0.01	5.3		29				420		170			5											
Graigue, Callan.	12/01/1995							244								27.4	238	14.1	0.7		1.06	0.09	0.01	0.166		
Spring at Paulstown Castle	23/01/1995	15:45:00	0.01	7		25				500		290			5											
Spring at Paulstown Castle	16/10/1995	15:23:00	0.016	4		22				150		72			5											
Borehole at Castlecomer Yarns	08/01/1996	11:10:00		0.05	0.006	18.5		304		999		999	22			20.2	321	18.6	0.9		0.116	0.434		< 0.02		
Borehole at Dunmore	08/01/1996	11:30:00	< 0.001	9.5	< 0.003	20.9		257		999		999	20			6.1	338	7.7	0.8		< 0.06	< 0.02		< 0.02		
Borehole at Dunmore S/G	08/01/1996	12:00:00	< 0.001	< 0.01	0.004	19.3		311				999	36			17.5	355	11.2	0.9		< 0.06	0.15		< 0.02		
Borehole at Kilkenny Mar	08/01/1996	12:15:00	< 0.001	5.9	< 0.003	19.7		312		5		999	40			18.3	389	10.2	1.3		< 0.06	< 0.02		< 0.02		
Borehole at Clara	08/01/1996	12:55:00	0.01	6.9	< 0.003	22.3		340		65		2	18			19.9	409	8.1	1.4		< 0.06	< 0.02		< 0.02		
Borehole at Rathcash	08/01/1996	13:10:00	0.001	5.1	< 0.003	23.6		360		999		999	18			25	427	7.6	1.1		< 0.06	< 0.02		0.024		
Spring at Paulstown Castle	08/01/1996	14:40:00	< 0.01	8	< 0.003			259	>	80	>	60				7.9	333	8	2.7		0.082	< 0.02		< 0.02		
Spring at Clomantagh	09/01/1996	10:40:00	0.06	5.8	0.032	15.6		195	>	200	>	100	7		Visible	4.2		6.5	1		0.93	0.14		0.115		
Spring Toberpatrick Urlingford	09/01/1996	11:05:00	0.037	11.1	< 0.003	23.1		317	>=	32		3	15			18.9		8.5	4.2		< 0.06	< 0.02		0.077		
Borehole at Bawnmore	09/01/1996	11:30:00	0.013	5.1	< 0.003	23.6		443		999		999	18			37.9		8.6	2.3		< 0.06	< 0.02		0.039		

EPA Regional Water Laboratory, Kilkenny. Monitoring Data for County Kilkenny Groundwaters 1993 to 1999.

Source	Sampling Date	Sampling Time	Cadmium mg/l Cd	Mercury mg/l Hg	Nickel mg/l Ni	Fluoride mg/l F	OMCTSiloxane µg/l	Comments1	Comments2	Comments3
Spring at Paulstown Castle	29/04/1992	11:38:00								
Spring at Paulstown Castle	01/07/1992	15:55:00								
Spring at Paulstown Castle	20/08/1992	15:15:00								
Spring at Paulstown Castle	18/11/1992	13:29:00								
Spring at Paulstown Castle	10/03/1993	16:00:00								
Borehole at Castlecomer Yarns	02/06/1993		< 0.0001					Copy to Castlecomer Yarns Ltd.		
Spring at Paulstown Castle	02/06/1993		< 0.0001							
Borehole at Rathcash	02/06/1993		< 0.0001					Copy to Rathcash G.W.S.		
Springs at Bausheenmore	02/06/1993		< 0.0001							
Spring at Westcourt	02/06/1993		< 0.0001							
Borehole at Galmoy	03/06/1993	11:25:00	< 0.0001		0.007					
Galmoy 35	03/06/1993	11:47:00	0.0001		0.001					
Galmoy 37	03/06/1993	12:02:00	0.0001		< 0.001					
Galmoy 25	03/06/1993	12:15:00	0.0001		0.005					
Galmoy 202	03/06/1993	12:55:00	0.0001		< 0.001					
Borehole at Bawnmore	03/06/1993	16:00:00	0.0001		< 0.001					
Spring at Clomantagh	10/06/1993	11:40:00	< 0.0001							
Spring at Clomantagh	10/06/1993	11:50:00	< 0.0001							
Borehole at Dunmore	10/06/1993	12:28:00	< 0.0001							
Spring Toberpatrick Urlingford	15/06/1993	10:45:00	< 0.0001							
Borehole at Kilmanagh	15/06/1993	12:00:00	< 0.0001							
Borehole at Dunmore S/G	15/06/1993	14:30:00	< 0.0001							
Borehole at Kilkenny Mar	15/06/1993	15:00:00	< 0.0001							
Borehole at Windgap	01/07/1993									
Spring at Paulstown Castle	05/08/1993	15:55:00								
Galmoy	08/11/1993	11:15:00	< 0.0001		< 0.001					
Galmoy	08/11/1993	11:45:00	< 0.0001		< 0.001					
Galmoy	08/11/1993	12:20:00	< 0.0001		< 0.001					
Galmoy	08/11/1993	12:40:00	< 0.0001		< 0.001					
Galmoy	08/11/1993	13:50:00	< 0.0001		< 0.001					
Galmoy	08/11/1993	13:55:00						Taken after well was pumped for approximately 1 1/2 hours.		
Galmoy	08/11/1993	14:44:00	< 0.0001		< 0.001					
Galmoy	08/11/1993	14:52:00	< 0.0001		< 0.001					
Borehole at Bawnmore	08/11/1993	15:15:00	< 0.0001		< 0.001					
Galmoy	08/11/1993	15:45:00	< 0.0001		< 0.001					
Spring Toberpatrick Urlingford	09/11/1993	11:45:00								
Borehole at Castlecomer Yarns	09/11/1993	12:35:00								
Spring at Paulstown Castle	09/11/1993	14:40:00								
Borehole at Clara	09/11/1993	15:15:00						167 Total Coliforms, 5 obvious coliform colonies, 162 probably	coliform colonies.	
Spring at Westcourt	09/11/1993	16:00:00								
Borehole at Dunmore	10/11/1993	10:30:00	< 0.0001							
Borehole at Dunmore S/G	10/11/1993	10:55:00	< 0.0001							
Borehole at Kilkenny Mar	10/11/1993	11:15:00	< 0.0001							
Borehole at Kilmanagh	10/11/1993	12:22:00	< 0.0001					Copy to Mr. Liam Delaney.		
Springs at Bausheenmore	10/11/1993	14:30:00	< 0.0001							
Borehole No.9, Thomastown	10/11/1993	15:10:00	< 0.0001							
Borehole at Windgap	10/11/1993	15:50:00	< 0.0001							
Borehole at Avonmore Dairy	11/11/1993	11:30:00	< 0.0001					Chlorinated sample		
Rathcash, Clifden,Co. Kilkenny	08/12/1993	09:45:00	< 0.0001							
Spring at Paulstown Castle	10/11/1994	11:25:00								
Graigue, Callan.	12/01/1995		< 0.0003					High iron and elevated manganese levels leading to high turbidity.		
Spring at Paulstown Castle	23/01/1995	15:45:00						Interference < mixed background colonies (non< coliform) on Total	Coliform plate.	
Spring at Paulstown Castle	16/10/1995	15:23:00						Interference from background colonies on Total Coliform plate.		
Borehole at Castlecomer Yarns	08/01/1996	11:10:00								
Borehole at Dunmore	08/01/1996	11:30:00								
Borehole at Dunmore S/G	08/01/1996	12:00:00						Total Coliform plate overgrown with non< coliforms.		
Borehole at Kilkenny Mar	08/01/1996	12:15:00								
Borehole at Clara	08/01/1996	12:55:00						Copy to: Paddy Coogan, Clifden, Clara, Co. Kilkenny		
Borehole at Rathcash	08/01/1996	13:10:00						Copy to: Mr. Joe Pyke, Ratcash, Clifden, Co. Kilkenny.		
Spring at Paulstown Castle	08/01/1996	14:40:00								
Spring at Clomantagh	09/01/1996	10:40:00							Spring in farmyard, sample taken at surface.	
Spring Toberpatrick Urlingford	09/01/1996	11:05:00								
Borehole at Bawnmore	09/01/1996	11:30:00								

EPA Regional Water Laboratory, Kilkenny. Monitoring Data for County Kilkenny Groundwaters 1993 to 1999.

Source	Sampling Date	Sampling Time	To	Ref No	Sampling Location	Taken By	Lab No	EPARef	Stn Grid Ref	Water Supply	Public/Group/Private	Temperature	Odour 1/2/3	Colour Hazen	pH	Conductivity µS/cm	Turbidity NTU	TOC mg/l C	Ammonia mg/l N
Borehole at Galmoy	09/01/1996	12:40:00	Kilkenny Co. Co.	KK00200	Leahy's House, Galmoy	C. Murray	92	KIK17	23020 17120	Galmoy	Group	8.6	1	5	7.3	779	0.1	1.8	< 0.01
Borehole at Kilmanagh	09/01/1996	14:20:00	Kilkenny Co. Co.	KK01400	In pumphouse	C. Murray	93	KIK45	23930 15250	Kilmanagh/Ballycuddihy	Group	8.2	1	5	7.6	645	0.1	2.3	0.021
Spring at Westcourt	09/01/1996	15:10:00	Kilkenny Co. Co.	KK00800	Spring at Earlsland, Westcourt, Callan	C. Murray	94	KIK91	S 407 442	Callan	Public	11.1	1	5	7.3	704	0.1	2.9	< 0.01
Borehole at Windgap	09/01/1996	15:40:00	Kilkenny Co. Co.	KK01900	Overflow from borehole	C. Murray	95		24200 13580	Farm supply	Private	11	1	5	7.4	380	0.2	< 0.12	0.023
Spring at Carrigeen,	15/01/1996	13:00:00	Kilkenny Co. Co.		Keoghans Field, Threecastles	J. Jennings	135						2	15	8	1045			0.03
Belview	27/02/1996	14:15:00	Kilkenny County Council		Well No.2 for proposed new water supply	Brian Connor	763			Belview proposed				5	6.8	351			< 0.01
Belview	29/02/1996	11:45:00	Kilkenny County Council		Well No.2 for proposed new water supply	Brian Connor	822			Belview proposed			1	5	6.7	359			< 0.01
Belview No. 2	07/03/1996	16:00:00	Kilkenny Co Co		Belview Proposed water supply Well No. 2	Brian Connor	973						1	5	6.7	365			
Belview No. 2	14/03/1996	11:00:00	Kilkenny Co Co		Belview Proposed water supply Well No. 2	Brian Connor	1050						1	5	6.7	357			< 0.01
Belview No. 2	23/03/1996	14:10:00	Kilkenny Co Co		Belview Proposed water supply Well No. 2	Brian Connor	1157						1	5	6.4	290			< 0.01
Belview No. 1	25/03/1996	15:00:00	Kilkenny Co Co		Belview Proposed water supply Well No. 1	Brian Connor	1130						1	5	6.5	290		0.67	< 0.01
Belview No. 1	27/03/1996	13:00:00	Kilkenny Co Co		Belview Proposed water supply Well No. 1	Brian Connor	1173						1	5	6.4	289			< 0.01
Dunmore Wells	02/07/1996	10:10:00	Kilkenny Co. Co.		Readymix	C. Murray	2536						1	5	7.5	651		0.15	< 0.01
Dunmore Wells	02/07/1996	10:15:00	Kilkenny Co. Co.		Leahy's	C. Murray	2537						1	10	8.3	413		< 0.12	< 0.01
Dunmore Wells	02/07/1996	10:15:00	Kilkenny Co. Co.		O'Dwyers	C. Murray	2538						2	5	7.5	513		< 0.12	0.03
Dunmore Wells	02/07/1996	10:35:00	Kilkenny Co. Co.		Tom Langtons	C. Murray	2539						1	10	7.9	350		< 0.12	0.02
Dunmore Wells	02/07/1996	10:55:00	Kilkenny Co. Co.		McDermotts	C. Murray	2540						1	10	7.4	599		0.69	< 0.01
Dunmore Wells	02/07/1996	11:10:00	Kilkenny Co. Co.		Nolans	C. Murray	2541						1	5	7.3	841		0.61	< 0.01
Dunmore Wells	02/07/1996	11:30:00	Kilkenny Co. Co.		O'Neill's	C. Murray	2542						1	10	7.4	700		0.15	< 0.01
Dunmore Wells	02/07/1996	11:45:00	Kilkenny Co. Co.		Fitzpatrick's	C. Murray	2543						1	5	7.4	737		0.53	< 0.01
Dunmore Wells	02/07/1996	12:10:00	Kilkenny Co. Co.		Canteen in Landfdill Site	C. Murray	2544						1	15	7.4	563		2.07	0.05
Dunmore Wells	02/07/1996	12:35:00	Kilkenny Co. Co.		Holohan's	C. Murray	2545						2	15	7.4	633		1.94	0.42
Dunmore Wells	02/07/1996	12:45:00	Kilkenny Co. Co.		Murphy's/Stacks	C. Murray	2546						2	50	7.5	689		< 0.12	0.013
Bellview	02/10/1996	11:10:00	Kilkenny Co. Co.		Well No. 3.	Brian Connor	3853						1	5	6.6	554	0.26		< 0.01
Bellview	03/10/1996	10:30:00	Kilkenny Co. Co.		Well No. 3.	Brian Connor	3873						1	5	6.4	565	0.2		
Bellview Water Supply	08/10/1996	10:30:00	Kilkenny Co. Co.		Well No. 3.	B. O'Connor	3971						1	5	6.5	551			< 0.01
Spring at Paulstown Castle	09/01/1997	12:17:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle	P. Mullins	106	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	9.3	1	< 5	7.3	613	0.23	1.9	< 0.01
Thomastown	10/01/1997	10:17:00	Kilkenny Co. Co.		Borehole No. 5	P. Mullins	111		S 589 411			9.6	1	< 5	7.1	439	0.09	1.3	< 0.01
Borehole No.9, Thomastown	10/01/1997	10:05:00	Kilkenny Co. Co.	KK01600	At pumphouse	P. Mullins	112	KIK32	25890 14160	Thomastown	Public	9.4	1	< 5	7.3	721	0.11	1.5	
Borehole at Dunmore	13/01/1997		Kilkenny Co. Co.	KK00700	C. Murray,s house, Dunmore.	C. Murray	216		24910 16200	Dunmore	Group								
Spring at Paulstown Castle	17/02/1997	11:30:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle	C. Murray	726	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	10.3	1	< 5	7.3	607		0.6	< 0.1
Springs at Bausheenmore	17/02/1997	12:30:00	Kilkenny Co. Co.	KK00500	At source (springs at Bausheenmore)	C. Murray	727	KIK39	25520 14690		Private	10.5	1	< 5	7.3	767		< 1	< 0.1
Spring at Westcourt	17/02/1997	14:05:00	Kilkenny Co. Co.	KK00800	Spring at Earlsland, Westcourt, Callan	C. Murray	728	KIK91	S 407 442	Callan	Public	11.3	1	< 5	7.3	702		< 1	< 0.1
Dunmore	09/05/1997		Kilkenny Co. Co.		Doyle's	M. Daly	1936				Private		1					0.53	2
Dunmore	09/05/1997		Kilkenny Co. Co.		Holohan's	M. Daly	1937				Private		3					1.8	0.5
Dunmore	09/05/1997		Kilkenny Co. Co.		No. 8 Stack	M. Daly	1938				Private		3					0.1	< 0.01
Dunmore	09/05/1997		Kilkenny Co. Co.		Well in landfill site	M. Daly	1939				Private		2						17.6
Dunmore	09/05/1997		Kilkenny Co. Co.		Unused Borehole, Doyle's Field	M. Daly	1940				Private		2					5.4	12.1
Dunmore	12/05/1997	10:45:00	Kilkenny Co. Co.		Readymix	C. Murray	1944					10.2	1	5	7.7	631	0.65	0.22	1.5
Dunmore	12/05/1997	10:55:00	Kilkenny Co. Co.		O'Dwyers	C. Murray	1945					10.8	2	15	7.6	473	3.8	0.09	0.05
Dunmore	12/05/1997	11:05:00	Kilkenny Co. Co.		Langtons	C. Murray	1946					9.7	1	15	8	352	12	0.08	0.04
Dunmore	12/05/1997	11:15:00	Kilkenny Co. Co.		Bergin's	C. Murray	1947					9.8	2	5	7.4	656	0.42	0.33	< 0.01
Dunmore	12/05/1997	11:25:00	Kilkenny Co. Co.		McDermott's	C. Murray	1948					10.8	2	5	7.3	615		0.39	< 0.01
Dunmore	12/05/1997	12:00:00	Kilkenny Co. Co.		Nolans	C. Murray	1949					10.8	2	5	7.3	794	0.19	0.64	< 0.01
Dunmore	12/05/1997	12:15:00	Kilkenny Co. Co.		O'Neill's	C. Murray	1950					10.9	1	5	7.4	700	0.42	0.09	< 0.01
Dunmore	12/05/1997	12:30:00	Kilkenny Co. Co.		Fitzpatricks	C. Murray	1951					10.4	2	5	7.3	736	0.21	0.43	< 0.01
Dunmore	12/05/1997	15:30:00	Kilkenny Co. Co.		Doyle's	C. Murray	1952					10.7	2	5	7.2	816	0.11	0.67	1.41
Dunmore	12/05/1997	15:45:00	Kilkenny Co. Co.		Holohan's	C. Murray	1953					12	2		7.3	640	69	1.88	0.33
Dunmore	12/05/1997	15:55:00	Kilkenny Co. Co.		Stacks/Murphys	C. Murray	1954					11.5	3		7.7	665	16	0.26	< 0.01
Dunmore	12/05/1997	14:35:00	Kilkenny Co. Co.		Canteen at landfill site.	C. Murray	1955			Canteen at landfill	private	11.5	3		7.9	1.8	100		110
Dunmore	12/05/1997	14:50:00	Kilkenny Co. Co.		New Bore at landfill site.	C. Murray	1956					12.4	2		7.2	994	6.1	7.2	0.5
Dunmore	12/05/1997	15:10:00	Kilkenny Co. Co.		Roches Pit, new cell	C. Murray	1957					10.8	2	5	7.3	653	1.2	0.64	< 0.01

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Source	Sampling Date	Sampling Time	o-Phosphate mg/l P	Nitrate mg/l N	Nitrite mg/l N	Chloride mg/l Cl	Ca Hardness mg/l CaCO3	Alkalinity mg/l CaCO3	TCS	Total Coliforms per 100 ml	FCS	Fecal Coliforms per 100 ml	Sulphate mg/l SO4	Dry Residue mg/l	Sus_ Solids mg/l	Magnesium mg/l Mg	Total Hardness mg/l CaCO3	Sodium mg/l Na	Potassium mg/l K	Aluminium mg/l Al	Iron mg/l Fe	Manganese mg/l Mn	Copper mg/l Cu	Zinc mg/l Zn	Chromium mg/l Cr	Lead mg/l Pb
Borehole at Galmoy	09/01/1996	12:40:00	0.002	9.6	< 0.003	27.7		364		999		999	20			31.8		7.9	0.8		< 0.06	< 0.02		0.061		
Borehole at Kilmanagh	09/01/1996	14:20:00	0.099	3.5	< 0.003	20.4		327	>=	15	>=	2	11			18.4		9.1	0.9		< 0.06	< 0.02		0.035		
Spring at Westcourt	09/01/1996	15:10:00	0.02	3.6	< 0.003	24.1		365		52		64	15			29.2		9.5	0.9		< 0.06	< 0.02		0.028		
Borehole at Windgap	09/01/1996	15:40:00	0.122	1.8	< 0.003	16		164		999		999	4			19.2		6.9	1		< 0.06	< 0.02		0.03		
Spring at Carrigeen,	15/01/1996	13:00:00	0.1	36.2	0.014	44		183					25													
Belview	27/02/1996	14:15:00	< 0.02	3.7	< 0.004	28		97		999		999					103									
Belview	29/02/1996	11:45:00	< 0.02	4.1	< 0.004	32.7		81		999		999					83									
Belview No. 2	07/03/1996	16:00:00						114		1		999					116				< 0.06	< 0.02		0.08		
Belview No. 2	14/03/1996	11:00:00	< 0.02	4.5	< 0.004	28		97		14		9									< 0.06	< 0.02		0.026		
Belview No. 2	23/03/1996	14:10:00	< 0.02	6.7	< 0.004	26		77		2		999														
Belview No. 1	25/03/1996	15:00:00	< 0.02	6.8	0.004	28		49		999		999									< 0.06	< 0.02		0.314		
Belview No. 1	27/03/1996	13:00:00	< 0.02	6.7	< 0.004	28		64		1		999														
Dunmore Wells	02/07/1996	10:10:00	< 0.02	< 0.1	0.004	20		317		999		999	29													
Dunmore Wells	02/07/1996	10:15:00	< 0.02	1.5	0.007	16		191	>=	3		999	11													
Dunmore Wells	02/07/1996	10:15:00	< 0.02	< 0.1	0.009	18				999		999	14													
Dunmore Wells	02/07/1996	10:35:00	< 0.02	< 0.1	0.003	13		164	>	80		999	4													
Dunmore Wells	02/07/1996	10:55:00	< 0.02	6.5	0.001	19		283	>=	3		6	15													
Dunmore Wells	02/07/1996	11:10:00	0.22	12	0.002	37		352	>	80		15	25													
Dunmore Wells	02/07/1996	11:30:00	< 0.02	7.4	0.002	28		323		999		999	15													
Dunmore Wells	02/07/1996	11:45:00	0.14	9.2	0.002	28		330	>	80	>	60	16													
Dunmore Wells	02/07/1996	12:10:00	0.03	2.6	0.041	22		250	>	80		6	25													
Dunmore Wells	02/07/1996	12:35:00	0.09	< 0.1	0.015	19		322		2		999	20													
Dunmore Wells	02/07/1996	12:45:00	< 0.02	< 0.1	0.005	21		323	>=	68		999	30													
Bellview	02/10/1996	11:10:00	< 0.02	19.3	0.003	43				999		999				21.3		22.5	2.6		0.12	0.033		0.184		
Bellview	03/10/1996	10:30:00								1		999				21.3		23.3	2.8		0.087	0.034	0.112			
Bellview Water Supply	08/10/1996	10:30:00	0.01	22	0.004	41		68	>=	2		999				21.3		22.8	2.8		0.087	0.029		0.074		
Spring at Paulstown Castle	09/01/1997	12:17:00	0.01	7	0.001	28		252		21		1	19													
Thomastown	10/01/1997	10:17:00	0.01	4.4	< 0.004	23	248			999		999														
Borehole No.9, Thomastown	10/01/1997	10:05:00	0.03	5.7	< 0.004	39	248			999		999														
Borehole at Dunmore	13/01/1997																									
Spring at Paulstown Castle	17/02/1997	11:30:00	< 0.02	6.4	0.01	22		245		200		22				11.5		8.7	2.6							
Springs at Bausheenmore	17/02/1997	12:30:00	< 0.02	7.1	< 0.004	26		345	>	80		50				29.5		8.7	3.6							
Spring at Westcourt	17/02/1997	14:05:00	< 0.02	4.8	0.011	20		329		3		2				23.3		8.3	0.9							
Dunmore	09/05/1997		< 0.02	11.2	< 0.004	45																				
Dunmore	09/05/1997		0.19	< 0.1	0.005	18																				
Dunmore	09/05/1997		< 0.02	< 0.1	< 0.003	21																				
Dunmore	09/05/1997		0.87	11.3	2	295																				
Dunmore	09/05/1997		0.08	3.3	0.1	29																				
Dunmore	12/05/1997	10:45:00	0.01	0.232	0.004	20				15		999														
Dunmore	12/05/1997	10:55:00	0.05	0.15	0.003	16			>=	37		6														
Dunmore	12/05/1997	11:05:00	0.01	0.16	0.004	13				999		999														
Dunmore	12/05/1997	11:15:00	< 0.02	16.2	0.007	23			>=	6		999														
Dunmore	12/05/1997	11:25:00	< 0.02	7.5	0.003	20			>=	13		999														
Dunmore	12/05/1997	12:00:00	0.17	12	0.004	30			>=	210		999														
Dunmore	12/05/1997	12:15:00	0.01	8.2	0.003	27						999														
Dunmore	12/05/1997	12:30:00	0.165	10.1	0.003	26				750		300														
Dunmore	12/05/1997	15:30:00	0.015	1.3	0.031	44			>	80		4														
Dunmore	12/05/1997	15:45:00	0.11	0.15	0.019	18																				
Dunmore	12/05/1997	15:55:00	< 0.02	0.18	2.2	19			>=	16		999														
Dunmore	12/05/1997	14:35:00	3	5.6	3.8	353			>	2000	>	2000														
Dunmore	12/05/1997	14:50:00	0.5	0.9	0.41	31					>	600														
Dunmore	12/05/1997	15:10:00	< 0.02	11	0.002	19			>=	9		999														

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Source	Sampling Date	Sampling Time	Cadmium mg/l Cd	Mercury mg/l Hg	Nickel mg/l Ni	Fluoride mg/l F	OMCTSiloxane µg/l	Comments1	Comments2	Comments3
Borehole at Galmoy	09/01/1996	12:40:00								
Borehole at Kilmanagh	09/01/1996	14:20:00								
Spring at Westcourt	09/01/1996	15:10:00								
Borehole at Windgap	09/01/1996	15:40:00								
Spring at Carrigeen,	15/01/1996	13:00:00						Very high Nitrate.	High Conductivity and chloride.	
Belview	27/02/1996	14:15:00						Sample taken after pumping for 1 hour.		
Belview	29/02/1996	11:45:00								
Belview No. 2	07/03/1996	16:00:00						Sample delivered to the laboratory on 8/3/96 by Finbar Coughlan.		
Belview No. 2	14/03/1996	11:00:00								
Belview No. 2	23/03/1996	14:10:00								
Belview No. 1	25/03/1996	15:00:00								
Belview No. 1	27/03/1996	13:00:00								
Dunmore Wells	02/07/1996	10:10:00								
Dunmore Wells	02/07/1996	10:15:00								
Dunmore Wells	02/07/1996	10:15:00								
Dunmore Wells	02/07/1996	10:35:00								
Dunmore Wells	02/07/1996	10:55:00								
Dunmore Wells	02/07/1996	11:10:00								
Dunmore Wells	02/07/1996	11:30:00								
Dunmore Wells	02/07/1996	11:45:00								
Dunmore Wells	02/07/1996	12:10:00								
Dunmore Wells	02/07/1996	12:35:00								
Dunmore Wells	02/07/1996	12:45:00								
Bellview	02/10/1996	11:10:00						Calcium Hardness = 152 mg/l CaCO3	Very high nitrate.	
Bellview	03/10/1996	10:30:00						Calcium Hardness = 144 mg/l CaCO3		
Bellview Water Supply	08/10/1996	10:30:00						Calcium Hardness = 144 mg/l CaCO3	Interference from background colonies on Total Coliform plate.	Very high Nitrate.
Spring at Paulstown Castle	09/01/1997	12:17:00						See GC/MS Purge & Trap analyses on separate sheet.		
Thomastown	10/01/1997	10:17:00								
Borehole No.9, Thomastown	10/01/1997	10:05:00						See GC/MS Purge & Trap analyses on separate sheet.	Octamethylcyclotetrasiloxane < 0.2 ug/l.	
Borehole at Dunmore	13/01/1997							Sample for GC/MS Purge & Trap analyses only. Results on separate sheet.	Octamethylcyclotetrasiloxane 0.7 ug/l.	
Spring at Paulstown Castle	17/02/1997	11:30:00						Octamethylcyclotetrasiloxane = 0.3 ug/l.		
Springs at Bausheenmore	17/02/1997	12:30:00						Octamethylcyclotetrasiloxane = 1.7 ug/l.	K/Na Ratio = 0.41	
Spring at Westcourt	17/02/1997	14:05:00						Octamethylcyclotetrasiloxane = 1.4 ug/l.		
Dunmore	09/05/1997							Very high ammmonia.	Sample taken after land-fill leachate escaped to groundwater.	Approximate ammonia concentration.
Dunmore	09/05/1997							Strong odour and high ammonia.	Sample taken after land-fill leachate escaped to groundwater.	Approximate ammonia concentration.
Dunmore	09/05/1997							Odour of sulphide.	Sample taken after land-fill leachate escaped to groundwater.	Approximate ammonia concentration.
Dunmore	09/05/1997							Very high TOC, ammonia and nitrite results < serious contamination.	Sample taken after land-fill leachate escaped to groundwater.	Approximate ammonia concentration.
Dunmore	09/05/1997							Very high ammonia and high nitrite.	Sample taken after land-fill leachate escaped to groundwater.	Approximate ammonia concentration.
Dunmore	12/05/1997	10:45:00						Ammonia >1.5 mg/l as N.	Sample taken after leachate at landfill site escaped to groundwater	Amended report, ammonia is >1.5 and not <1.5 as reported on 15/5/97.
Dunmore	12/05/1997	10:55:00							Sample taken after leachate at landfill site escaped to groundwater	
Dunmore	12/05/1997	11:05:00							Sample taken after leachate at landfill site escaped to groundwater	No coliforms detected but possible interference from suspended solids.
Dunmore	12/05/1997	11:15:00							Sample taken after leachate at landfill site escaped to groundwater	
Dunmore	12/05/1997	11:25:00							Sample taken after leachate at landfill site escaped to groundwater	
Dunmore	12/05/1997	12:00:00							Sample taken after leachate at landfill site escaped to groundwater	Interference from suspended solids on the total coliform test.
Dunmore	12/05/1997	12:15:00							Sample taken after leachate at landfill site escaped to groundwater	Background interference on the total coliform test.
Dunmore	12/05/1997	12:30:00							Sample taken after leachate at landfill site escaped to groundwater	Very high coliform levels (total and faecal).
Dunmore	12/05/1997	15:30:00						High ammonia and nitrite concentrations.	Sample taken after leachate at landfill site escaped to groundwater	
Dunmore	12/05/1997	15:45:00						Very turbid. High ammonia indicitave of pollution.	Sample taken after leachate at landfill site escaped to groundwater	Interference from suspended solids on the coliform tests (total & faecal).
Dunmore	12/05/1997	15:55:00						Very turbid. High nitrite. Odour detected.	Sample taken after leachate at landfill site escaped to groundwater	Background interference on the total coliform test.
Dunmore	12/05/1997	14:35:00						Turbidity > 100 NTU and ammonia > 110 mg/l N. Very high coliform levels.	Sample taken after leachate at landfill site escaped to groundwater	
Dunmore	12/05/1997	14:50:00						High ammonia and nitrite levels.	Sample taken after leachate at landfill site escaped to groundwater	Interference on the total coliform test.
Dunmore	12/05/1997	15:10:00							Sample taken after leachate at landfill site escaped to groundwater	Interference on the total coliform test.

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Source	Sampling Date	Sampling Time	To	Ref No	Sampling Location	Taken By	Lab No	EPARef	Stn Grid Ref	Water Supply	Public/Group/Private	Temperature	Odour 1/2/3	Colour Hazen	pH	Conductivity µS/cm	Turbidity NTU	TOC mg/l C	Ammonia mg/l N
Borehole at Dunmore	18/06/1997	11:45:00	Kilkenny Co. Co.	KK00700	C. Murray,s house, Dunmore.	C. Murray	2630		24910 16200	Dunmore	Group	15		15	7.4	604			< 0.01
Dunmore	08/07/1997	14:50:00	Kilkenny Co. Co.		Stacks	M. Daly	2973						2	60	7.6	659	7.5		< 0.01
Dunmore	08/07/1997	15:00:00	Kilkenny Co. Co.		Holohans	M. Daly	2974						1		7.3	639	72		0.4
Borehole at Kilmanagh	01/09/1997	10:24:00	Kilkenny Co. Co.	KK01400	In pumphouse	P. Mullins	3796	KIK45	23930 15250	Kilmanagh/Ballycuddihy	Group	14.4	1	< 5	7.5	641	0.26	0.4	< 0.01
Spring at Westcourt	01/09/1997	11:17:00	Kilkenny Co. Co.	KK00800	Spring at Earlsland, Westcourt, Callan	P. Mullins	3797	KIK91	S 407 442	Callan	Public	11.9	1	< 5	7.3	701	0.14	0.28	< 0.01
Borehole at Windgap	01/09/1997	11:54:00	Kilkenny Co. Co.	KK01900	Overflow from borehole	P. Mullins	3798		24200 13580	Farm supply	Private	11.3	1	< 5	7.3	386	0.39	0.07	< 0.01
Springs at Bausheenmore	01/09/1997	13:36:00	Kilkenny Co. Co.	KK00500	At source (springs at Bausheenmore)	P. Mullins	3799	KIK39	25520 14690		Private	11.9	1	20	7.4	717	2.6	3.3	< 0.01
Borehole at Dunmore S/G	01/09/1997	14:17:00	Kilkenny Co. Co.	KK01000	Canteen at Dunmore Sand & Gravel	P. Mullins	3800	KIK53	25000 16020	Dunmore Sand & Gravel	Private	13.6	1	5	7.7	645	1	0.41	< 0.01
Borehole at Dunmore	01/09/1997	14:26:00	Kilkenny Co. Co.	KK00700	C. Murray,s house, Dunmore.	P. Mullins	3801		24910 16200	Dunmore	Group	16	1	< 5	7.4	643	0.14	0.34	< 0.01
Borehole at Kilkenny Mart	01/09/1997	15:13:00	Kilkenny Co. Co.	KK01300	Cattle holding shed	P. Mullins	3802		25070 15670	Kilkenny Mart	Private	16.7	1	60	8.4	130	27	3.2	0.03
Borehole at Galmoy	27/08/1997	11:19:00	Kilkenny Co. Co.	KK00200	Leahy's House, Galmoy	P. Mullins	3743	KIK17	23020 17120	Galmoy	Group	14.3	1	5	7.6	763	0.15	0.55	< 0.01
Borehole at Bawnmore	27/08/1997	11:39:00	Kilkenny Co. Co.	KK00100	Phelan's house, Bawnmore	P. Mullins	3744	KIK50	22580 16610	Bawnmore	Group	15.4	1	5	7.3	826	0.08	1.04	< 0.01
Spring Toberpatrick Urlingford	27/08/1997	12:05:00	Kilkenny Co. Co.	KK01500	In chamber at source	P. Mullins	3745	KIK34	23000 16350	Urlingford/Johnstown	Public	11.1	1	5	7.2	743	0.12	2.47	< 0.01
Spring at Clomantagh	27/08/1997	12:20:00	Kilkenny Co. Co.	KK00900	Beside Nuenna river, 50m SE of road	P. Mullins	3746		23520 16320		Private	12.4	1	5	7.4	638	1.6	1.01	< 0.01
Borehole at Castlecomer Yarns	27/08/1997	14:00:00	Kilkenny Co. Co.	KK00300	Tap in yard at Castlecomer Yarns	P. Mullins	3747		25360 17330	Castlecomer Yarns	Private	12	1	5	7.4	600	5.8	0.56	0.033
Spring at Paulstown Castle	27/08/1997	14:51:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle	P. Mullins	3748	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	11.9	1	5	7.3	636	0.72	1.13	< 0.01
Borehole at Rathcash	27/08/1997	15:12:00	Kilkenny Co. Co.	KK02000	Joe Pykes house, Rathcash, Clara.	P. Mullins	3749	KIK55	25870 15510	Rathcash	Group	16.9	1	5	7.4	709	0.07	0.49	< 0.01
Borehole at Clara	27/08/1997	15:30:00	Kilkenny Co. Co.	KK00400	At pumphouse	P. Mullins	3750	KIK41	25770 15530	Clara	Group	16.3	1	5	7.4	673	0.06	0.59	< 0.01
Dunmore	03/03/1998	11:10:00	Kilkenny Co. Co.		1. Billy O'Dwyers	C. Murray	1116			1. Billy O'Dwyers		9.8	1	10	7.6	473	3.7	0.03	0.073
Dunmore Group Scheme	19/05/1998	11:45:00	Kilkenny Co. Co.			P. Mullins	2330					17.6	1	5	7.44	636			
	19/05/1998	11:55:00	Kilkenny Co. Co.		Readymix	P. Mullins	2331					14.8	1	< 5	7.59	648			
Borehole at Windgap	09/02/1999	09:30:00	Kilkenny Co. Co.	KK01900	Overflow from borehole	Redmond Bergin	815		24200 13580	Farm supply	Private			5	7.3	330	< 0.1		< 0.2
Spring at Clomantagh	17/02/1999	10:40:00	Kilkenny Co. Co.	KK00900	Beside Nuenna river, 50m SE of road	C. Murray	998		23520 16320		Private	10	1	5	7.3	669	0.6	4	
Spring Toberpatrick Urlingford	17/02/1999	11:00:00	Kilkenny Co. Co.	KK01500	In chamber at source	C. Murray	999	KIK34	23000 16350	Urlingford/Johnstown	Public	9.2	1	5	7.3	747	0.2	4.3	
Borehole at Bawnmore	17/02/1999	11:30:00	Kilkenny Co. Co.	KK00100	Phelan's house, Bawnmore	C. Murray	1000	KIK50	22580 16610	Bawnmore	Group	7	1	5	7.1	881	< 0.1	4.5	
Borehole at Galmoy	17/02/1999	12:00:00	Kilkenny Co. Co.	KK00200	Leahy's House, Galmoy	C. Murray	1001	KIK17	23020 17120	Galmoy	Group		1	5	7.3	776	0.4	2.1	
Borehole at Castlecomer Yarns	17/02/1999	12:50:00	Kilkenny Co. Co.	KK00300	Tap in yard at Castlecomer Yarns	C. Murray	1002		25360 17330	Castlecomer Yarns	Private	10.5	1	40	7.4	535	11.6	2	
Borehole at Dunmore	17/02/1999	14:05:00	Kilkenny Co. Co.	KK00700	C. Murray,s house, Dunmore.	C. Murray	1003		24910 16200	Dunmore	Group	7.7	1	5	7.3	663	< 0.1	1.7	< 0.2
Borehole at Kilkenny Mart	17/02/1999	15:00:00	Kilkenny Co. Co.	KK01300	Cattle holding shed	C. Murray	1004		25070 15670	Kilkenny Mart	Private	9.7	1	10	7.9	690	1.5	1.8	< 0.2
Borehole at Kilmanagh	17/02/1999	16:00:00	Kilkenny Co. Co.	KK01400	In pumphouse	C. Murray	1005	KIK45	23930 15250	Kilmanagh/Ballycuddihy	Group	7.3	1	5	7.6	658	< 0.1	3.9	< 0.2
Spring at Westcourt	14/04/1999	10:47:00	Kilkenny Co. Co.	KK00800	Spring at Earlsland, Westcourt, Callan	P. Mullins	1889	KIK91	S 407 442	Callan	Public	9.8	1	< 5	7.5	699	< 0.1		< 0.01
Borehole at Windgap	14/04/1999	11:14:00	Kilkenny Co. Co.	KK01900	Overflow from borehole	P. Mullins	1890		24200 13580	Farm supply	Private	10.5	1	< 5	7.3	388	0.2		< 0.01
Springs at Bausheenmore	14/04/1999	12:12:00	Kilkenny Co. Co.	KK00500	At source (springs at Bausheenmore)	P. Mullins	1891	KIK39	25520 14690		Private	9.6	1	< 5	7.4	772	0.2		< 0.01
Borehole at Rathcash	14/04/1999	14:00:00	Kilkenny Co. Co.	KK02000	Joe Pykes house, Rathcash, Clara.	P. Mullins	1892	KIK55	25870 15510	Rathcash	Group	9.4	1	< 5	7.3	722	< 0.1		< 0.01
Borehole at Clara	14/04/1999	14:18:00	Kilkenny Co. Co.	KK00400	At pumphouse	P. Mullins	1893	KIK41	25770 15530	Clara	Group	9.6	1	< 5	7.3	695	< 0.1		< 0.01
	07/09/1999	10:20:00	Kilkenny Co. Co.		Kenny's Well, Kilkenny City	T. Doherty	4410												
Bennettsbridge	29/03/2000	14:16:00	Kilkenny Co. Co.		New well - feeding the infiltration gallery	P. Mullins	1688			Bennettsbridge	Public	10.6	1	< 5	7.6	727			< 0.003
Borehole at Kilmanagh	27/09/2000	10:30:00	Kilkenny Co. Co.	KK01400	In pumphouse	C. Murray	5048	KIK45	23930 15250	Kilmanagh/Ballycuddihy	Group	13.8			7.3	664	0.1		< 0.003
Borehole at Windgap	27/09/2000	12:10:00	Kilkenny Co. Co.	KK01900	Overflow from borehole	C. Murray	5049		24200 13580	Farm supply	Private	11.5			7.3	388	0.6		< 0.003
Borehole No.9, Thomastown	27/09/2000	14:15:00	Kilkenny Co. Co.	KK01600	At pumphouse	C. Murray	5050	KIK32	25890 14160	Thomastown	Public	13.3			7.2	758	0.2		< 0.003
Springs at Bausheenmore	27/09/2000	14:50:00	Kilkenny Co. Co.	KK00500	At source (springs at Bausheenmore)	C. Murray	5051	KIK39	25520 14690		Private	11			7.1	787	0.6		0.005
Spring at Paulstown Castle	27/09/2000	15:40:00	Kilkenny Co. Co.	KK00600	Spring at Paulstown Castle	C. Murray	5052	KIK46	S 660 570	Gowran/Goresbr./P-town	Public	11.1			7.1	656	0.4		0.016
Spring at Clomantagh	26/09/2000	10:20:00	Kilkenny Co. Co.	KK00900	Beside Nuenna river, 50m SE of road	C. Murray	5026		23520 16320		Private	11.4	1	15	7.4	282			0.083
Spring Toberpatrick Urlingford	26/09/2000	10:40:00	Kilkenny Co. Co.	KK01500	In chamber at source	C. Murray	5027	KIK34	23000 16350	Urlingford/Johnstown	Public	10.3	1	5	7.2	813			< 0.003
Borehole at Bawnmore	26/09/2000	11:05:00	Kilkenny Co. Co.	KK00100	Phelan's house, Bawnmore	C. Murray	5028	KIK50	22580 16610	Bawnmore	Group	13.5	1	5	7.3	863			< 0.003
Borehole at Galmoy	26/09/2000	12:15:00	Kilkenny Co. Co.	KK00200	Leahy's House, Galmoy	C. Murray	5029	KIK17	23020 17120	Galmoy	Group	14.7	1	5	7.4	789			< 0.003
Borehole at Castlecomer Yarns	26/09/2000	14:00:00	Kilkenny Co. Co.	KK00300	Tap in yard at Castlecomer Yarns	C. Murray	5030		25360 17330	Castlecomer Yarns	Private	12.2	1	20	7.5	578			0.036
Borehole at Dunmore	26/09/2000	14:25:00	Kilkenny Co. Co.	KK00700	C. Murray,s house, Dunmore.	C. Murray	5031		24910 16200	Dunmore	Group	14.7	1	5	7.4	668			< 0.003
Borehole at Dunmore S/G	26/09/2000	14:40:00	Kilkenny Co. Co.	KK01000	Canteen at Dunmore Sand & Gravel	C. Murray	5032	KIK53	25000 16020	Dunmore Sand & Gravel	Private	12.4	1	5	7.6	660			< 0.003
Borehole at Kilkenny Mart	26/09/2000	14:55:00	Kilkenny Co. Co.	KK01300	Cattle holding shed	C. Murray	5033		25070 15670	Kilkenny Mart	Private	14.6	1	5	7.6	708			< 0.003
Borehole at Clara	26/09/2000	15:35:00	Kilkenny Co. Co.	KK00400	At pumphouse	C. Murray	5034	KIK41	25770 15530	Clara	Group	11.6	1	5	7.4	667			< 0.003
Kiloshaun/Barna	03/10/2000	11:15:00	Kilkenny Co. Co./G.S.I.		GWS06	M. Daly	5218								7	663			0.015
Tubrid Lower	03/10/2000	11:40:00	Kilkenny Co. Co./G.S.I.		GWS14	M. Daly	5219								7.2	766			0.012
Balief Clomantagh	03/10/2000	12:00:00	Kilkenny Co. Co./G.S.I.		GWS03	M. Daly	5220								7.3	794			0.007
Graine/Craddockstown	03/10/2000	12:30:00	Kilkenny Co. Co./G.S.I.		GWS07	M. Daly	5221								7.4	727			0.006
Pilltown (PWS07)	03/10/2000	09:45:00	Kilkenny Co. Co./G.S.I.			Ruth Buckley	5222								6.5	184			0.01
Tullahought (GWS16)	03/10/2000	10:30:00	Kilkenny Co. Co./G.S.I.			Ruth Buckley	5223								6.3	194			0.007
Hugginstown (GWS10)	03/10/2000	11:30:00	Kilkenny Co. Co./G.S.I.			Ruth Buckley	5224								6.7	448			0.005
Ahenure (PWS09)	03/10/2000	14:15:00	Kilkenny Co. Co./G.S.I.			Ruth Buckley	5225								7.3	743			0.005

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Source	Sampling Date	Sampling Time	o-Phosphate mg/l P	Nitrate mg/l N	Nitrite mg/l N	Chloride mg/l Cl	Ca Hardness mg/l CaCO3	Alkalinity mg/l CaCO3	TCS	Total Coliforms per 100 ml	FCS	Fecal Coliforms per 100 ml	Sulphate mg/l SO4	Dry Residue mg/l	Sus_ Solids mg/l	Magnesium mg/l Mg	Total Hardness mg/l CaCO3	Sodium mg/l Na	Potassium mg/l K	Aluminium mg/l Al	Iron mg/l Fe	Manganese mg/l Mn	Copper mg/l Cu	Zinc mg/l Zn	Chromium mg/l Cr	Lead mg/l Pb
Borehole at Dunmore	18/06/1997	11:45:00	< 0.02	10		19.7		240		999		999														
Dunmore	08/07/1997	14:50:00	< 0.02	< 0.1	0.003	20			<	100	<	100			Visible	19.5		10.2	0.6							
Dunmore	08/07/1997	15:00:00	0.1	< 0.1	0.016	19			<	200	<	100			Visible	10.3		15.2	0.4							
Borehole at Kilmanagh	01/09/1997	10:24:00	< 0.02	4.6	< 0.004	17	270	287	>	100	>	100	7													
Spring at Westcourt	01/09/1997	11:17:00	< 0.02	4.3	< 0.004	22	262	310		15		5	12													
Borehole at Windgap	01/09/1997	11:54:00	0.02	2.1	< 0.004	15	144	151		6		2	4													
Springs at Bausheenmore	01/09/1997	13:36:00	0.04	5.6	0.004	26	270	304	>	100	>	100	17													
Borehole at Dunmore S/G	01/09/1997	14:17:00	< 0.02	< 0.1	< 0.004	21	252			480		9	36													
Borehole at Dunmore	01/09/1997	14:26:00	< 0.02	10.6	< 0.004	19	272	272		2		999	20													
Borehole at Kilkenny Mar	01/09/1997	15:13:00	0.09	0.5	0.018	3	64		>	160	>	120	< 1.5													
Borehole at Galmoy	27/08/1997	11:19:00	< 0.02	16.1	< 0.004	20	228	298		1		999	19													
Borehole at Bawnmore	27/08/1997	11:39:00	< 0.02	11	< 0.004	23	316	363	>	80		7	17													
Spring Toberpatrick Urlingford	27/08/1997	12:05:00	< 0.02	8.1	< 0.004	22	292	332		51		9	17													
Spring at Clomantagh	27/08/1997	12:20:00	< 0.02	7.4	0.001	18	236	276	>	160	>	120	10													
Borehole at Castlecomer Yarns	27/08/1997	14:00:00	< 0.02	0.13	0.004	20	144	262		999		999	25													
Spring at Paulstown Castle	27/08/1997	14:51:00	< 0.02	7	< 0.004	25	232	256	>	160	>	120	17													
Borehole at Rathcash	27/08/1997	15:12:00	< 0.02	6.2	< 0.004	24	212	314		999		999	15													
Borehole at Clara	27/08/1997	15:30:00	0.02	8.7	< 0.004	21	272	283		29		18	13													
Dunmore	03/03/1998	11:10:00	< 0.02			17.6		206	<	40	<	1														
Dunmore Group Scheme	19/05/1998	11:45:00	0.011	9.4		19				999		999														
	19/05/1998	11:55:00	0.011	0.4		22				12		999														
Borehole at Windgap	09/02/1999	09:30:00	0.05	2	< 0.003	13.3	93	148		999		999	6.1			13.9		7.2								
Spring at Clomantagh	17/02/1999	10:40:00	< 0.04	6.1	< 0.003	15.4		299		10		2	9.5		Not Vis.											
Spring Toberpatrick Urlingford	17/02/1999	11:00:00	< 0.04	5.7	< 0.003	17.5		340		13		1	10.1		Not Vis.											
Borehole at Bawnmore	17/02/1999	11:30:00	< 0.04	7.9	< 0.003	17.9		416		999		999	11.2		Not Vis.											
Borehole at Galmoy	17/02/1999	12:00:00	< 0.04	11.5	< 0.003	24.5		317		29		999	13.3		Not Vis.											
Borehole at Castlecomer Yarns	17/02/1999	12:50:00	< 0.04	0.6	< 0.003	16.7		241		999		999	18.4		Not Vis.											
Borehole at Dunmore	17/02/1999	14:05:00		8.9	< 0.003	21.3	303	262		999		999	15.1		Not Vis.	4.5		9	0.9							
Borehole at Kilkenny Mar	17/02/1999	15:00:00	< 0.04	6.6	< 0.003	18.8	273	270		9		999	37.9		Not Vis.	14.1		11.2	1.3							
Borehole at Kilmanagh	17/02/1999	16:00:00	< 0.04	4	< 0.003	15.2	276	308		999		999	9.7		Not Vis.	12		9.2	0.8							
Spring at Westcourt	14/04/1999	10:47:00	< 0.04	4.2	< 0.004	20	288	330		1		1	11.4			24.2		8.9	0.6							
Borehole at Windgap	14/04/1999	11:14:00	< 0.04	2.2	< 0.004	13	138	174		999		999	5.6			17.9		6.6	0.7							
Springs at Bausheenmore	14/04/1999	12:12:00	< 0.04	5.7	< 0.004	23	272	360		74		2	15			30.5		8.3	2.3							
Borehole at Rathcash	14/04/1999	14:00:00	< 0.04	6.7	< 0.004	21	286	326		999		999	14			22.3		7.9	0.8							
Borehole at Clara	14/04/1999	14:18:00	< 0.04	8.5	< 0.004	19	288	318		45		2	12.8			17.1		7.8	1							
	07/09/1999	10:20:00								999		999														
Bennettsbridge	29/03/2000	14:16:00	< 0.006	5.1		22				999		999			Not Vis.											
Borehole at Kilmanagh	27/09/2000	10:30:00	< 0.006	3.7	< 0.001	14	288		>=	43		999	13			15	349	11	1.2		< 0.06	< 0.02		0.026		
Borehole at Windgap	27/09/2000	12:10:00	0.019	2.4	< 0.001	14	143					999	9.1			15	204	7.9	1.4		< 0.06	< 0.02		0.024		
Borehole No.9, Thomastown	27/09/2000	14:15:00	0.032	5.8	< 0.001	31	293			8		1	19			22	383	18	3.5		< 0.06	< 0.02		0.138		
Springs at Bausheenmore	27/09/2000	14:50:00	0.014	6	< 0.001	23	308		>	80	>	60	20			30	431	10	3.9		< 0.06	< 0.02		0.022		
Spring at Paulstown Castle	27/09/2000	15:40:00	0.008	4.7	0.007	23	290		>	80	>	60	18			11	335	11	3.4		< 0.06	< 0.02		0.021		
Spring at Clomantagh	26/09/2000	10:20:00	0.012	1.5	0.007	6.9	83		>	80	>	60	7.8			2.4	92.8	6	6.5		0.086	< 0.02		0.189		
Spring Toberpatrick Urlingford	26/09/2000	10:40:00	0.009	7.1	0.011	20	338		>	80	>	60	15			19	416	9.4	5		0.106	< 0.02		0.48		
Borehole at Bawnmore	26/09/2000	11:05:00	< 0.006	6.7	< 0.001	18	348		>=	50		28	16			30	471	8.1	3.4		0.114	< 0.02		0.421		
Borehole at Galmoy	26/09/2000	12:15:00	< 0.006	8.2	< 0.001	21	305			999		999	18			27	416	9.6	1.4		0.082	< 0.02		0.258		
Borehole at Castlecomer Yarns	26/09/2000	14:00:00	0.077	1.1	0.003	17	150			7		999	25			17	220	43	1.7		0.664	0.536		0.152		
Borehole at Dunmore	26/09/2000	14:25:00	< 0.006	8.9	< 0.001	23	308			21	<	1	18			3.1	320	9.9	1.4		< 0.06	< 0.02		0.102		
Borehole at Dunmore S/G	26/09/2000	14:40:00	< 0.006	0.67	0.002	19	278		>=	44		999	38			14	294	12	1.4		0.063	0.273		0.076		
Borehole at Kilkenny Mar	26/09/2000	14:55:00	< 0.006	6.2	< 0.001	18	295			47		3	39			16	360	12	1.9		< 0.06	< 0.02		0.151		
Borehole at Clara	26/09/2000	15:35:00	0.03	5.9	< 0.001	18	275			5		999	16			16	340	9.7	1.9		< 0.06	< 0.02		0.068		
Kiloshaun/Barna	03/10/2000	11:15:00	0.023	5.9	< 0.001	14	360	305	>	80	>	80	7.8			10.4	402	6.9	2.1	< 0.05	0.075	0.01	0.004	0.262	0.012	< 0.001
Tubrid Lower	03/10/2000	11:40:00	0.009	8.5	< 0.001	18	413	353		7		1	10.6			15.5	476	7.7	0.6	< 0.05	0.097	0.003	0.005	0.463	0.034	< 0.001
Balief Clomantagh	03/10/2000	12:00:00	0.01	8.5	0.01	18	427	383		62		58	9.6			14.2	485	9.4	5	< 0.05	0.078	0.005	0.005	0.343	0.028	< 0.001
Graine/Craddockstown	03/10/2000	12:30:00	0.007	5.2	< 0.01	15	321	362		999		999	10.7			37.1	7.4	< 0.3		< 0.05	< 0.05	0.002	0.009	0.208	0.019	< 0.001
Pilltown (PWS07)	03/10/2000	09:45:00	0.03	2.9	0.003	14.3	40	53		28		999	4.9			3.1	52.7	8	1.4	< 0.05	< 0.05	0.002	< 0.001	0.124	0.009	< 0.001
Tullahought (GWS16)	03/10/2000	10:30:00	0.027	7.1	< 0.001	17	35	26		2		999	9.8			5.5	57.6	11.4	< 0.3	< 0.05	< 0.05	0.002	0.011	0.084	0.005	< 0.001
Hugginstown (GWS10)	03/10/2000	11:30:00	0.026	4.3	< 0.001	15	193	176	>	80	>	60	14.5			8.4	227	10.5	5.9	< 0.05	< 0.05	< 0.001	0.011	0.071	0.006	< 0.001
Ahenure (PWS09)	03/10/2000	14:15:00	< 0.006	2.6	< 0.001	19	348	347		14		999	16.5			28.3	464	8.8	1.7	< 0.05	< 0.05	0.739	0.009	0.051	0.007	< 0.001

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Source	Sampling Date	Sampling Time	Cadmium mg/l Cd	Mercury mg/l Hg	Nickel mg/l Ni	Fluoride mg/l F	OMCTSiloxane µg/l	Comments1	Comments2	Comments3
Borehole at Dunmore	18/06/1997	11:45:00								
Dunmore	08/07/1997	14:50:00						Total Coliforms present. Accurate count not possible due to	Suspended Solids.	
Dunmore	08/07/1997	15:00:00						Total Coliforms present. Accurate count not possible due to	Suspended Solids.	
Borehole at Kilmanagh	01/09/1997	10:24:00								
Spring at Westcourt	01/09/1997	11:17:00								
Borehole at Windgap	01/09/1997	11:54:00								
Springs at Bausheenmore	01/09/1997	13:36:00								
Borehole at Dunmore S/G	01/09/1997	14:17:00								
Borehole at Dunmore	01/09/1997	14:26:00								
Borehole at Kilkenny Mar	01/09/1997	15:13:00								
Borehole at Galmoy	27/08/1997	11:19:00								
Borehole at Bawnmore	27/08/1997	11:39:00								
Spring Toberpatrick Urlingford	27/08/1997	12:05:00								
Spring at Clomantagh	27/08/1997	12:20:00								
Borehole at Castlecomer Yarns	27/08/1997	14:00:00								
Spring at Paulstown Castle	27/08/1997	14:51:00								
Borehole at Rathcash	27/08/1997	15:12:00								
Borehole at Clara	27/08/1997	15:30:00								
Dunmore	03/03/1998	11:10:00								
Dunmore Group Scheme	19/05/1998	11:45:00								
	19/05/1998	11:55:00								
Borehole at Windgap	09/02/1999	09:30:00						Sodium and calcium for guide only.		
Spring at Clomantagh	17/02/1999	10:40:00				< 0.1				
Spring Toberpatrick Urlingford	17/02/1999	11:00:00				< 0.1				
Borehole at Bawnmore	17/02/1999	11:30:00				< 0.1				
Borehole at Galmoy	17/02/1999	12:00:00				< 0.1				
Borehole at Castlecomer Yarns	17/02/1999	12:50:00				< 0.1				
Borehole at Dunmore	17/02/1999	14:05:00				< 0.1				
Borehole at Kilkenny Mar	17/02/1999	15:00:00				< 0.1				
Borehole at Kilmanagh	17/02/1999	16:00:00				< 0.1				
Spring at Westcourt	14/04/1999	10:47:00				< 0.1				
Borehole at Windgap	14/04/1999	11:14:00				< 0.1				
Springs at Bausheenmore	14/04/1999	12:12:00				< 0.1				
Borehole at Rathcash	14/04/1999	14:00:00				< 0.1				
Borehole at Clara	14/04/1999	14:18:00				< 0.1				
	07/09/1999	10:20:00						Sample for bacteriological analyses only.		
Bennettsbridge	29/03/2000	14:16:00						This is a sample from a new well that feeds the old infiltration gallery for	Bennettsbridge water supply.	
Borehole at Kilmanagh	27/09/2000	10:30:00					3.2		VOC analysis results on separate sheet.	
Borehole at Windgap	27/09/2000	12:10:00					2.1	Total Coliforms not reported.	VOC analysis results on separate sheet.	
Borehole No.9, Thomastown	27/09/2000	14:15:00					1.8		VOC analysis results on separate sheet.	
Springs at Bausheenmore	27/09/2000	14:50:00								
Spring at Paulstown Castle	27/09/2000	15:40:00					10.3		VOC analysis results on separate sheet.	
Spring at Clomantagh	26/09/2000	10:20:00					0.6		VOC analysis results on separate sheet.	
Spring Toberpatrick Urlingford	26/09/2000	10:40:00					1.7		VOC analysis results on separate sheet.	
Borehole at Bawnmore	26/09/2000	11:05:00					0.7	Background interference on Total Coliform plate.	VOC analysis results on separate sheet.	
Borehole at Galmoy	26/09/2000	12:15:00					2.4		VOC analysis results on separate sheet.	
Borehole at Castlecomer Yarns	26/09/2000	14:00:00					0.6		VOC analysis results on separate sheet.	
Borehole at Dunmore	26/09/2000	14:25:00					1.1	Small underdeveloped colonies on Total Coliform plate.	VOC analysis results on separate sheet.	
Borehole at Dunmore S/G	26/09/2000	14:40:00					2.2	Background interference on Total Coliform plate.	VOC analysis results on separate sheet.	
Borehole at Kilkenny Mar	26/09/2000	14:55:00					1.3		VOC analysis results on separate sheet.	
Borehole at Clara	26/09/2000	15:35:00					2.9		VOC analysis results on separate sheet.	
Kiloshaun/Barna	03/10/2000	11:15:00	< 0.0001	< 0.0001	0.008	< 0.1		Samples as part of Kilkenny Groundwater Protection Scheme.		
Tubrid Lower	03/10/2000	11:40:00	< 0.0001	< 0.0001	0.015	< 0.1		Samples as part of Kilkenny Groundwater Protection Scheme.		
Balief Clomantagh	03/10/2000	12:00:00	< 0.0001	< 0.0001	0.012	< 0.1		Samples as part of Kilkenny Groundwater Protection Scheme.		
Graine/Craddockstown	03/10/2000	12:30:00	< 0.0001	< 0.0001	0.007	< 0.1		Samples as part of Kilkenny Groundwater Protection Scheme.		
Pilltown (PWS07)	03/10/2000	09:45:00	< 0.0001	< 0.0001	0.004	< 0.1		Samples as part of Kilkenny Groundwater Protection Scheme.		
Tullahought (GWS16)	03/10/2000	10:30:00	< 0.0001	< 0.0001	0.002	< 0.1		Samples as part of Kilkenny Groundwater Protection Scheme.		
Hugginstown (GWS10)	03/10/2000	11:30:00	< 0.0001	< 0.0001	0.002	< 0.1		Samples as part of Kilkenny Groundwater Protection Scheme.		
Ahenure (PWS09)	03/10/2000	14:15:00	< 0.0001	< 0.0001	0.024	< 0.1		Samples as part of Kilkenny Groundwater Protection Scheme.		

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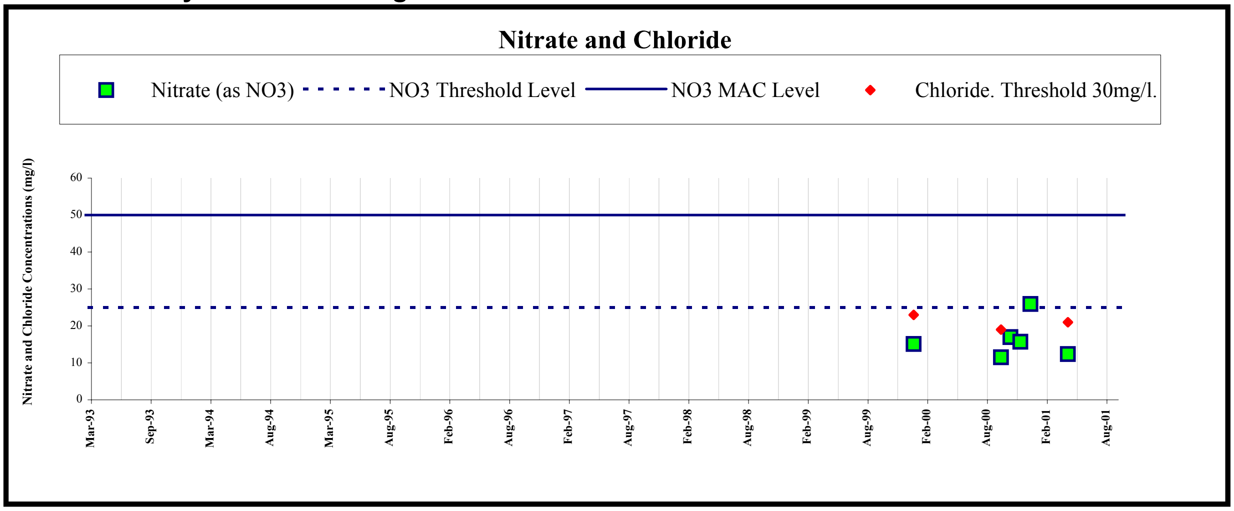
Source	Sampling Date	Sampling Time	To	Ref No	Sampling Location	Taken By	Lab No	EPARef	Stn Grid Ref	Water Supply	Public/Group/Private	Temperature	Odour 1/2/3	Colour Hazen	pH	Conductivity µS/cm	Turbidity NTU	TOC mg/l C	Ammonia mg/l N
Callan (PWS06)	03/10/2000	15:00:00	Kilkenny Co. Co./G.S.I.			Ruth Buckley	5226								7.3	705			0.004
Windgap (GWS17)	03/10/2000	12:45:00	Kilkenny Co. Co./G.S.I.			Ruth Buckley	5227								6.7	267			0.007
Highrath (GWS11)	04/10/2000	12:00:00	Kilkenny Co. Co./G.S.I.		Highrath (GWS11)	M. Daly	5260						1	5	7.1	999			0.024
Maddoxtown (GWS12)	04/10/2000	12:30:00	Kilkenny Co. Co./G.S.I.		Maddoxtown (GWS12)	M. Daly	5261						1	5	7.2	931			0.022
Glenmore Spring (PWS02-1)	04/10/2000	11:10:00	Kilkenny Co. Co./G.S.I.		Glenmore Spring (PWS02-1)	Ruth Buckley	5266							5	6.4	259			0.018
Glenmore Spring (PWS02-2)	04/10/2000	13:25:00	Kilkenny Co. Co./G.S.I.		Glenmore Spring (PWS02-2)	Ruth Buckley	5267												
Cuffesgrange No. 1 (GWS13)	02/10/2000	11:00:00	Kilkenny Co. Co./G.S.I.		Cuffesgrange No. 1 (GWS13)	M. Daly	5094						1	5	7.3	772			0.011
Ballymack (GWS02)	02/10/2000	11:20:00	Kilkenny Co. Co./G.S.I.		Ballymack (GWS02)	M. Daly	5095						1	5	7.2	800			0.004
Newtown Kells (GWS04)	02/10/2000	11:45:00	Kilkenny Co. Co./G.S.I.		Newtown Kells (GWS04)	M. Daly	5096						1	5	7.3	789			0.007
Caherlesk Goolaghmore	02/10/2000	12:20:00	Kilkenny Co. Co./G.S.I.		Caherlesk Goolaghmore	M. Daly	5097						1	5	6.8	459			0.008
Paulstown (PWS7)	04/10/2000	10:30:00	Kilkenny Co. Co./G.S.I.		Paulstown (PWS7)	V. Fitzsimons	5262						1	5	7.3	676			0.016
Tullaroan (PWS5)	04/10/2000	11:30:00	Kilkenny Co. Co./G.S.I.		Tullaroan (PWS5)	V. Fitzsimons	5263						1	5	7.5	616			0.004
Urlingford (PWS5-S)	04/10/2000	12:30:00	Kilkenny Co. Co./G.S.I.		Urlingford (PWS5-S)	V. Fitzsimons	5264						1	5	7.2	803			0.007
Urlingford (PWS5-R)	04/10/2000	12:40:00	Kilkenny Co. Co./G.S.I.		Urlingford (PWS5-R)	V. Fitzsimons	5265							10	7.3	825			0.094
Thomastown BH1 (PWS01-1)	02/10/2000	10:30:00	Kilkenny Co. Co./G.S.I.		Thomastown BH1 (PWS01-1)	Ruth Buckley	5114							5	7	466			0.003
Thomastown BH2 (PWS01-2)	02/10/2000	10:50:00	Kilkenny Co. Co./G.S.I.		Thomastown BH2 (PWS01-2)	Ruth Buckley	5115							5	7.3	748			< 0.003
Bennettsbridge BH (PWS04-B)	02/10/2000	12:10:00	Kilkenny Co. Co./G.S.I.		Bennettsbridge BH (PWS04-B)	Ruth Buckley	5116							5	7.3	721			< 0.003
Bennettsbridge River (PWS04-R)	02/10/2000	12:15:00	Kilkenny Co. Co./G.S.I.		Bennettsbridge River (PWS04-R)	Ruth Buckley	5117							175	8	447			0.022
Bennettsbridge Gravel (PWS04-G)	02/10/2000	12:25:00	Kilkenny Co. Co./G.S.I.		Bennettsbridge Gravel (PWS04-G)	Ruth Buckley	5118							20	7.5	563			0.006
Bennettsbridge Mixed (PWS04-M)	02/10/2000	12:50:00	Kilkenny Co. Co./G.S.I.		Bennettsbridge Mixed (PWS04-M)	Ruth Buckley	5119						1	5	7.4	681			< 0.003
Kilree Stoneyford (GWS08)	02/10/2000	15:00:00	Kilkenny Co. Co./G.S.I.		Kilree Stoneyford (GWS08)	Ruth Buckley	5120						1	5	7.1	866			< 0.003
Spring at Clomantagh	12/02/2001	11:00:00	Kilkenny Co. Co.	KK00900	Beside Nuenna river, 50m SE of roac		633		23520 16320		Private	9.7			7.2	615	1.4		0.007

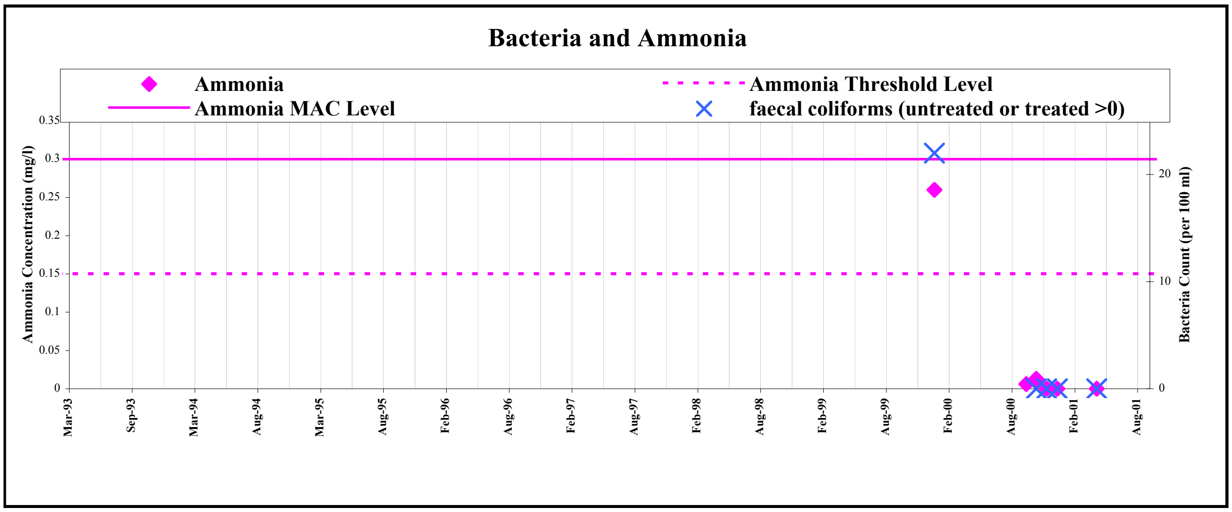
EPA Regional Water Laboratory, Kilkenny. Monitoring Data for County Kilkenny Groundwaters 1993 to 1999.

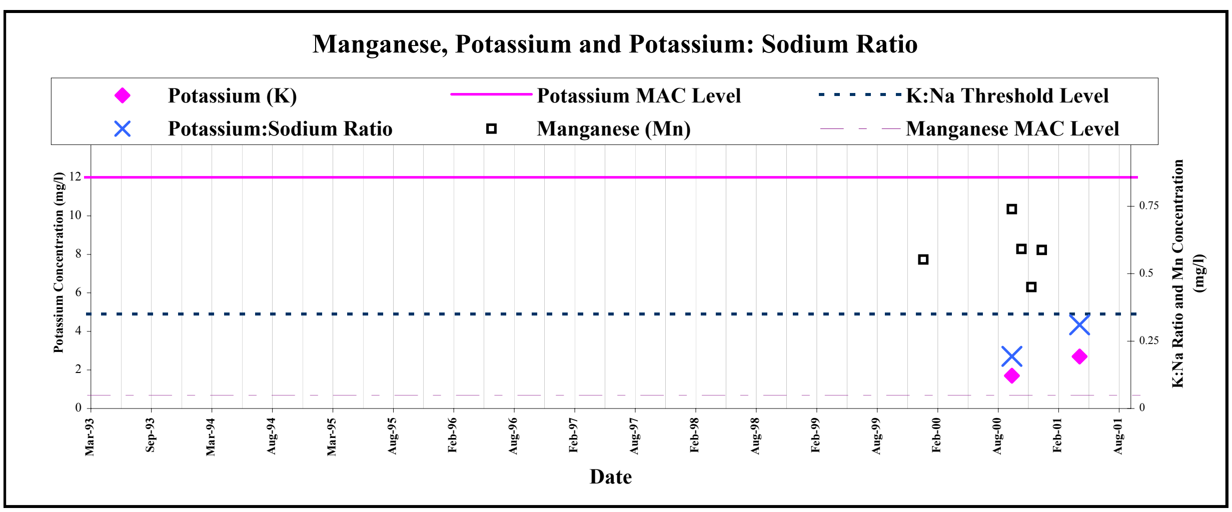
Source	Sampling Date	Sampling Time	o-Phosphate mg/l P	Nitrate mg/l N	Nitrite mg/l N	Chloride mg/l Cl	Ca Hardness mg/l CaCO3	Alkalinity mg/l CaCO3	TCS	Total Coliforms per 100 ml	FCS	Fecal Coliforms per 100 ml	Sulphate mg/l SO4	Dry Residue mg/l	Sus_ Solids mg/l	Magnesium mg/l Mg	Total Hardness mg/l CaCO3	Sodium mg/l Na	Potassium mg/l K	Aluminium mg/l Al	Iron mg/l Fe	Manganese mg/l Mn	Copper mg/l Cu	Zinc mg/l Zn	Chromium mg/l Cr	Lead mg/l Pb
Callan (PWS06)	03/10/2000	15:00:00	0.006	4.1	< 0.001	19	334	336		24		10	11.6			25.1	437	10.1	0.9	< 0.05	< 0.05	0.0014	< 0.001	0.046	0.004	< 0.001
Windgap (GWS17)	03/10/2000	12:45:00	0.062	9.6	< 0.001	15	99.7	64		1		999	6.8			2.8	75.5	7.8	< 0.3	< 0.05	< 0.05	< 0.001	< 0.001	0.039	0.003	< 0.001
Highrath (GWS11)	04/10/2000	12:00:00	0.023	5.3	0.003	49	443	436	>	80	>	60	13.5			30	566	11	5.6	< 0.05	< 0.05	0.003	0.004	0.027	0.024	< 0.001
Maddoxtown (GWS12)	04/10/2000	12:30:00	0.015	11.7	< 0.001	25	383	404		17		4	18.6			29.1	502	11.1	3.3	< 0.05	< 0.05	< 0.001	< 0.001	0.003	0.021	< 0.001
Glenmore Spring (PWS02-1)	04/10/2000	11:10:00	< 0.006	9.6	0.001	22	44	38		45		1	12.8			11.5	91.3	10.9	3.8	< 0.05	< 0.05	< 0.001	< 0.001	0.02	0.003	< 0.001
Glenmore Spring (PWS02-2)	04/10/2000	13:25:00								36		1														
Cuffesgrange No. 1 (GWS13)	02/10/2000	11:00:00	0.02	4.2	0.009	19	362	362	>	80		29	13.1			25	464	11.2	3.6	< 0.05	< 0.05	< 0.001	0.005	0.037	0.005	< 0.001
Ballymack (GWS02)	02/10/2000	11:20:00	< 0.006	6.4	< 0.001	23	345	365		52		7	13.9			36.2	494	11.7	1.5	< 0.05	< 0.05	< 0.001	< 0.001	0.035	0.005	< 0.001
Newtown Kells (GWS04)	02/10/2000	11:45:00	0.006	5.6	< 0.001	26	359	367	>	80		7	13			29.2	479	12.5	1.5	< 0.05	< 0.05	< 0.001	0.004	0.049	0.003	< 0.001
Caherlesk Goolaghmore	02/10/2000	12:20:00	0.008	5.3	< 0.001	19	197	178		51		8	10			15.5	260	9.2	2.3	< 0.05	< 0.05	< 0.001	0.003	0.046	0.004	< 0.001
Paulstown (PWS7)	04/10/2000	10:30:00	0.008	5.7	0.008	22	330	286	>	80	>	60	12.8			11.5	377	10.9	3.8	< 0.05	< 0.05	< 0.001	< 0.001	0.014	0.016	< 0.001
Tullaroan (PWS5)	04/10/2000	11:30:00	< 0.006	2.9	< 0.001	14	301	284		999		999	7.4			10	342	8.2	1.4	< 0.05	< 0.05	< 0.001	< 0.001	< 0.001	0.015	< 0.001
Urlingford (PWS5-S)	04/10/2000	12:30:00	0.006	8	0.002	18	377	369	>	80	>	60	10.7			18.5	453	8	5.9	< 0.05	< 0.05	< 0.001	< 0.001	< 0.001	0.012	< 0.001
Urlingford (PWS5-R)	04/10/2000	12:40:00	0.039	7.2	0.056	19	375	375		1080		370	15.9			13.5	430	10.8	1.1	< 0.05	< 0.05	< 0.001	< 0.001	0.013	0.021	< 0.001
Thomastown BH1 (PWS01-1)	02/10/2000	10:30:00	0.012	4.9	< 0.001	18	186	105		8		999	10.4			15.5	249	11	1.3	< 0.05	< 0.05	< 0.001	0.005	0.05	0.004	< 0.001
Thomastown BH2 (PWS01-2)	02/10/2000	10:50:00	0.037	6.2	< 0.001	30	325	320		6		1	16			22.5	417	17.6	3.3	< 0.05	< 0.05	0.001	0.013	0.046	0.006	< 0.001
Bennettsbridge BH (PWS04-B)	02/10/2000	12:10:00	< 0.006	4.3	0.002	24	320	317		17		999	28.5			25.4	424	16.1	2.3	< 0.05	< 0.05	0.004	< 0.001	0.034	0.002	< 0.001
Bennettsbridge River (PWS04-R)	02/10/2000	12:15:00	0.083	2.1	0.014	16	223	185		42000		5600	15.8			7.8	255	10.3	4.4	0.119	0.279	0.02	0.003	0.037	0.004	< 0.001
Bennettsbridge Gravel (PWS04-G)	02/10/2000	12:25:00	0.05	1.1	0.051	22	260	253	>=	76		4	21.2			10.1	301	18.3	3.8	< 0.05	< 0.05	0.066	0.037	0.042	0.005	< 0.001
Bennettsbridge Mixed (PWS04-M)	02/10/2000	12:50:00	0.02	4.5	0.009	23	311	291		104		5	23			19.2	390	16.7	3.3	< 0.05	< 0.05	0.025	0.002	0.046	0.006	< 0.001
Kilree Stoneyford (GWS08)	02/10/2000	15:00:00	0.131	15.4	< 0.001	19	397	370	>	80		60	11.3			29.9	520	11.4	3	< 0.05	< 0.05	< 0.001	0.008	0.039	0.002	< 0.001
Spring at Clomantagh	12/02/2001	11:00:00	0.015	4.1	0.002	14	305	270		15		12	34.9			6.5	331	5.5	1.3		< 0.01	< 0.02		0.031		

Appendix VI: Summary of trends in water quality over time for selected supply sources in Kilkenny

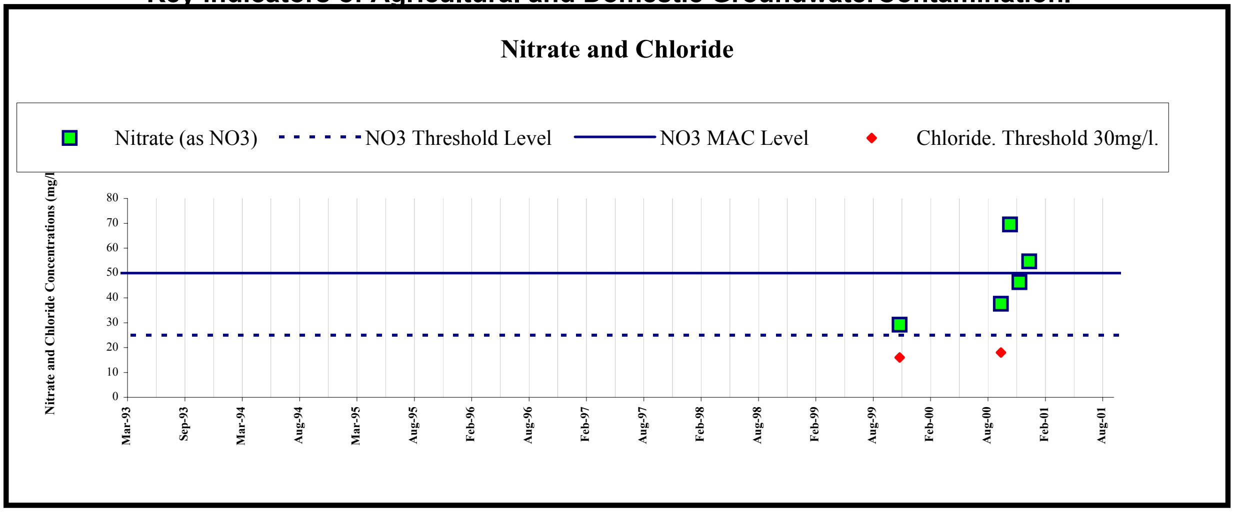
Ahanure GWS.
Key indicators of Agricultural and Domestic GroundwaterContamination.

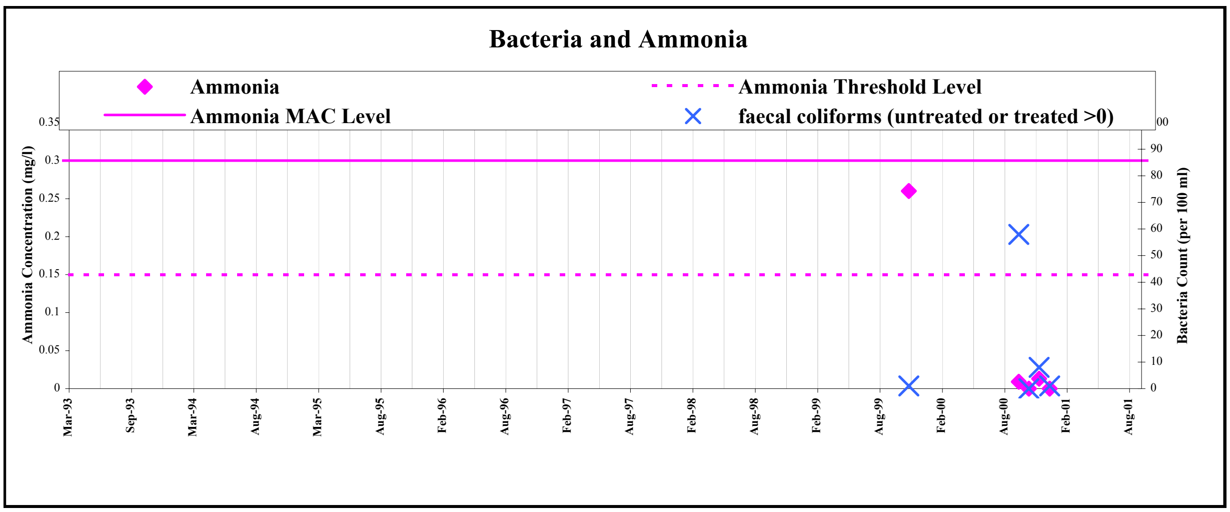


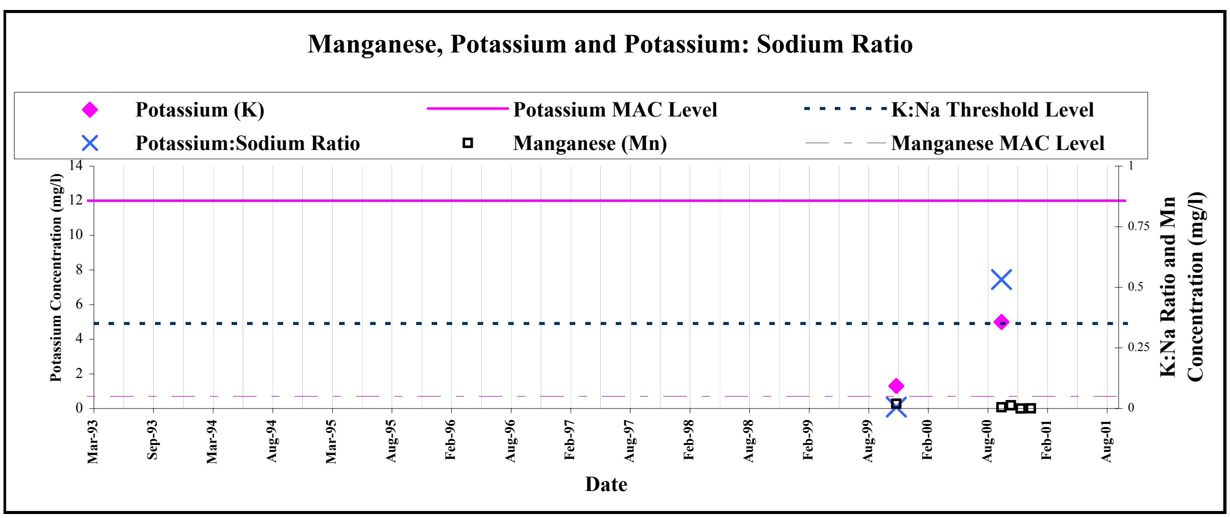




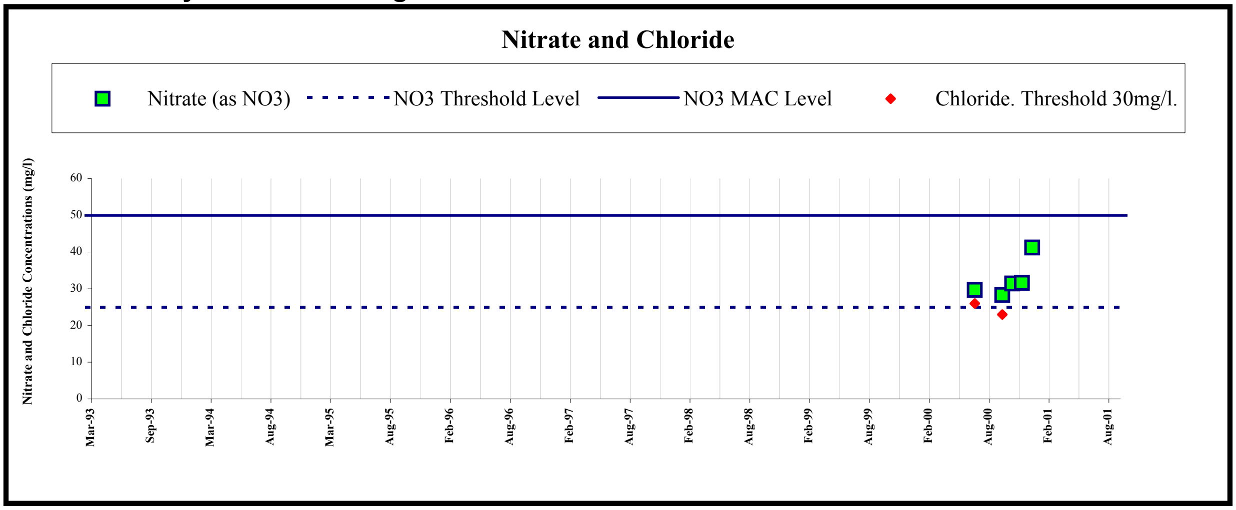
Balief Clomantagh GWS.
Key indicators of Agricultural and Domestic GroundwaterContamination.

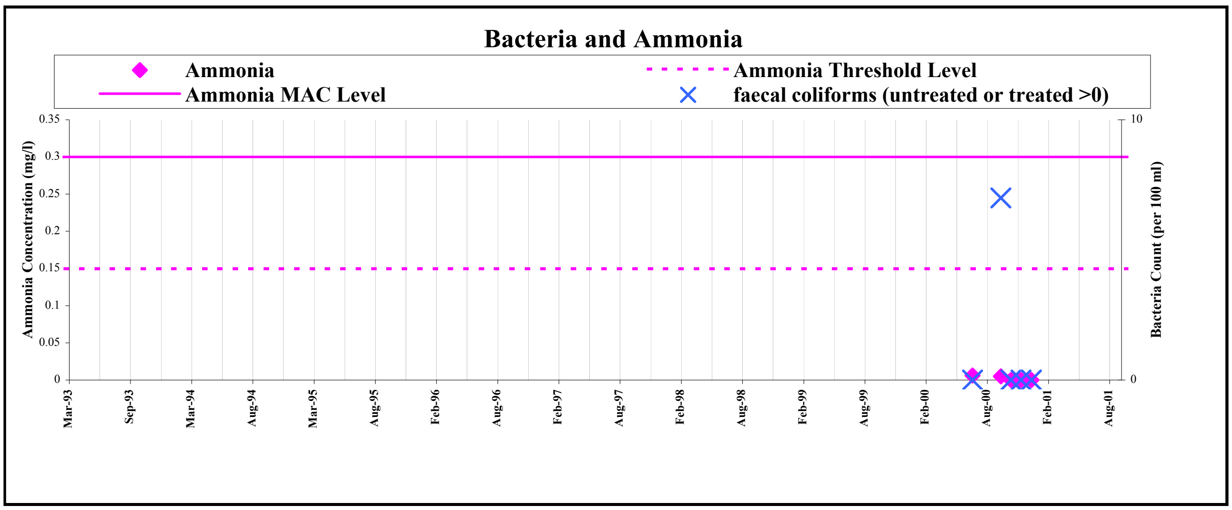


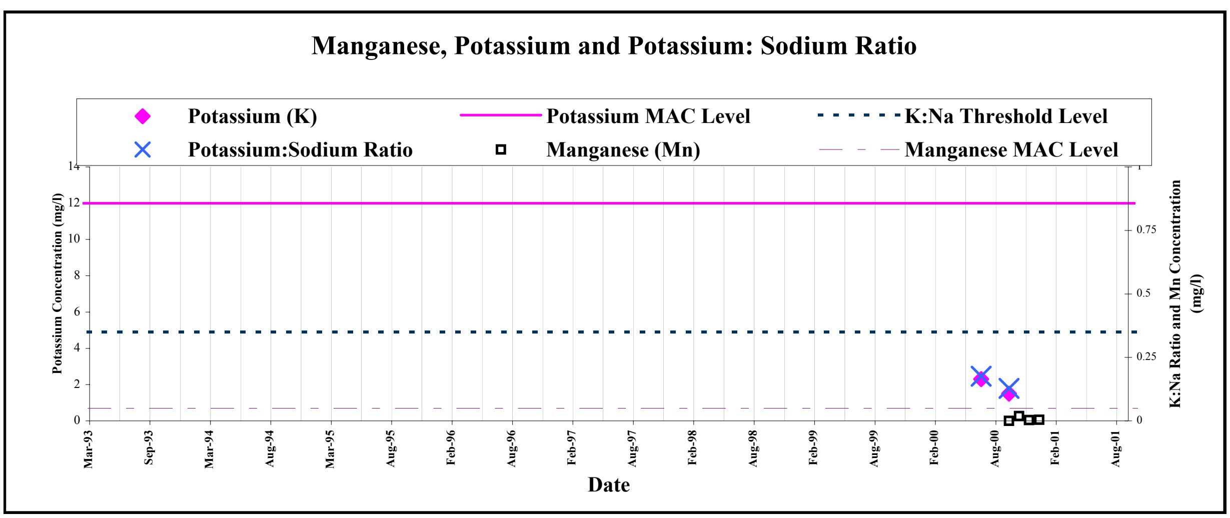




Ballymack GWS
Key indicators of Agricultural and Domestic GroundwaterContamination.

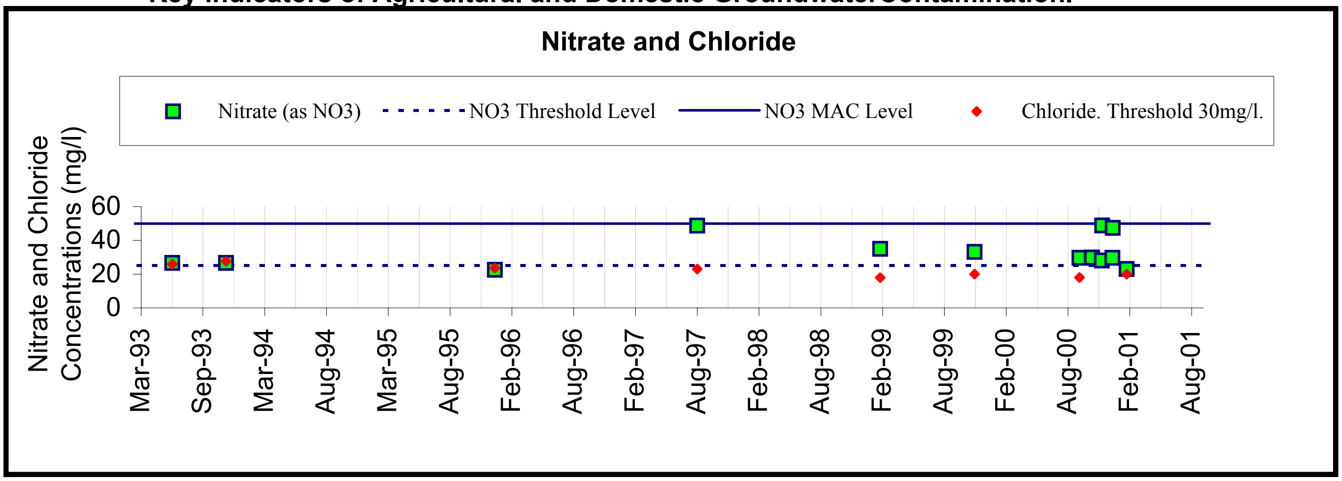


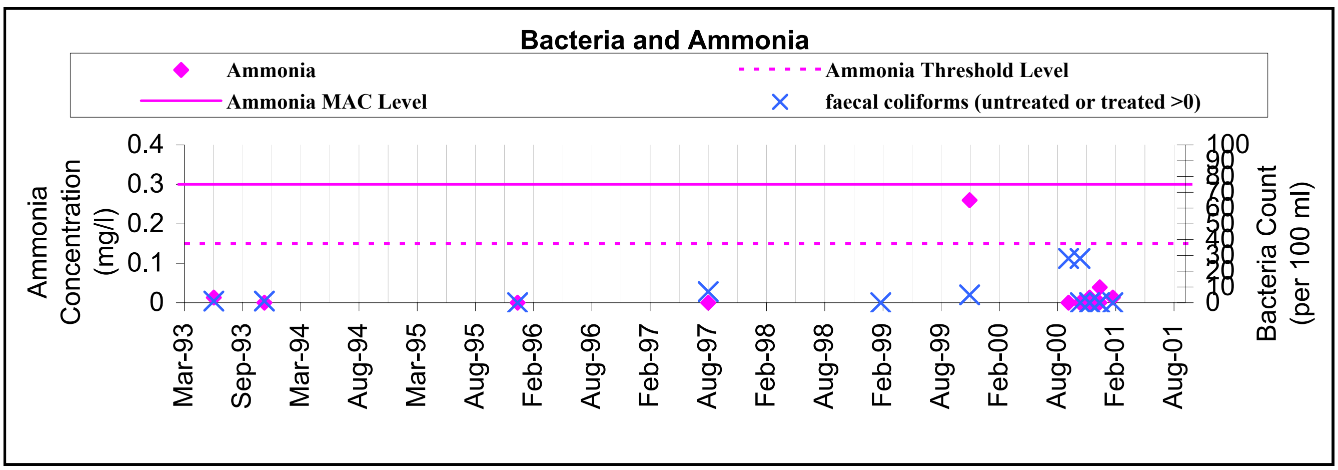


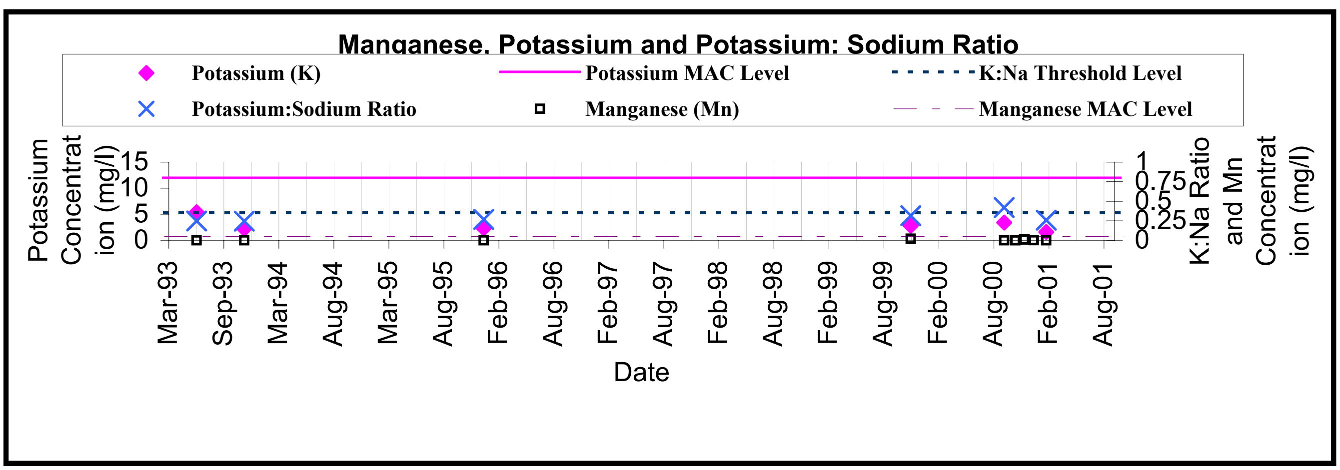


Bawnmore GWS

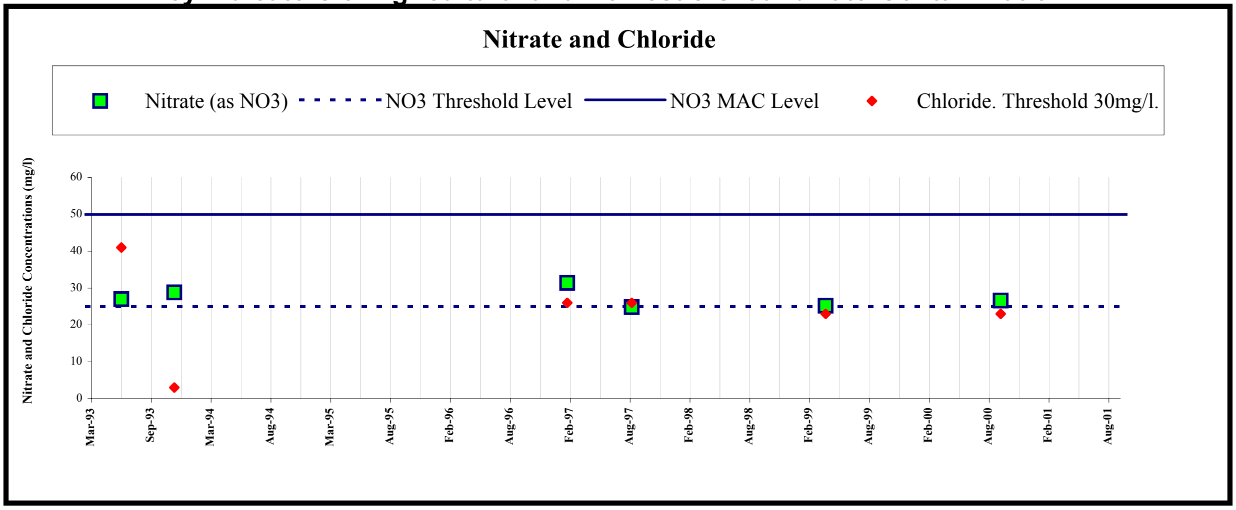
Key indicators of Agricultural and Domestic GroundwaterContamination.

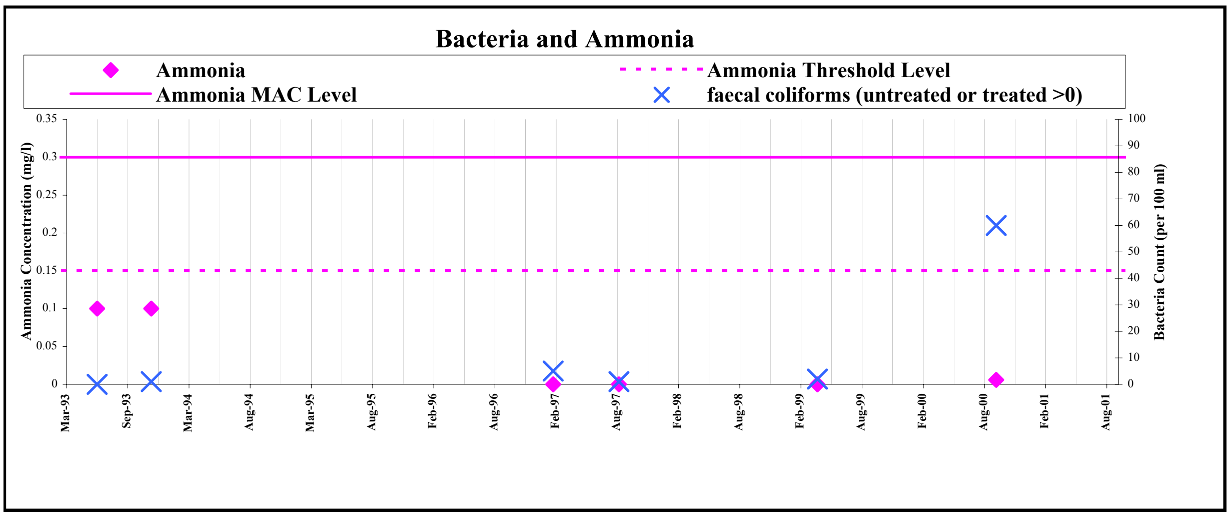


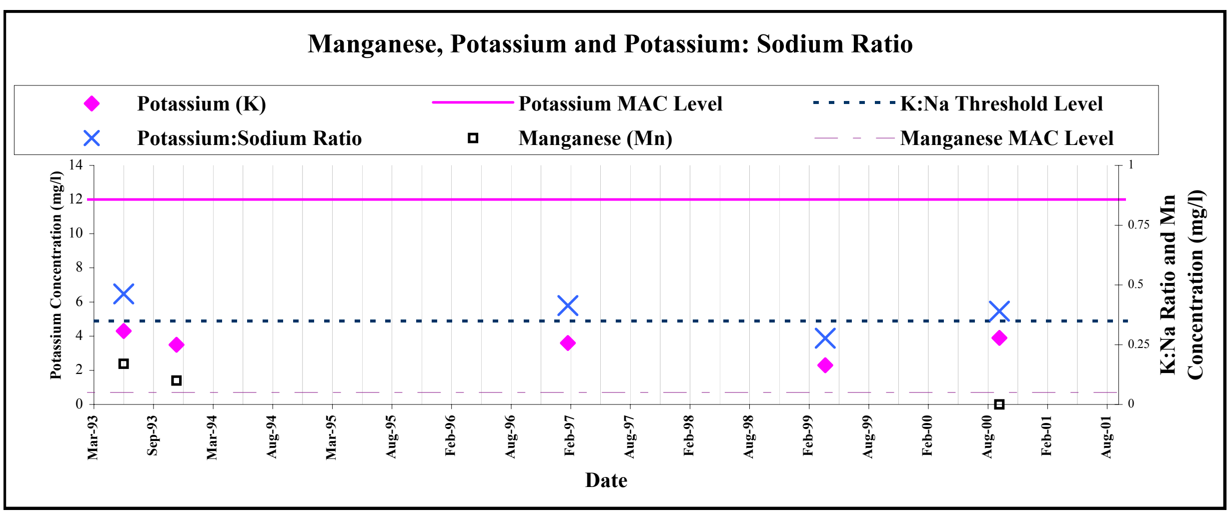




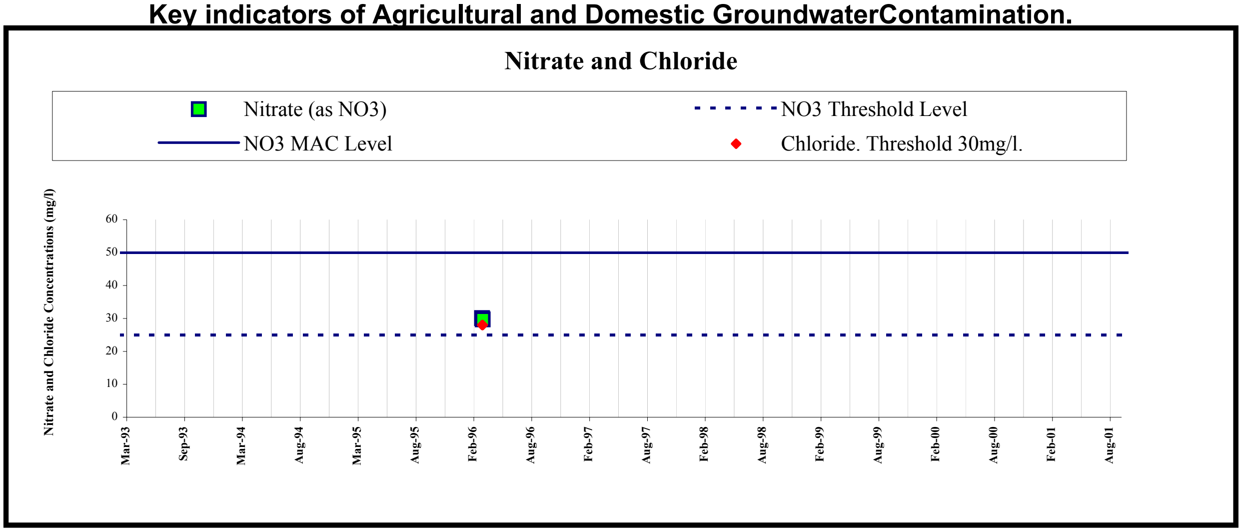
Bausheenmore Springs
Key indicators of Agricultural and Domestic GroundwaterContamination.

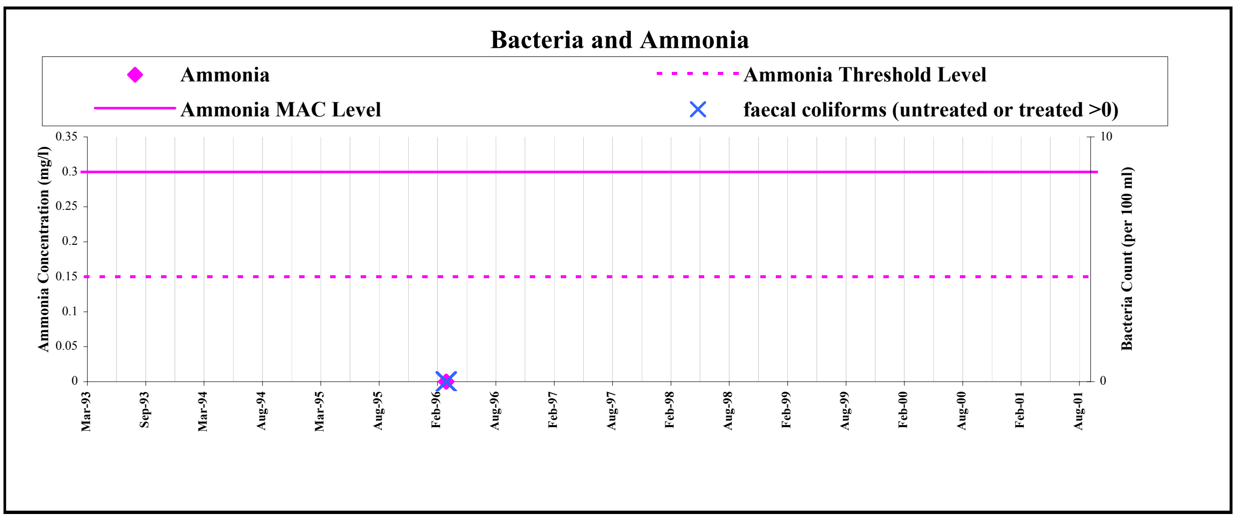


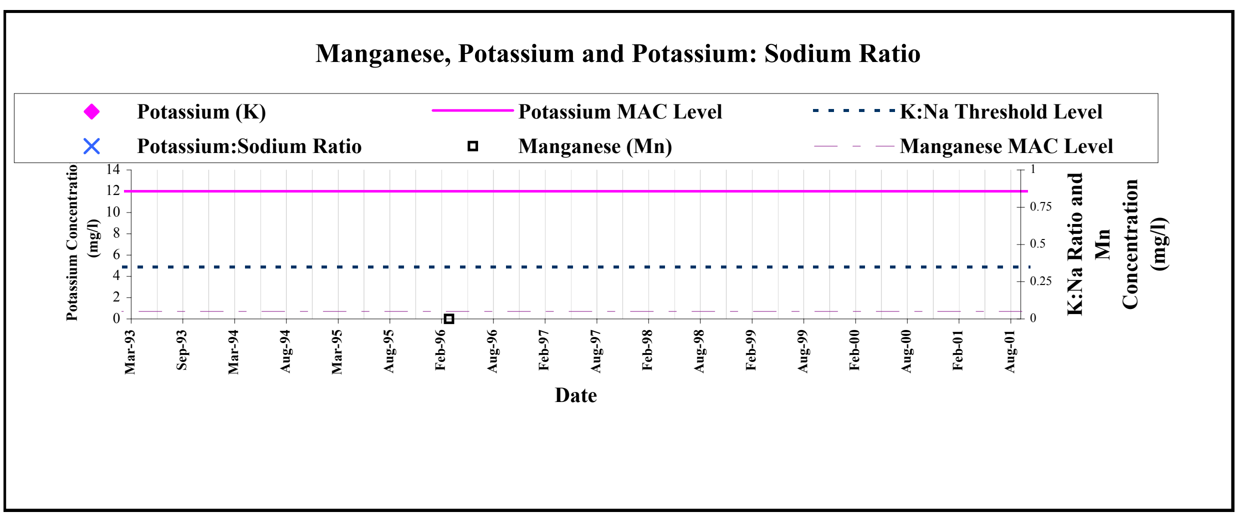




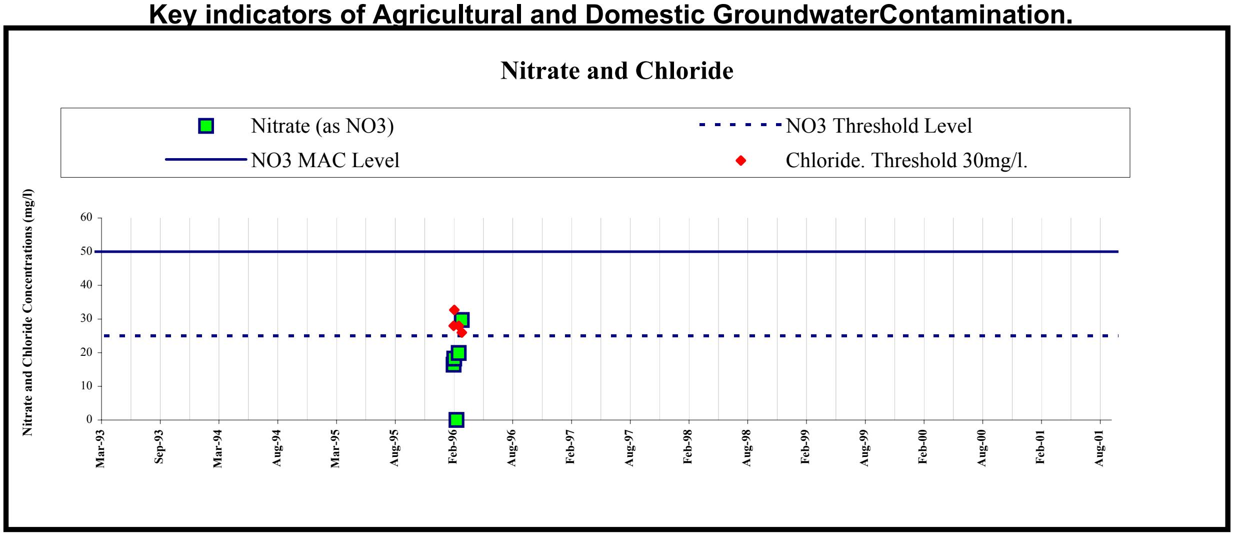
Belview 1 (Proposed Scheme)
Key indicators of Agricultural and Domestic GroundwaterContamination.

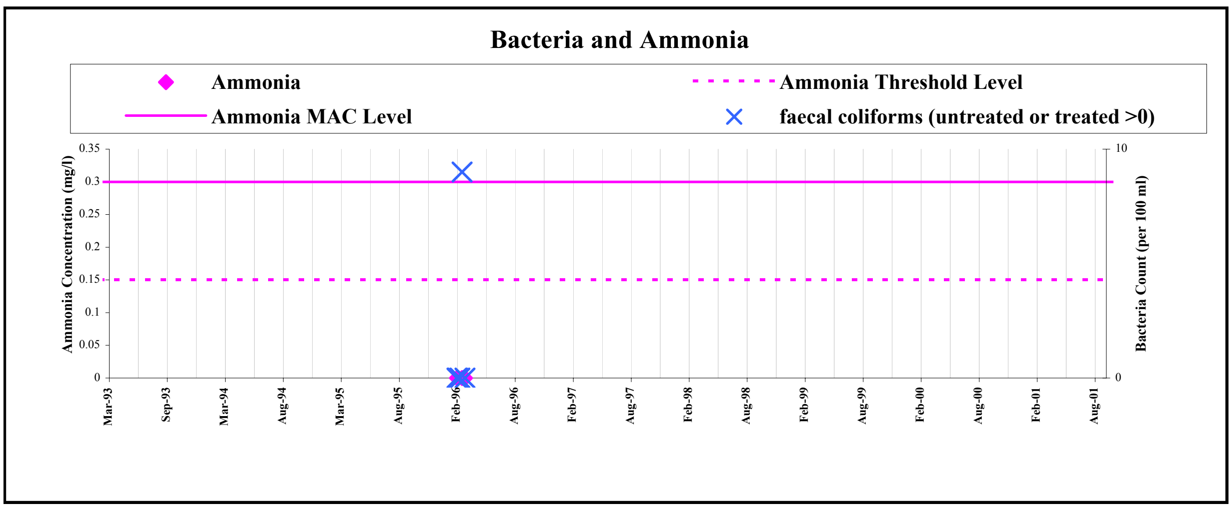


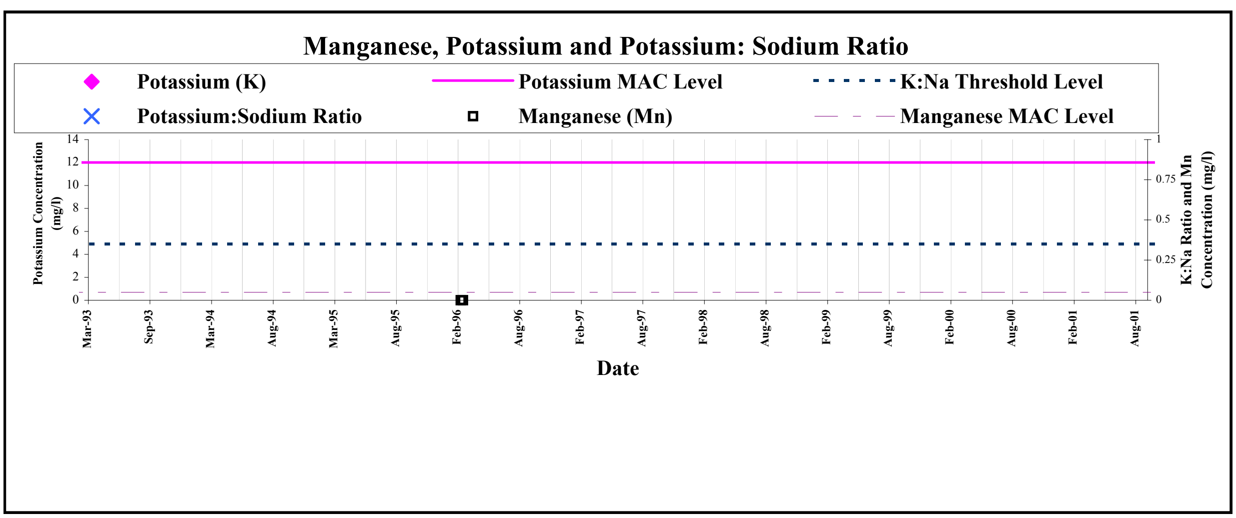




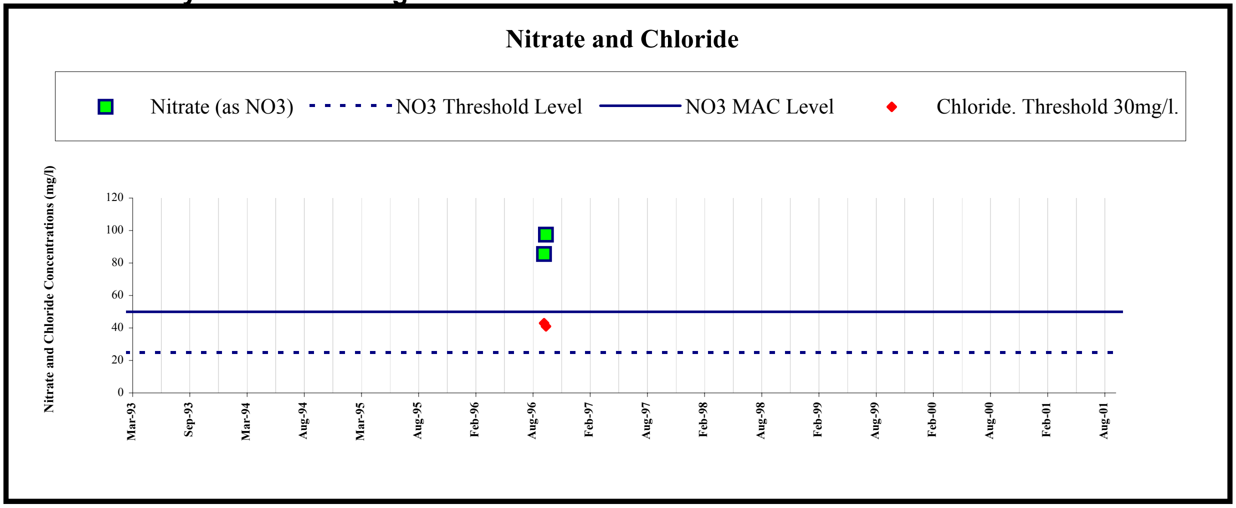
Belview 2 (Proposed Scheme)
Key indicators of Agricultural and Domestic GroundwaterContamination.

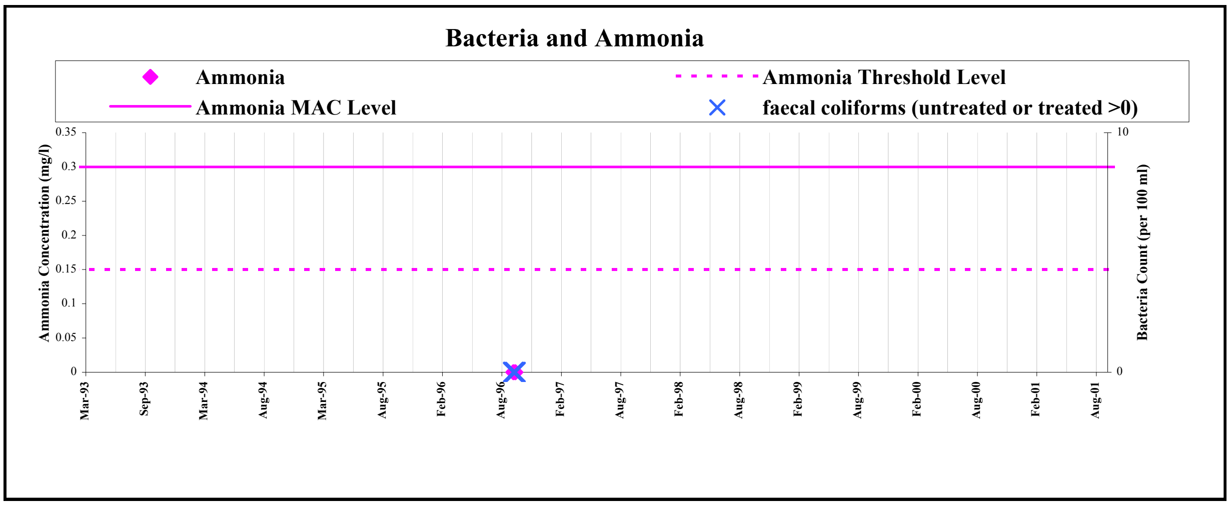






Belview 3 (Proposed Scheme)
Key indicators of Agricultural and Domestic GroundwaterContamination.





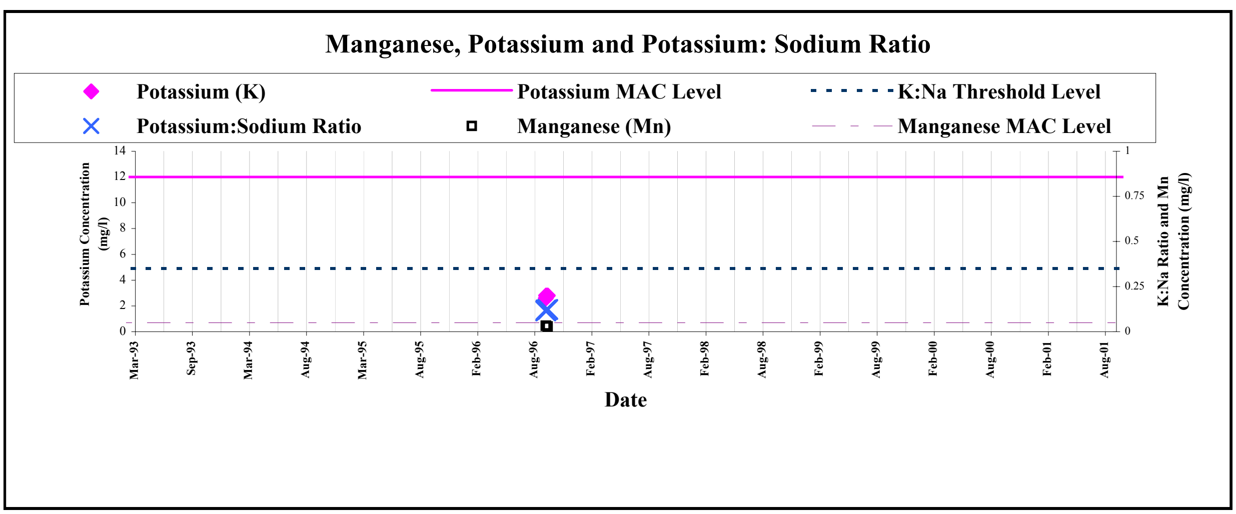
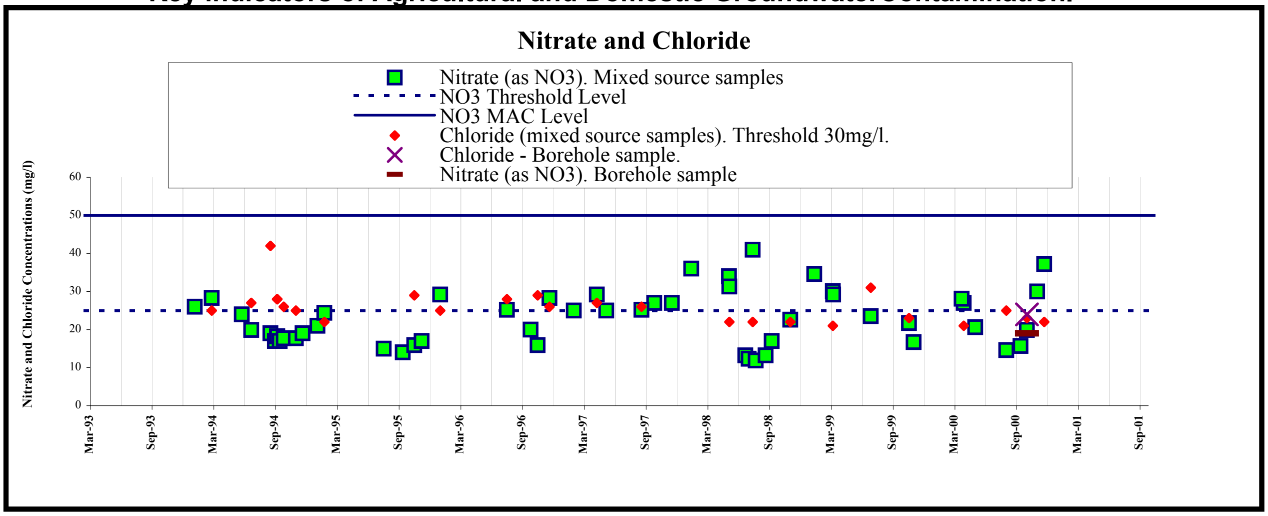
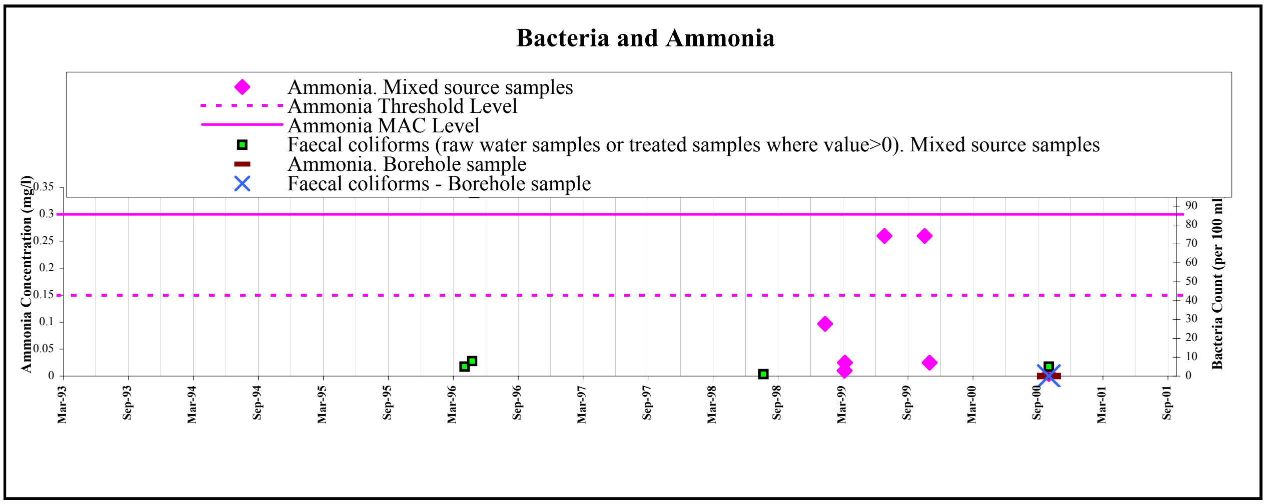
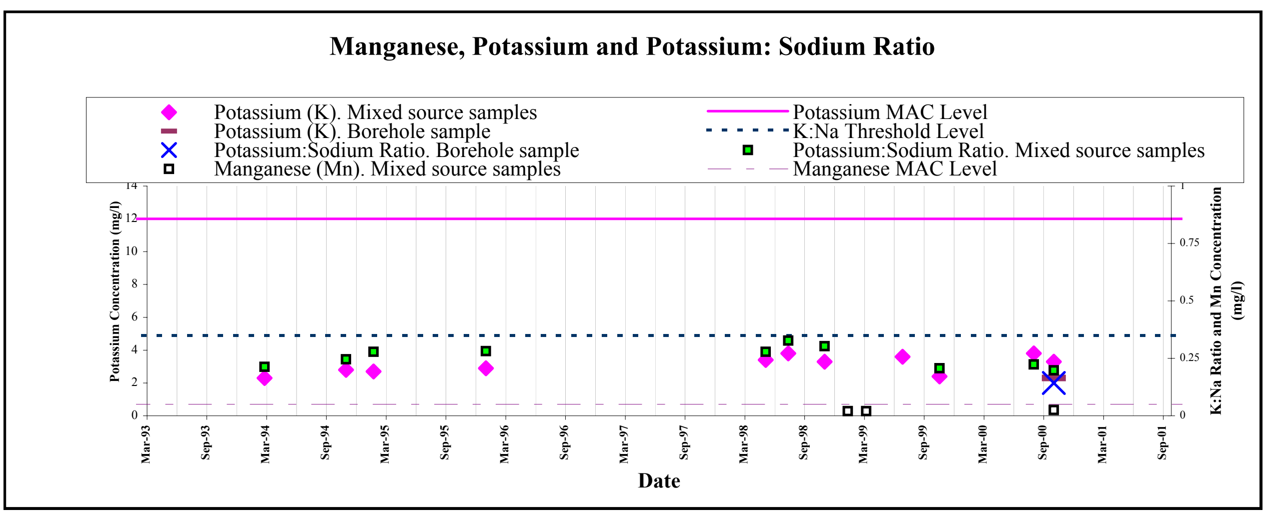


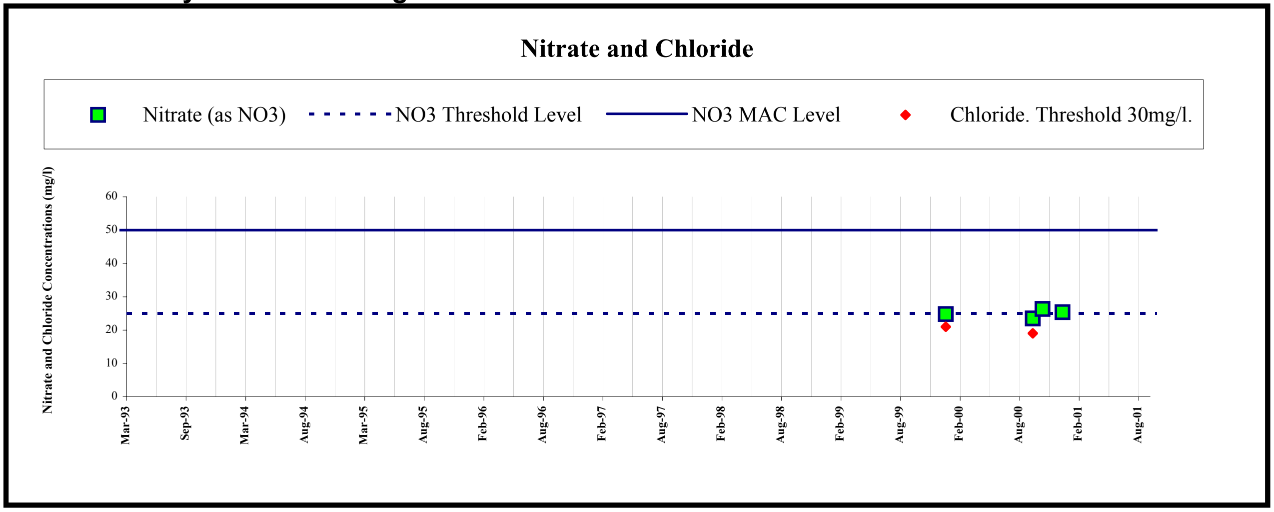
Fig 8.2-Bennettsbridge
Key indicators of Agricultural and Domestic GroundwaterContamination.

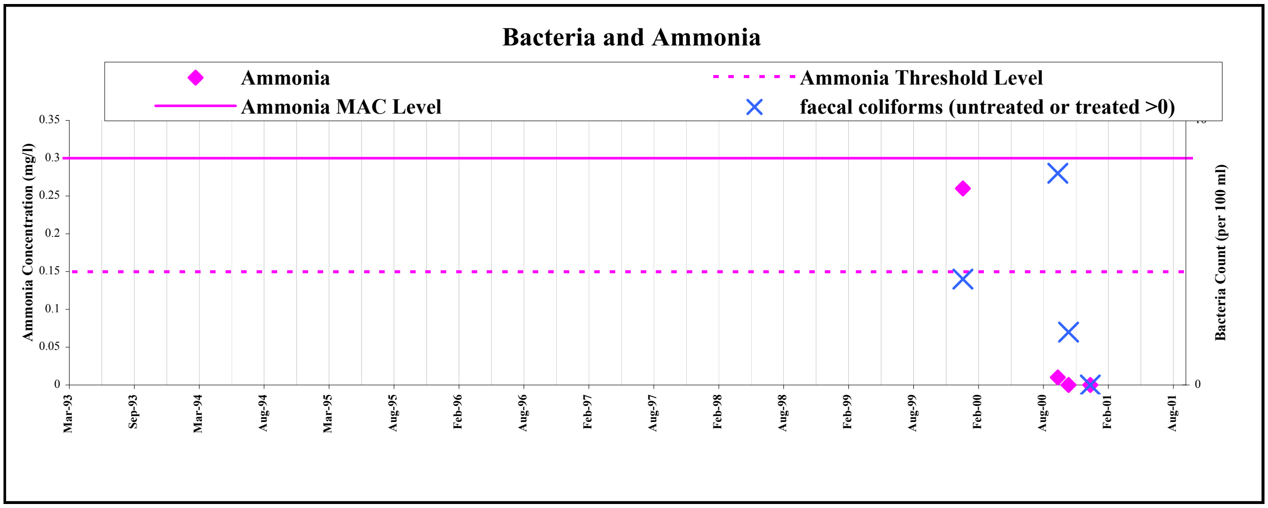






Caherlesk GWS
Key indicators of Agricultural and Domestic GroundwaterContamination.





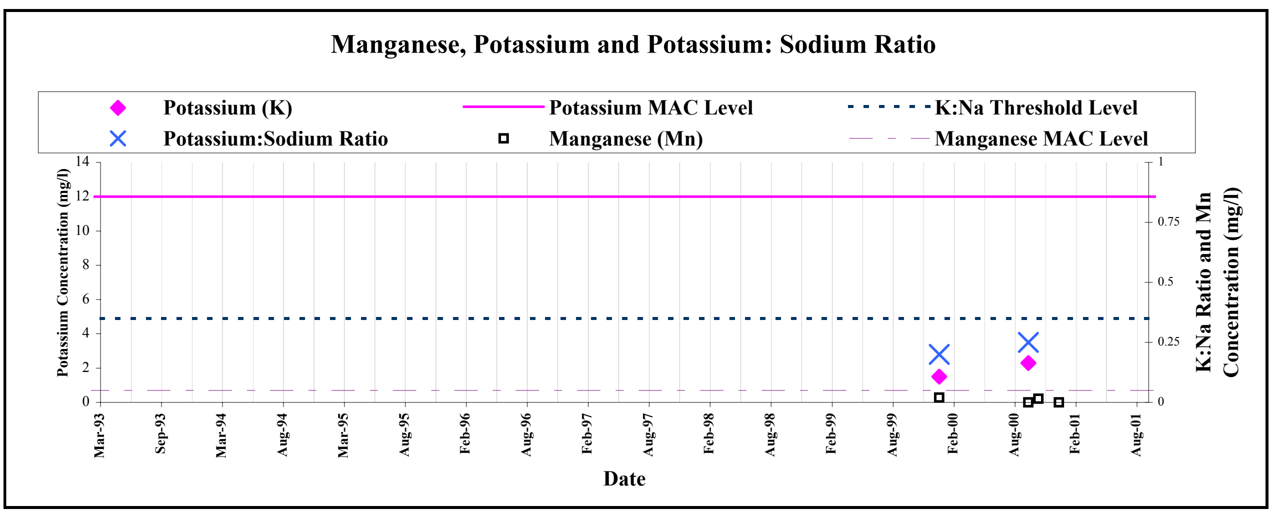
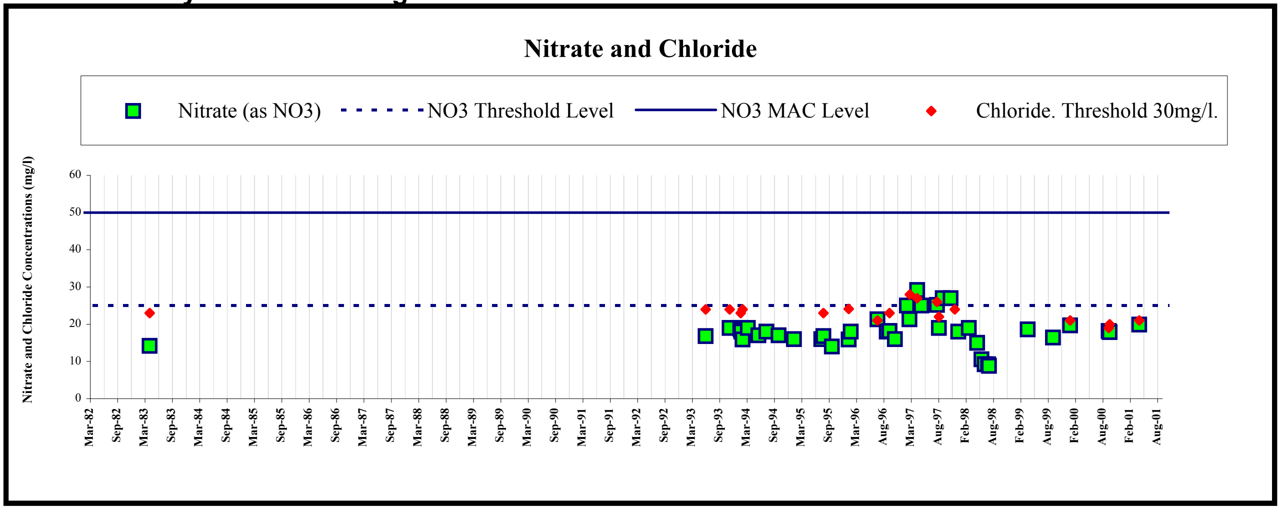
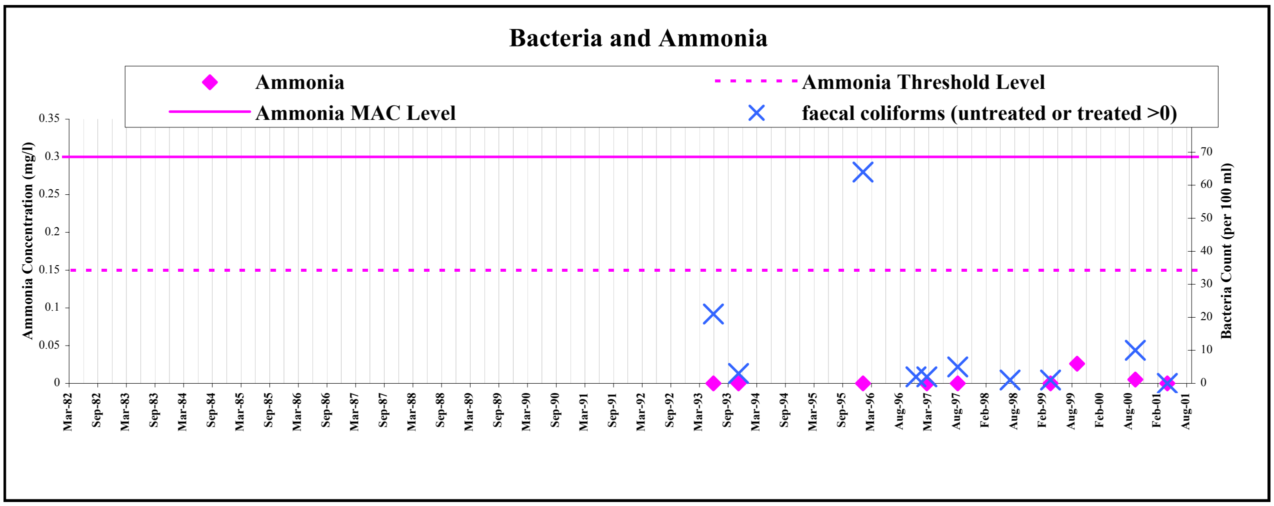
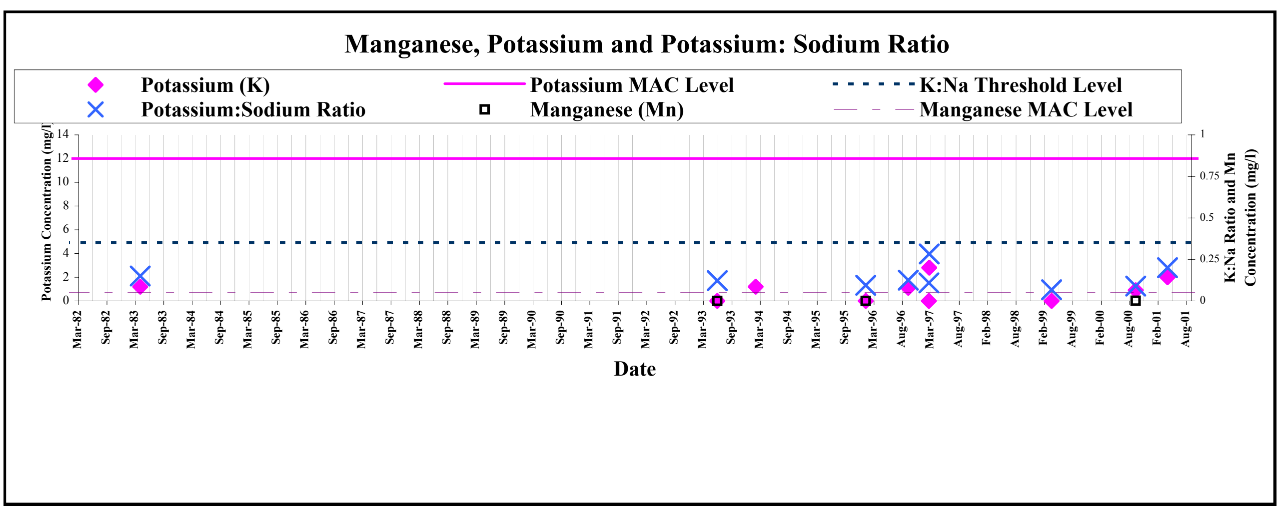


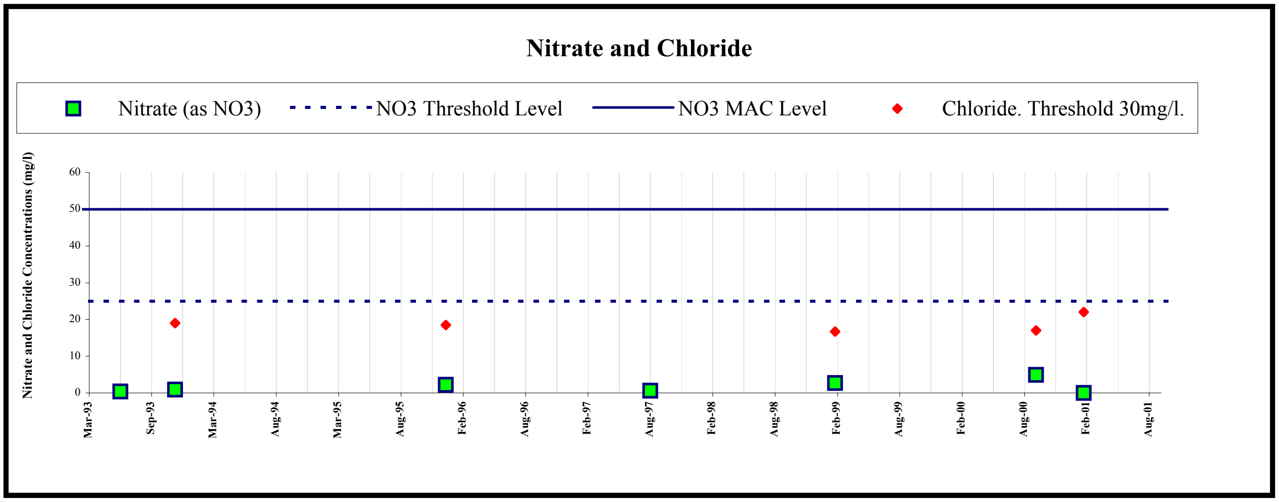
Figure 9.2- Callan Spring
Key indicators of Agricultural and Domestic GroundwaterContamination.

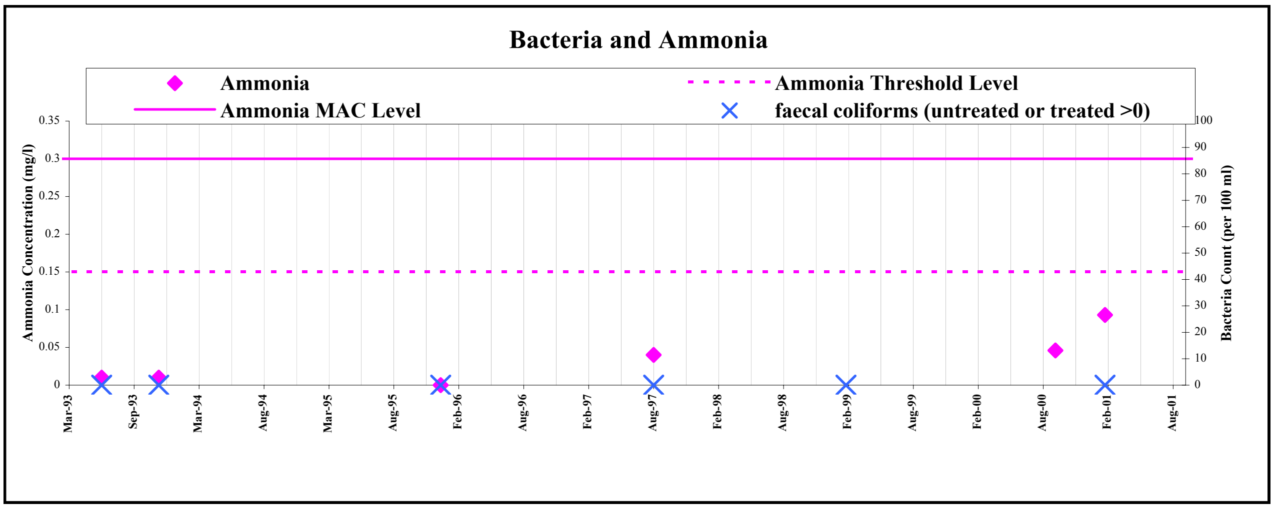


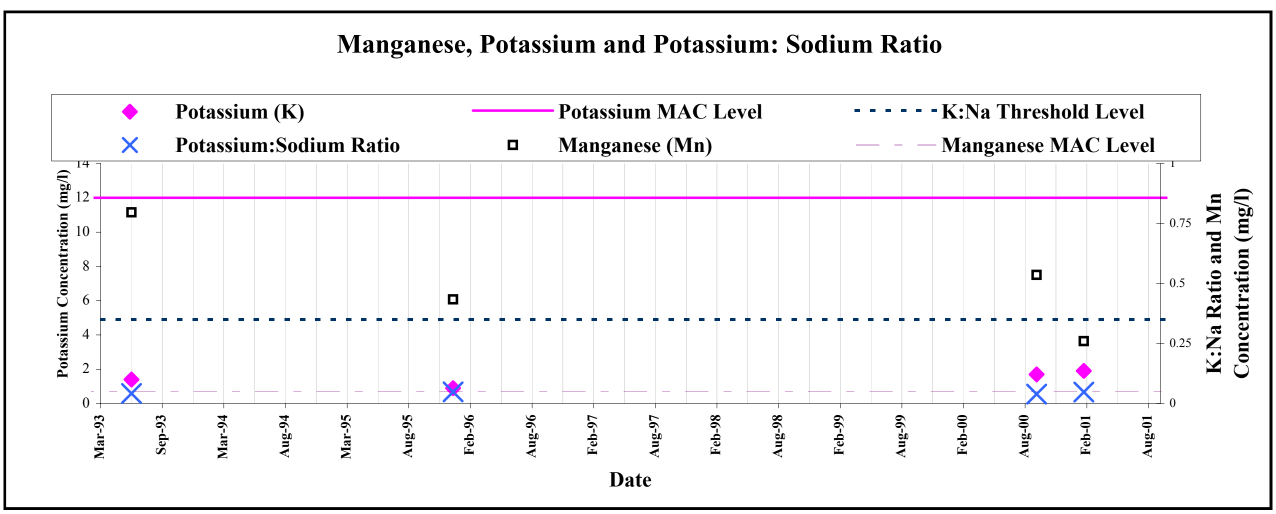




Castlecomer Yarns (Industrial)
Key indicators of Agricultural and Domestic GroundwaterContamination.

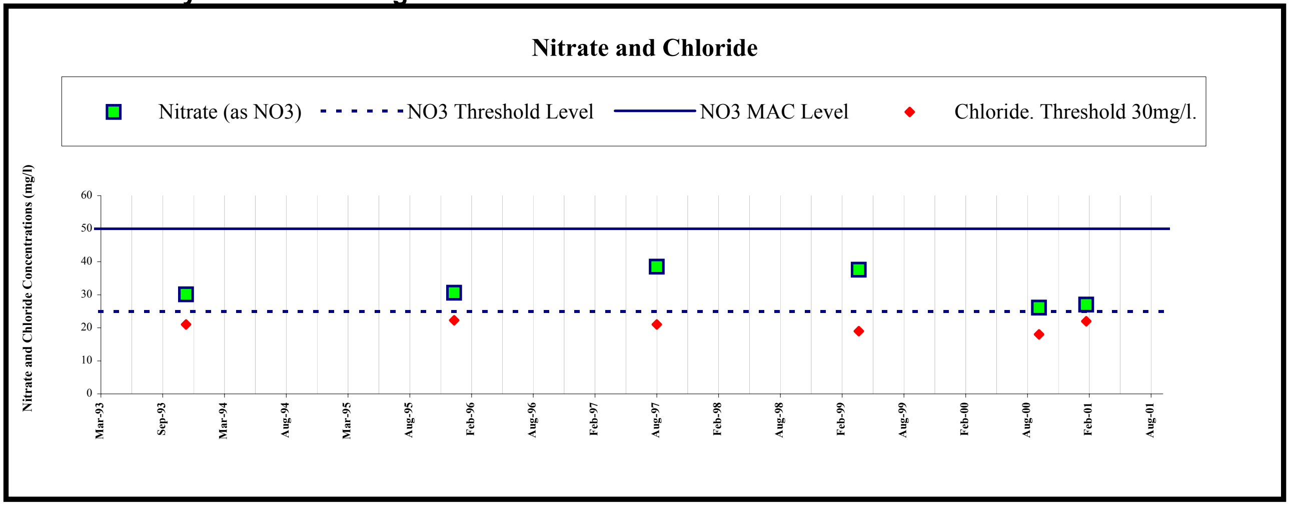


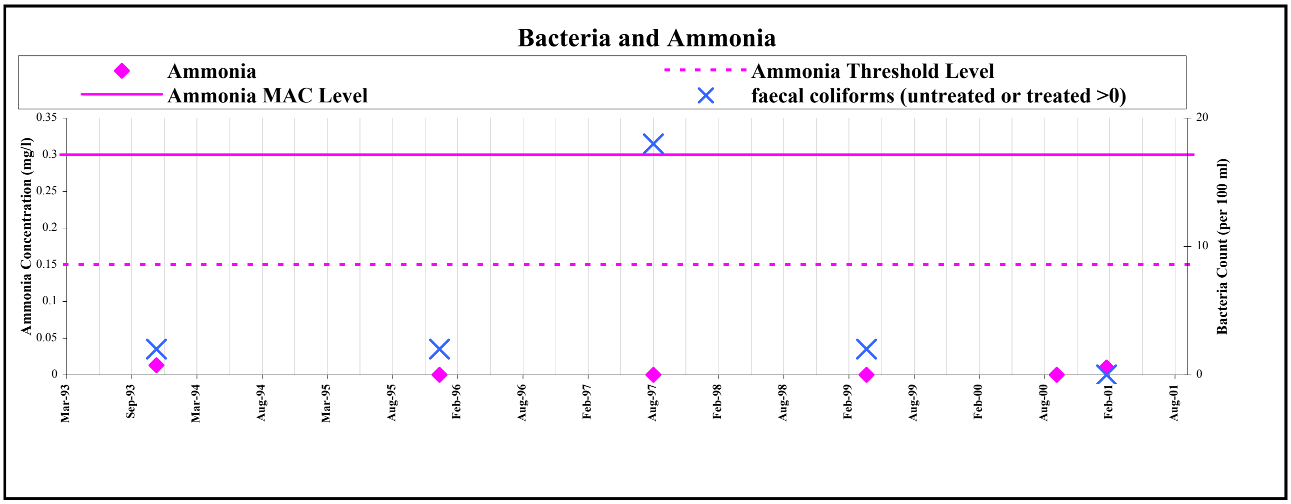


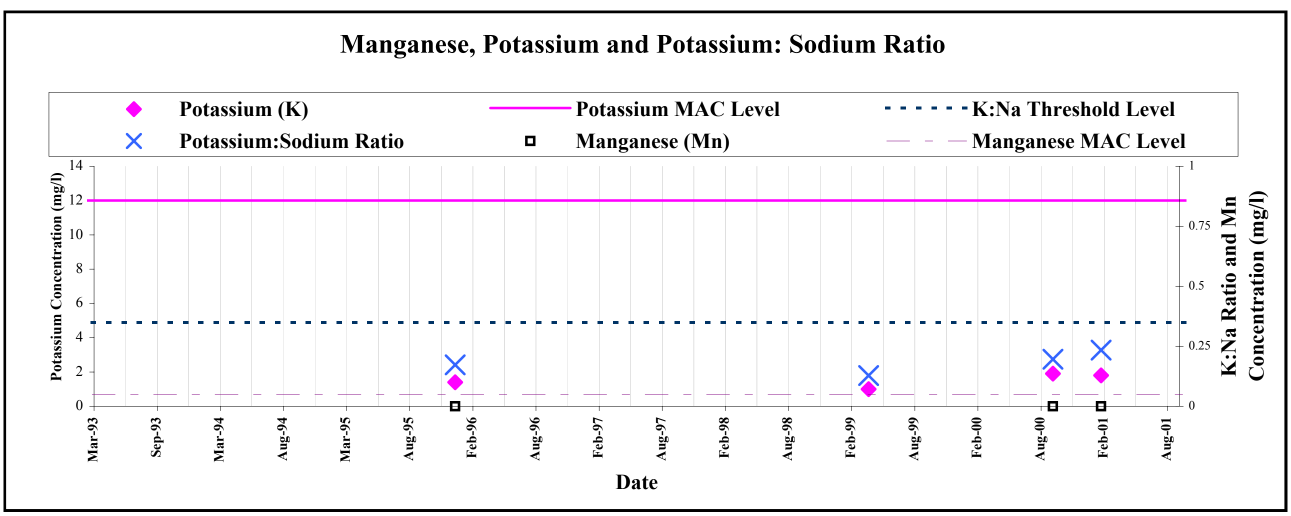


Clara GWS

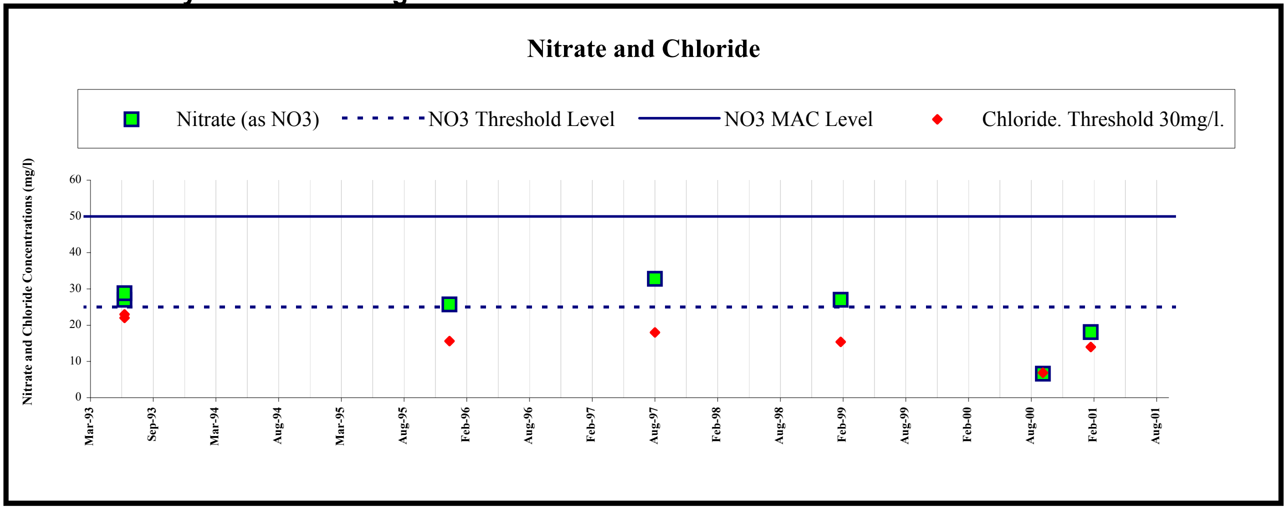
Key indicators of Agricultural and Domestic GroundwaterContamination.

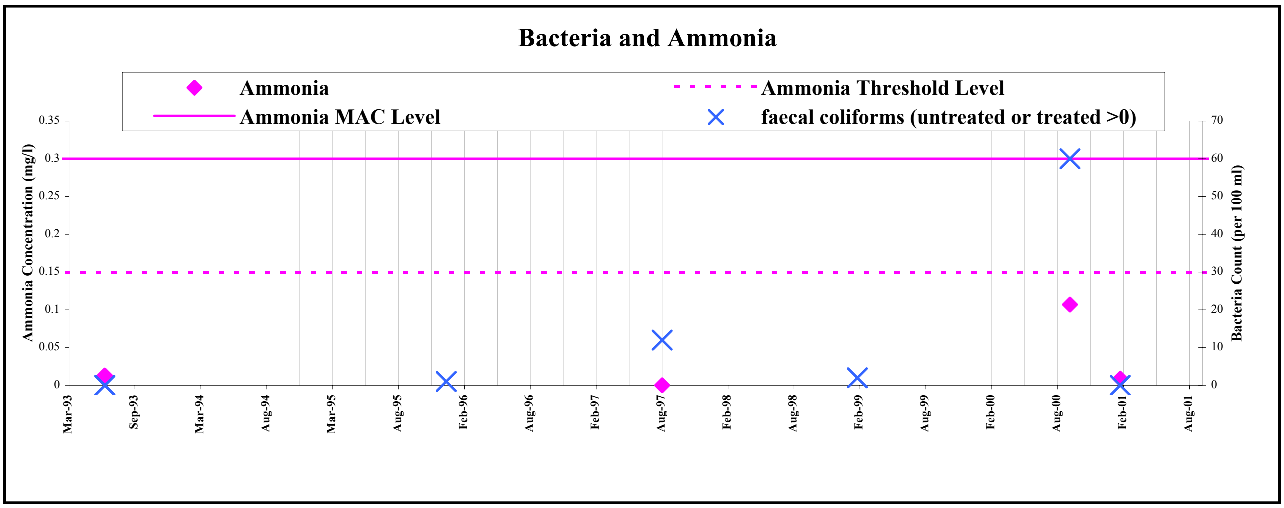


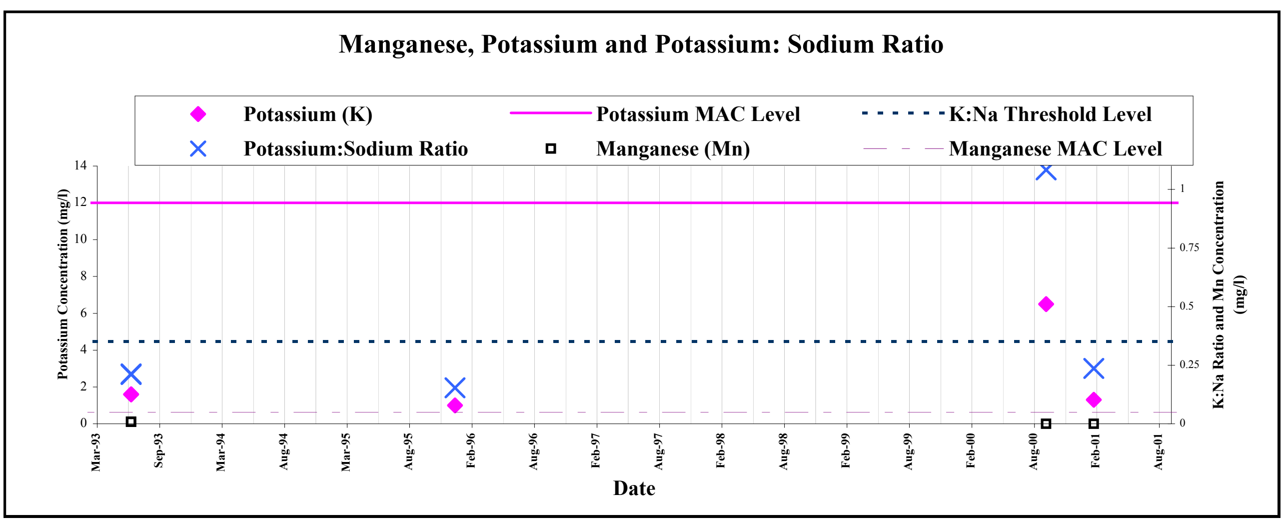




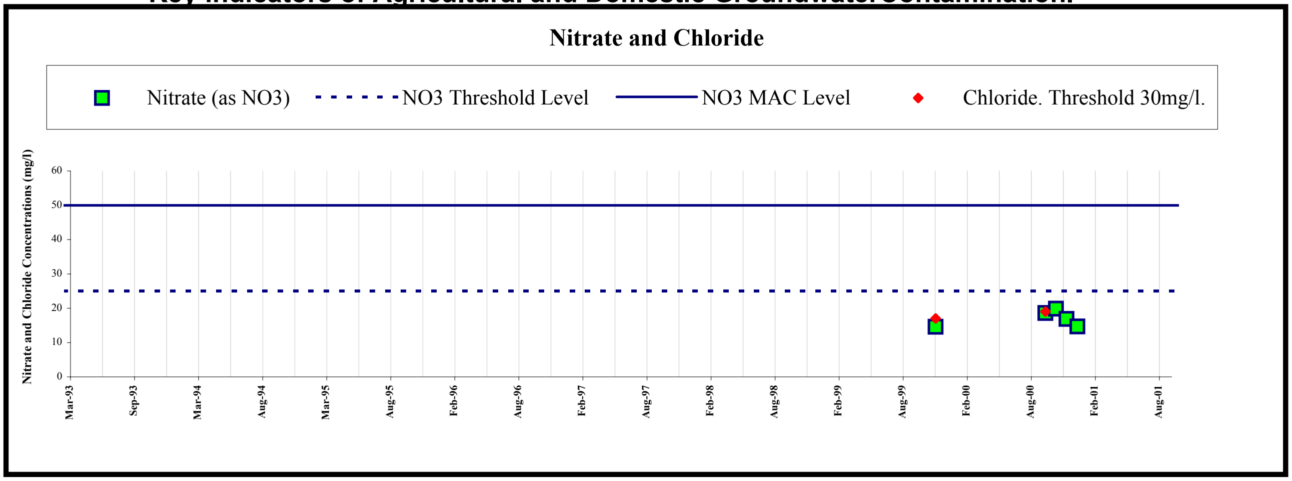
Clomantagh Spring
Key indicators of Agricultural and Domestic GroundwaterContamination.

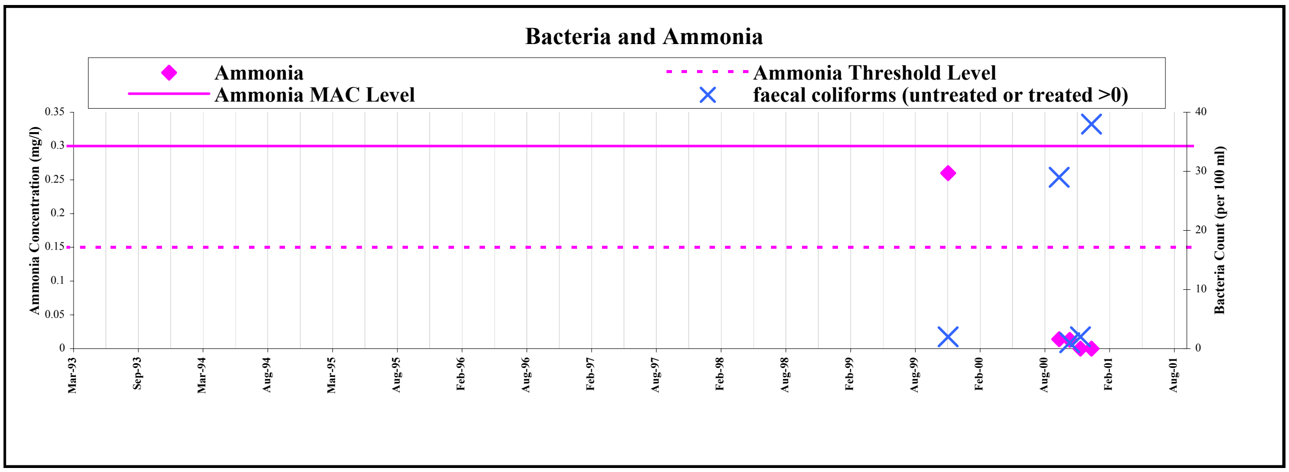


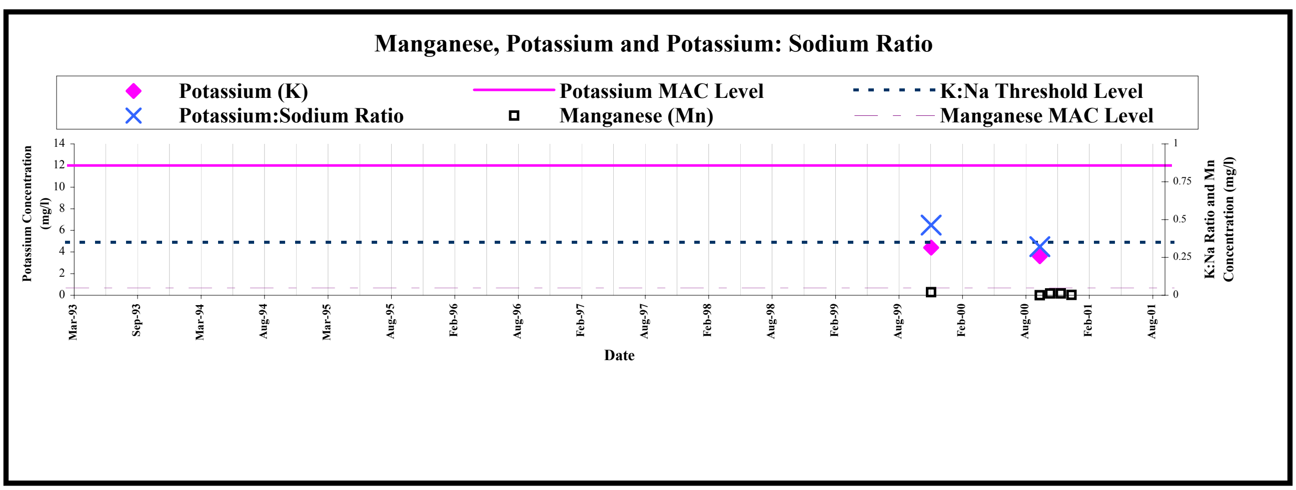




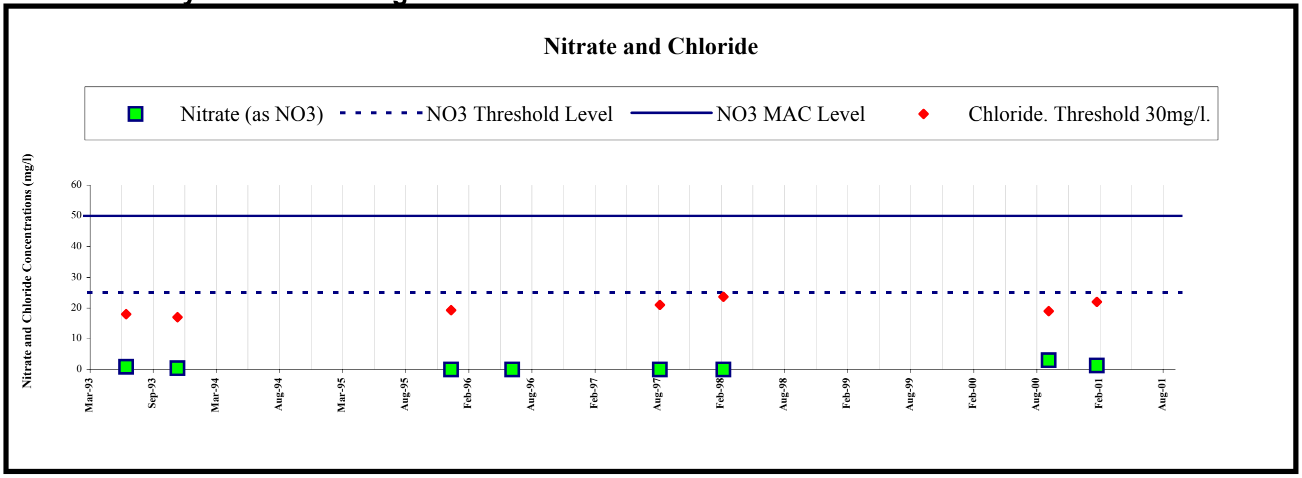
Cuffesgrange GWS
Key indicators of Agricultural and Domestic GroundwaterContamination.

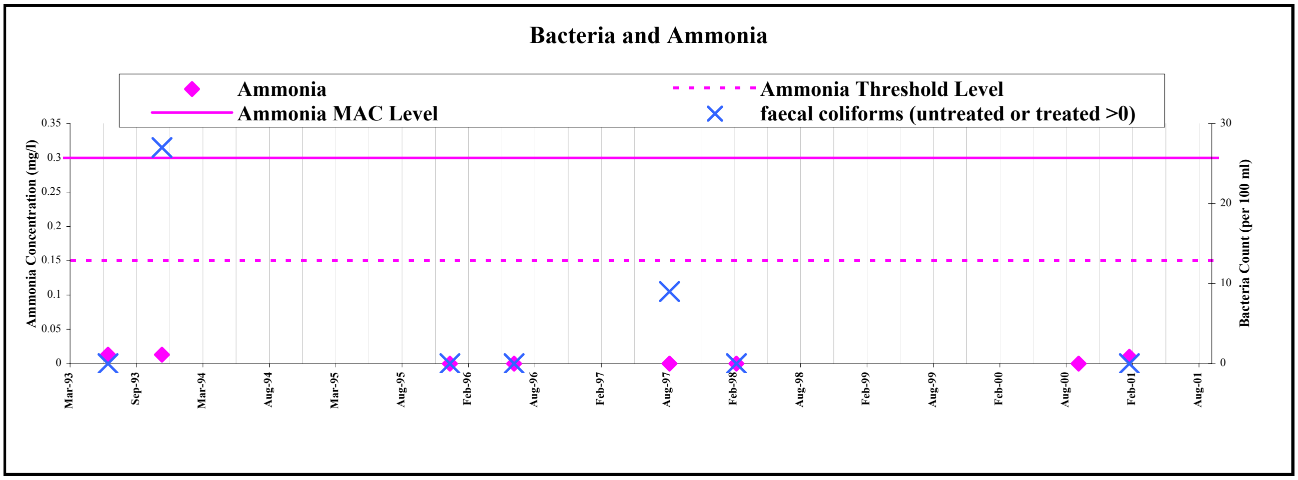


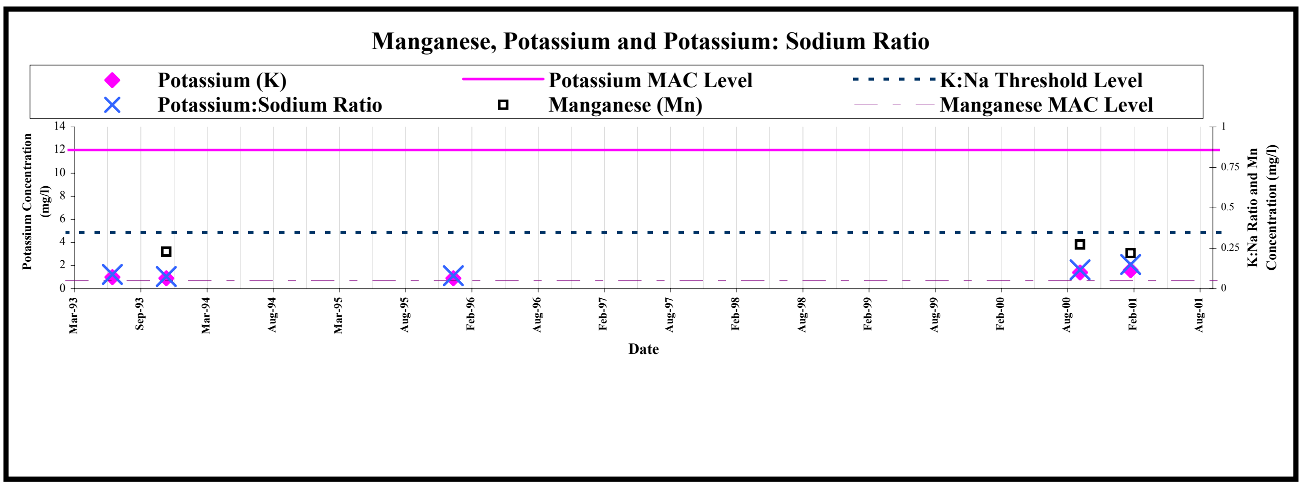




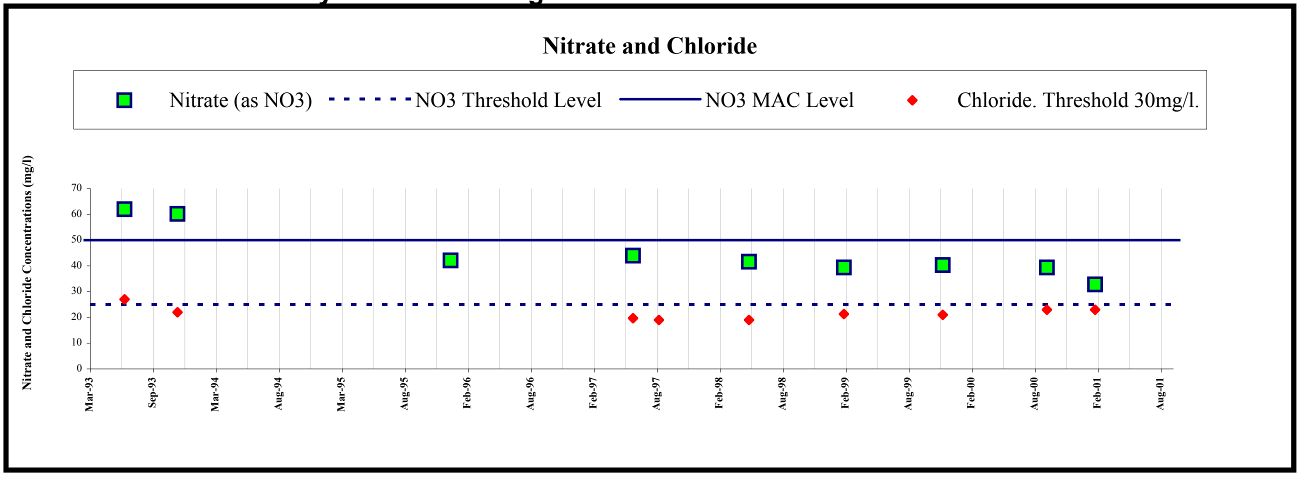
Drunmore SAG (Industrial)
Key indicators of Agricultural and Domestic GroundwaterContamination.

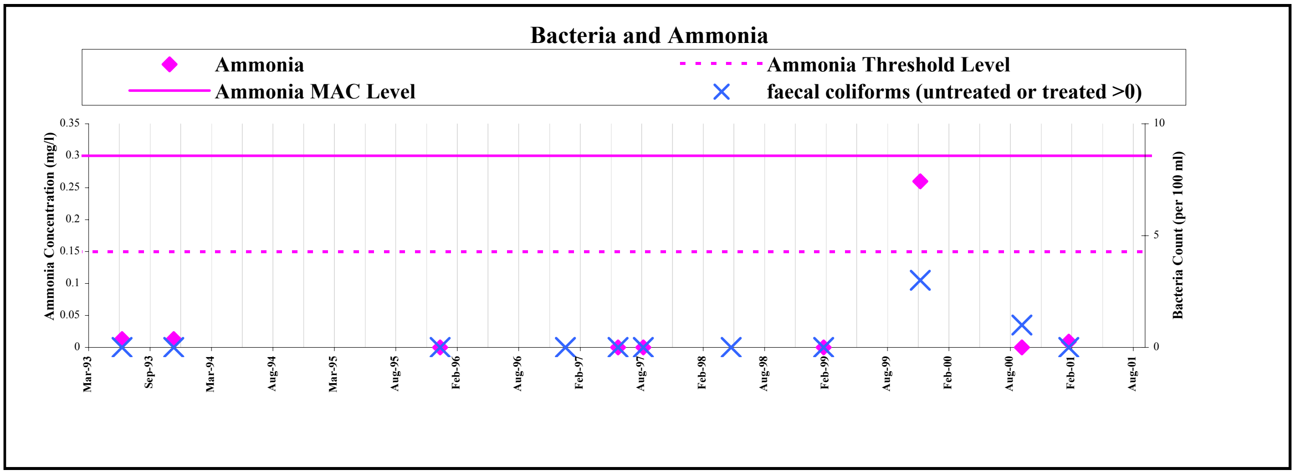


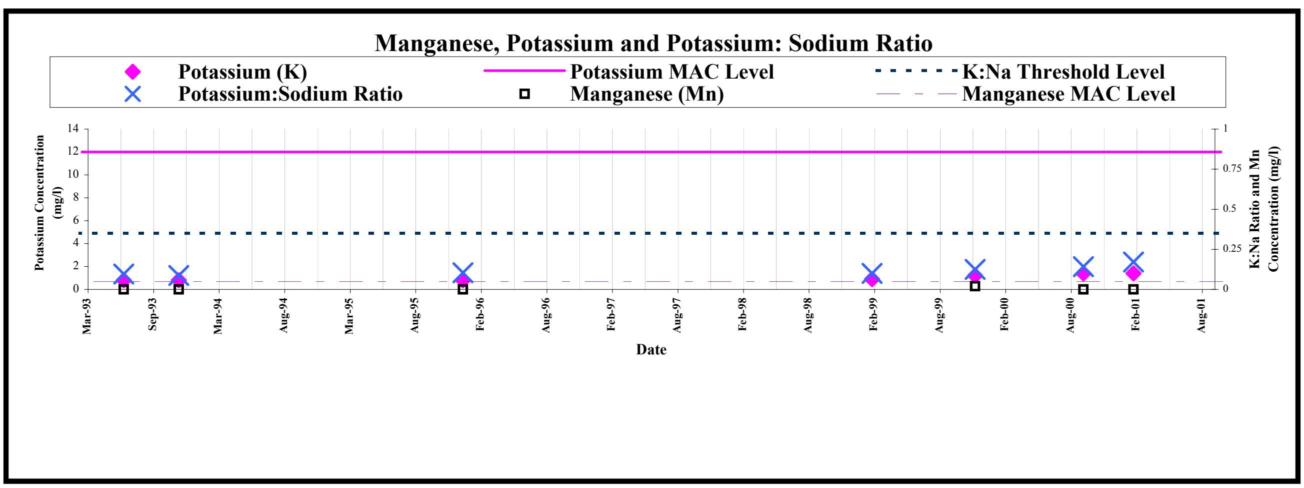




Drunmore GWS
Key indicators of Agricultural and Domestic GroundwaterContamination.

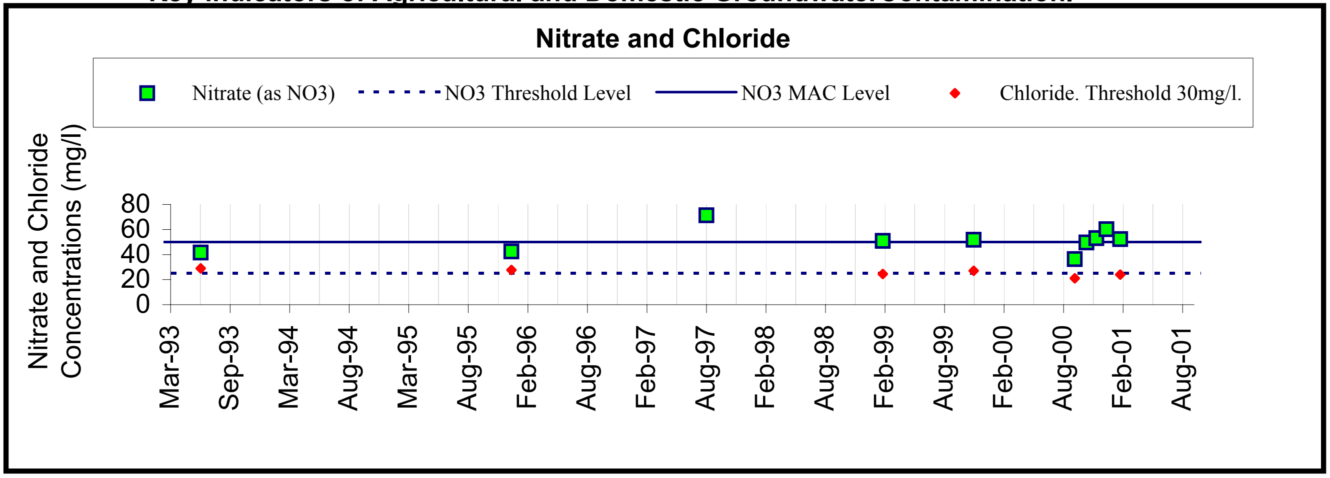


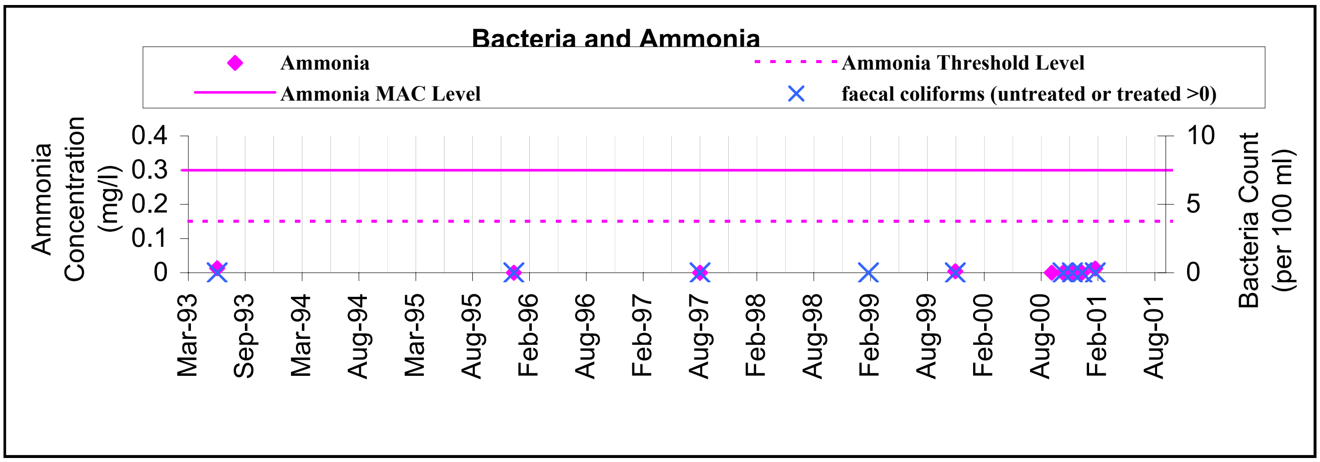




Galmoy GWS

Key indicators of Agricultural and Domestic GroundwaterContamination.





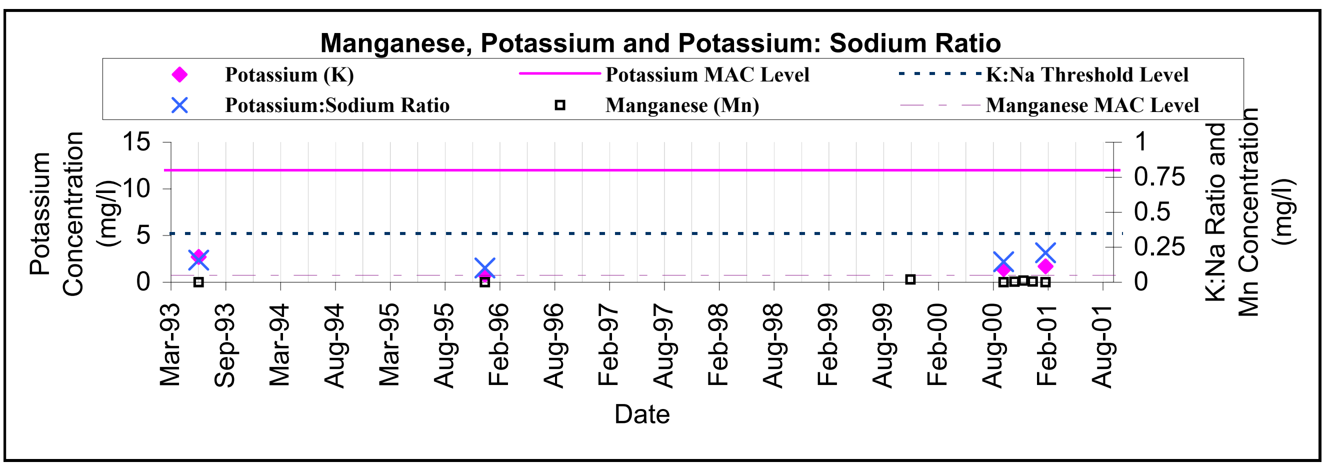
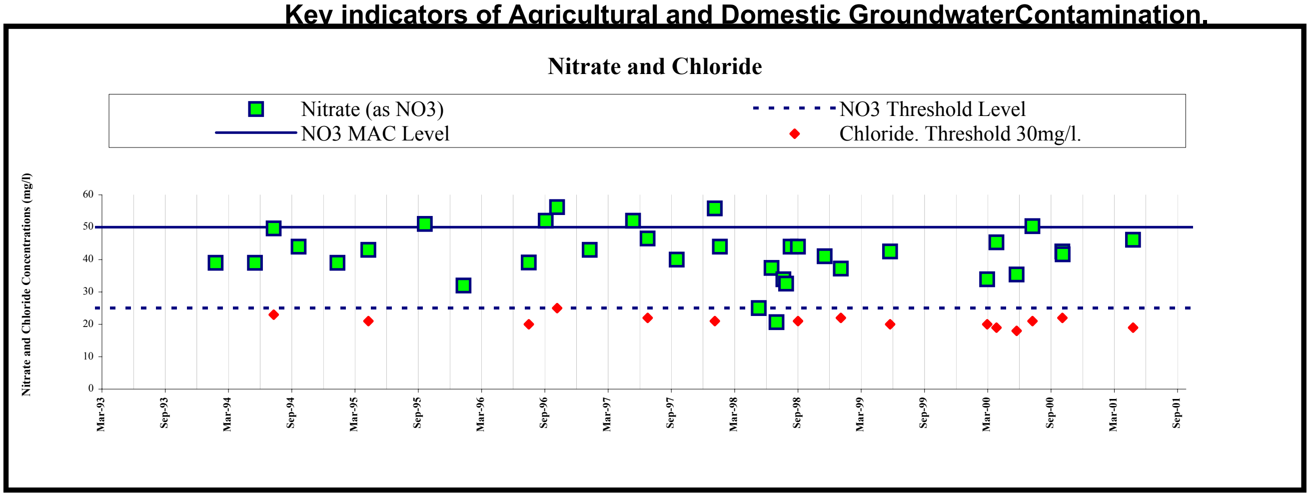
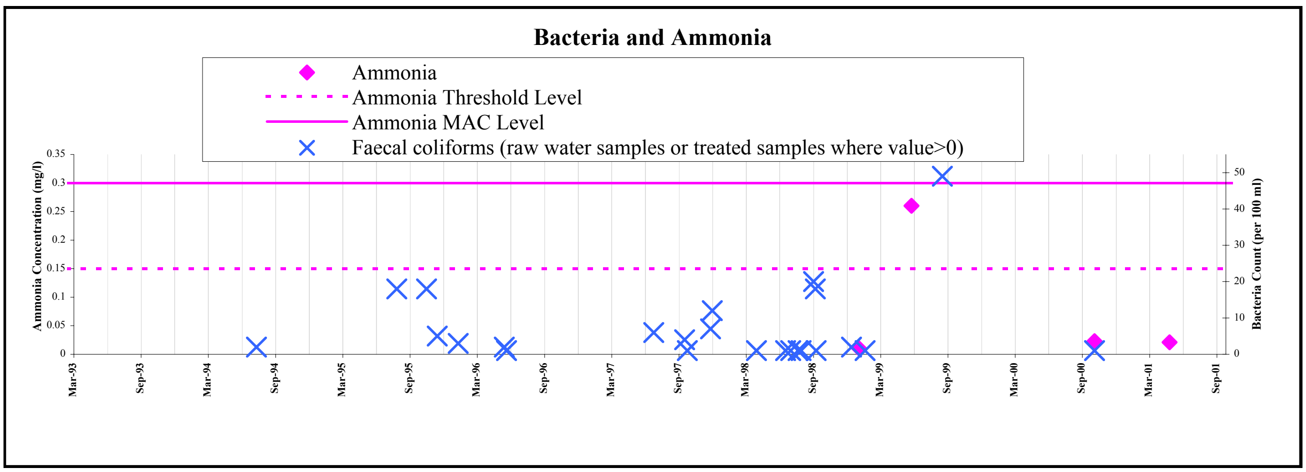
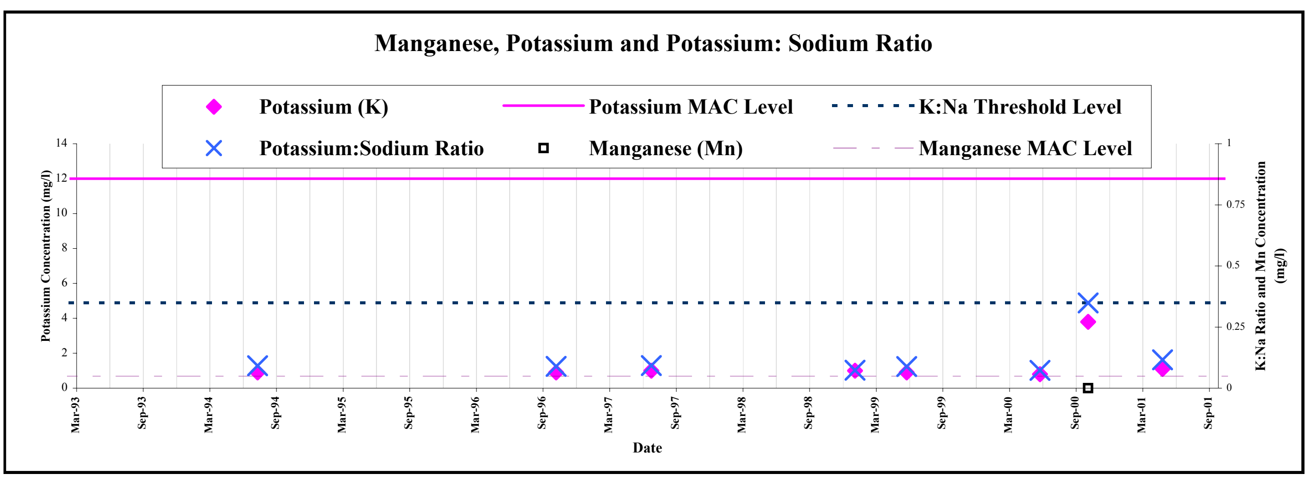


Figure 10.1- Glenmore Spring

Key indicators of Agricultural and Domestic GroundwaterContamination.

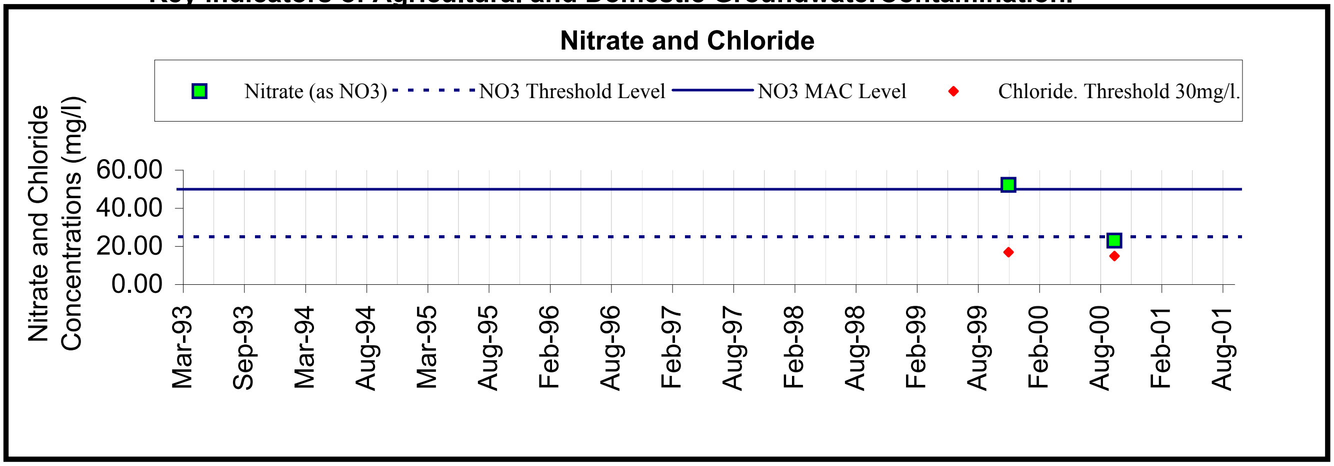


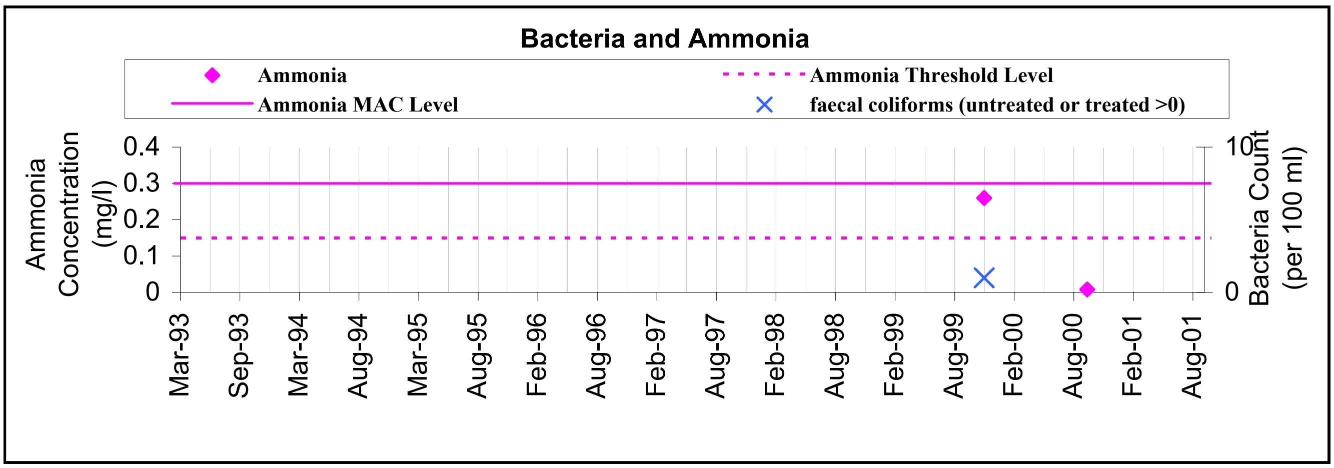


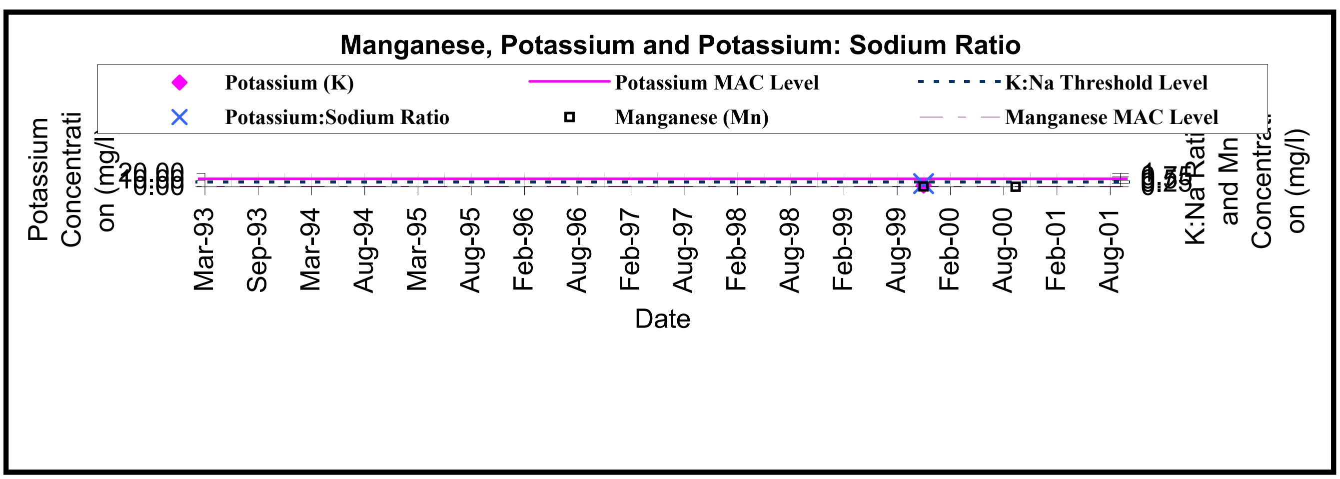


Graine-Craddockstown GWS GWS

Key indicators of Agricultural and Domestic GroundwaterContamination.

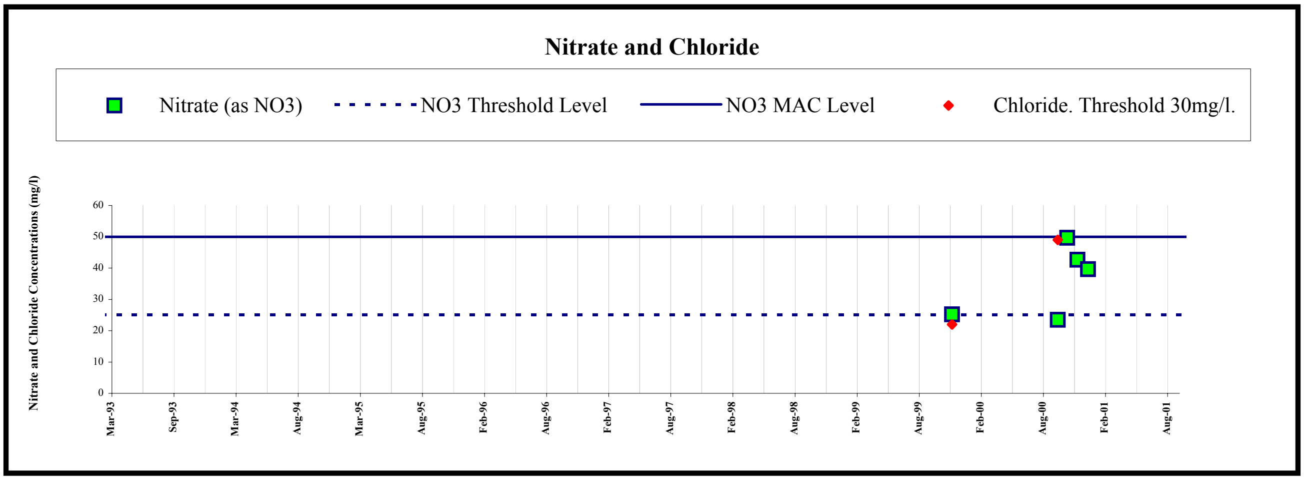


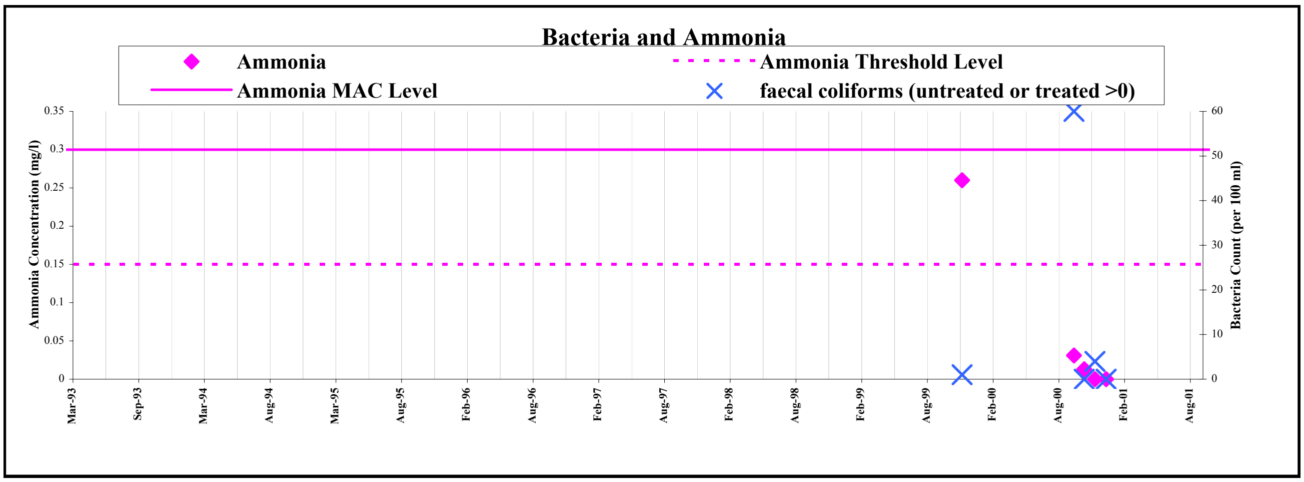


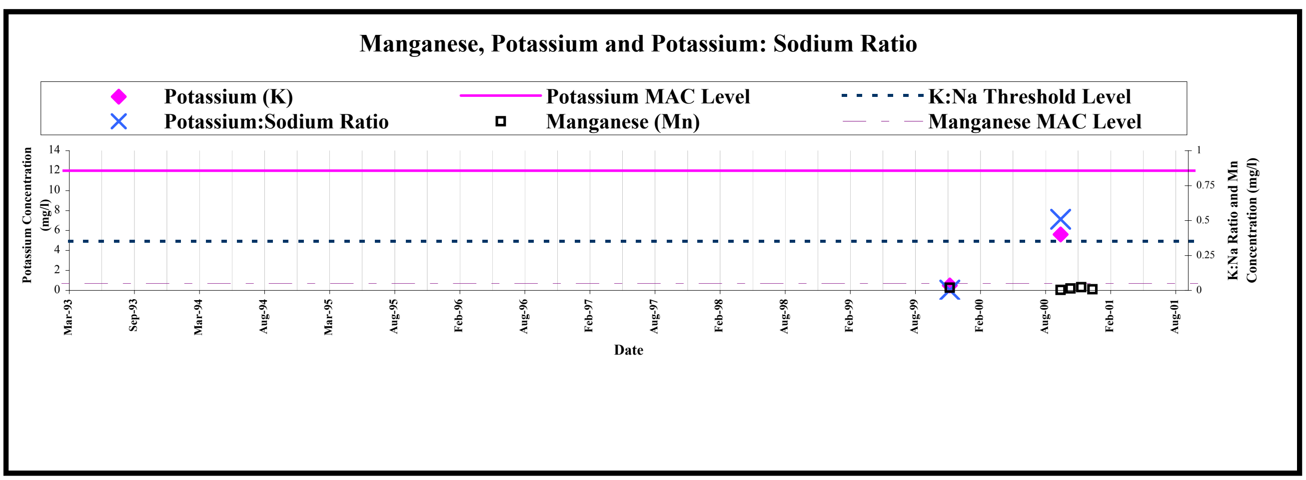


Highrath GWS

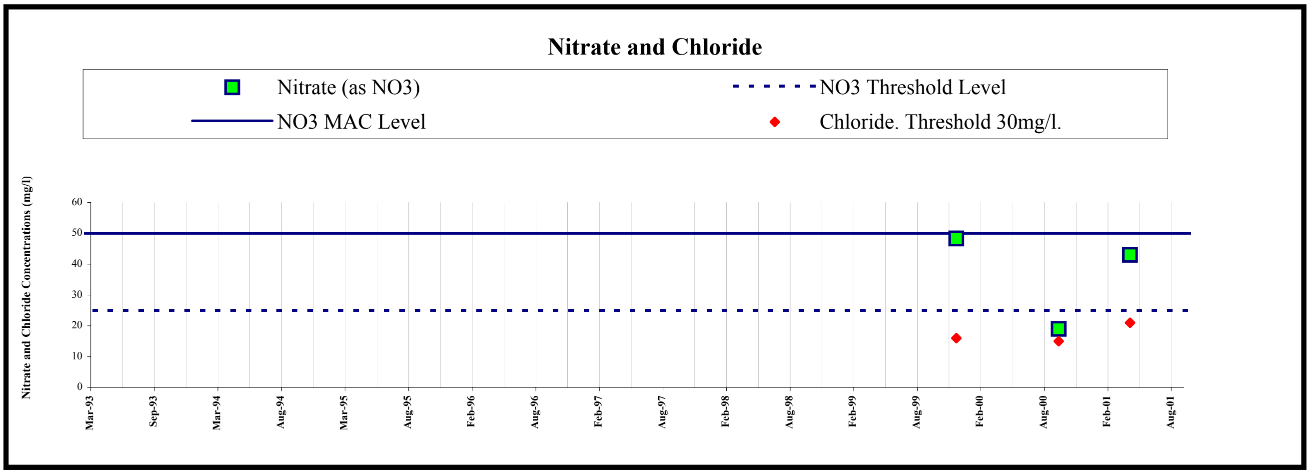
Key indicators of Agricultural and Domestic GroundwaterContamination.

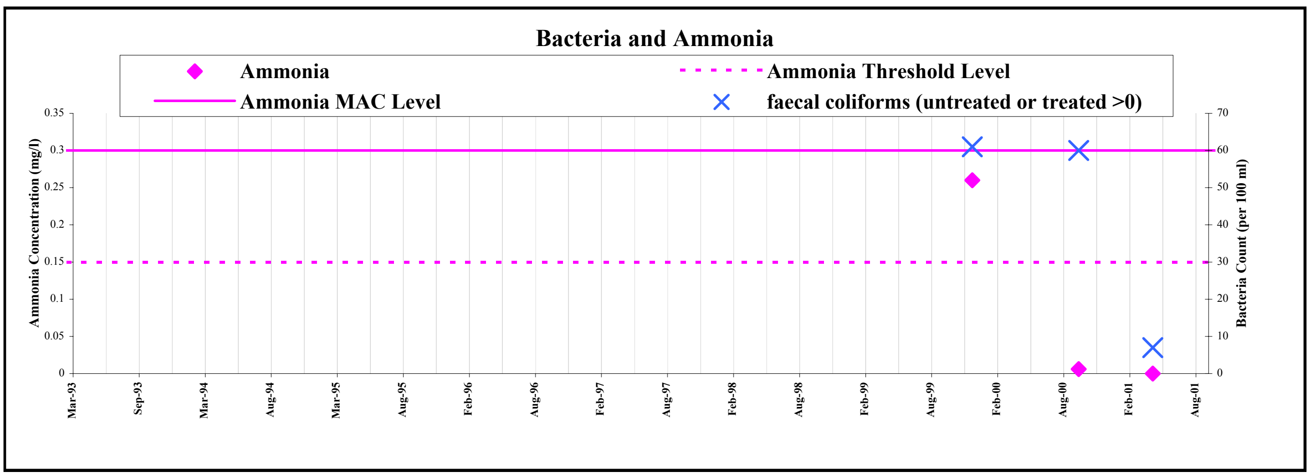


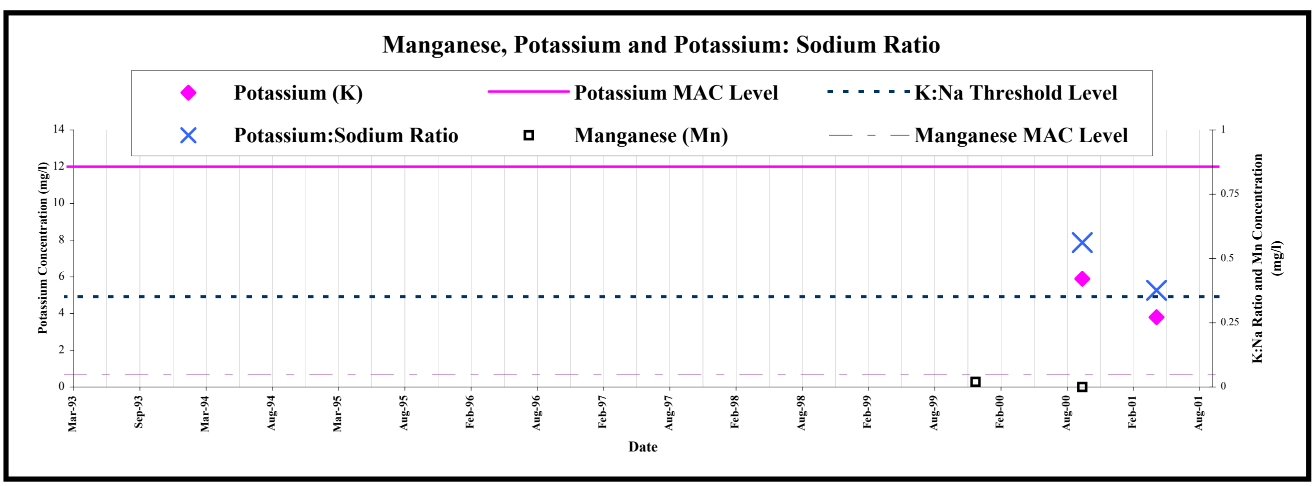




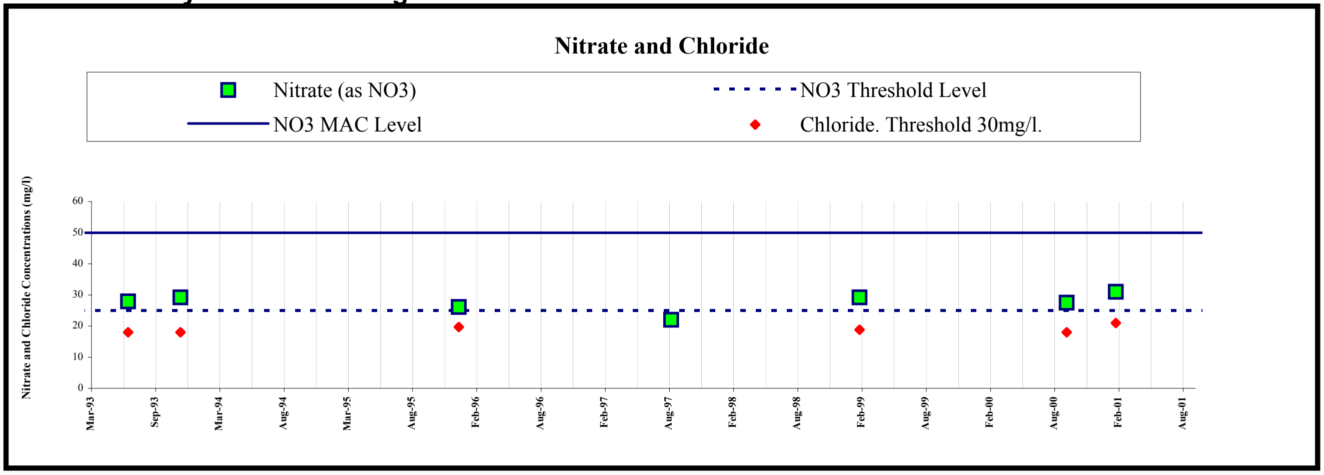
Hugginstown GWS
Key indicators of Agricultural and Domestic GroundwaterContamination.

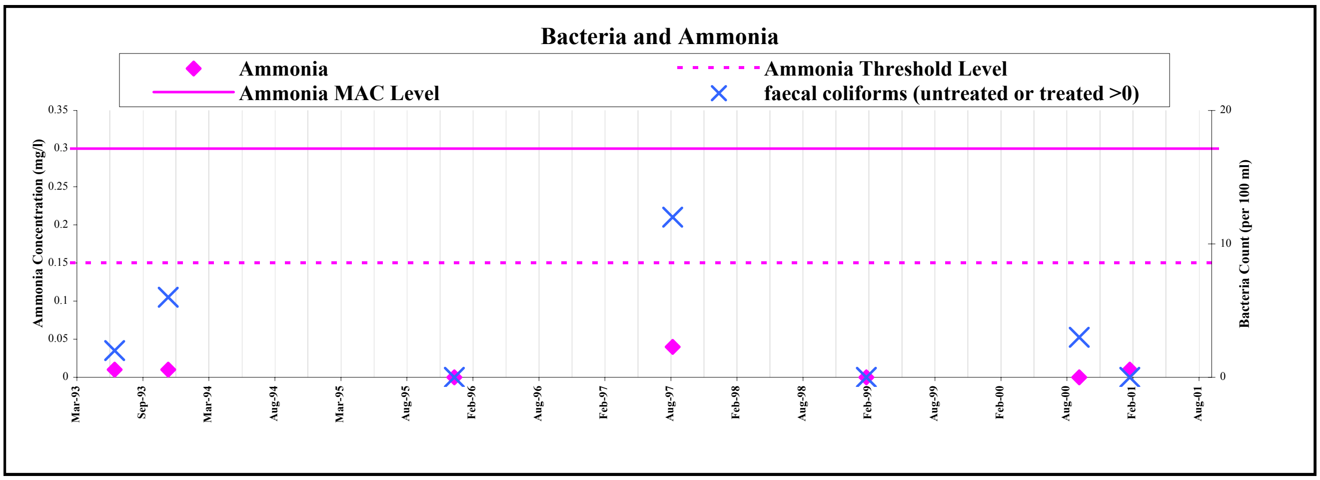


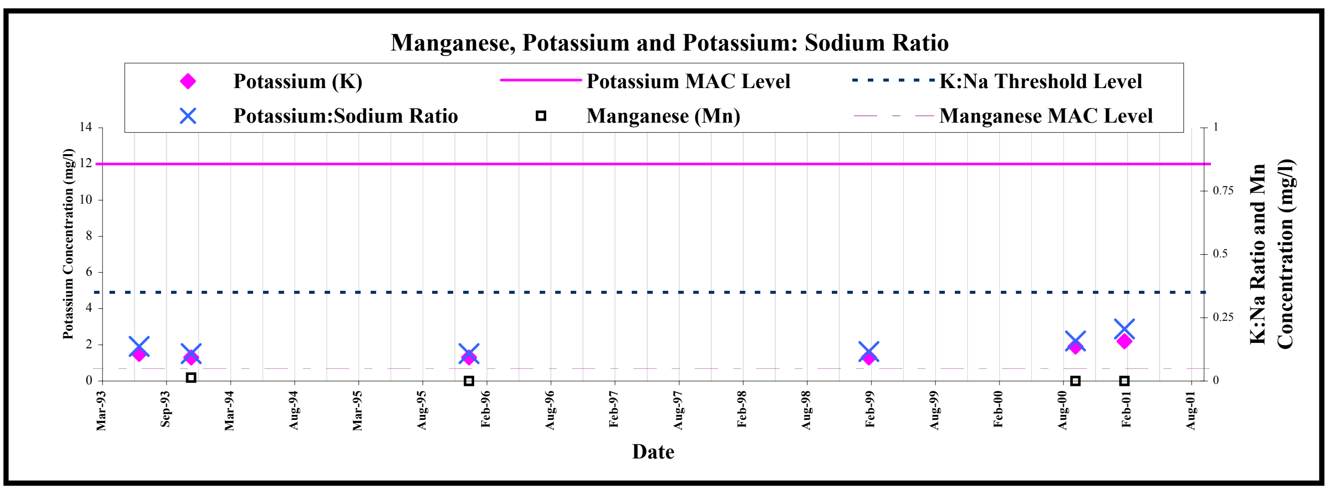




Kilkenny Mart (Industrial)
Key indicators of Agricultural and Domestic GroundwaterContamination.

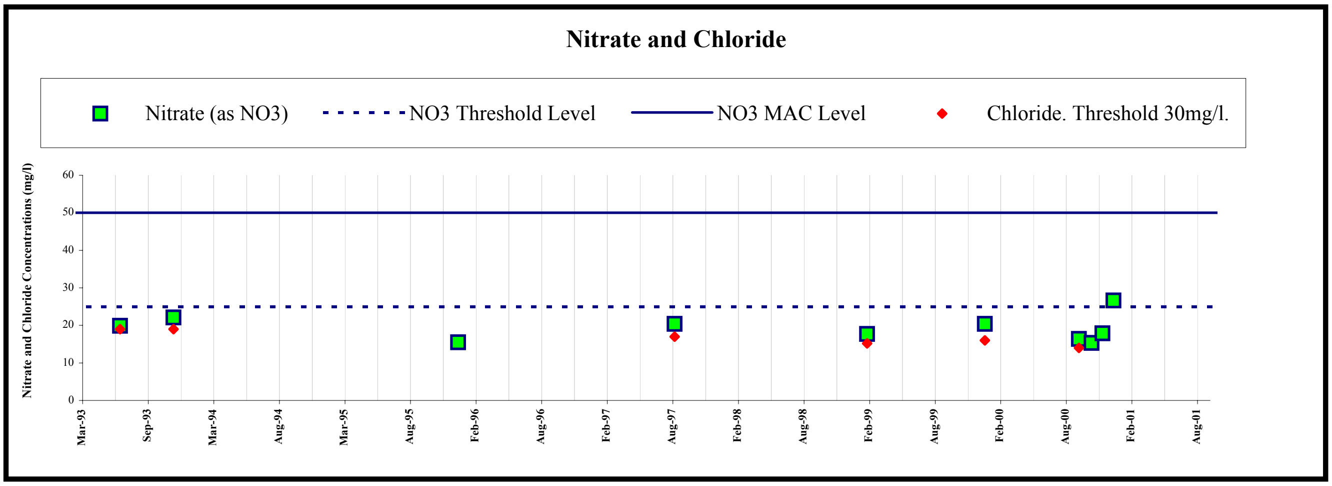


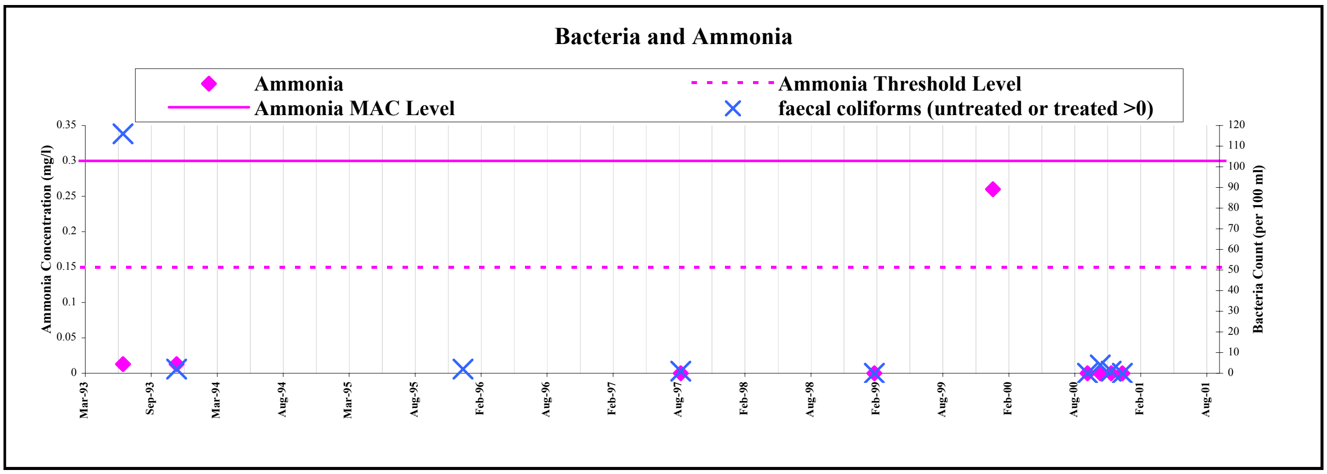


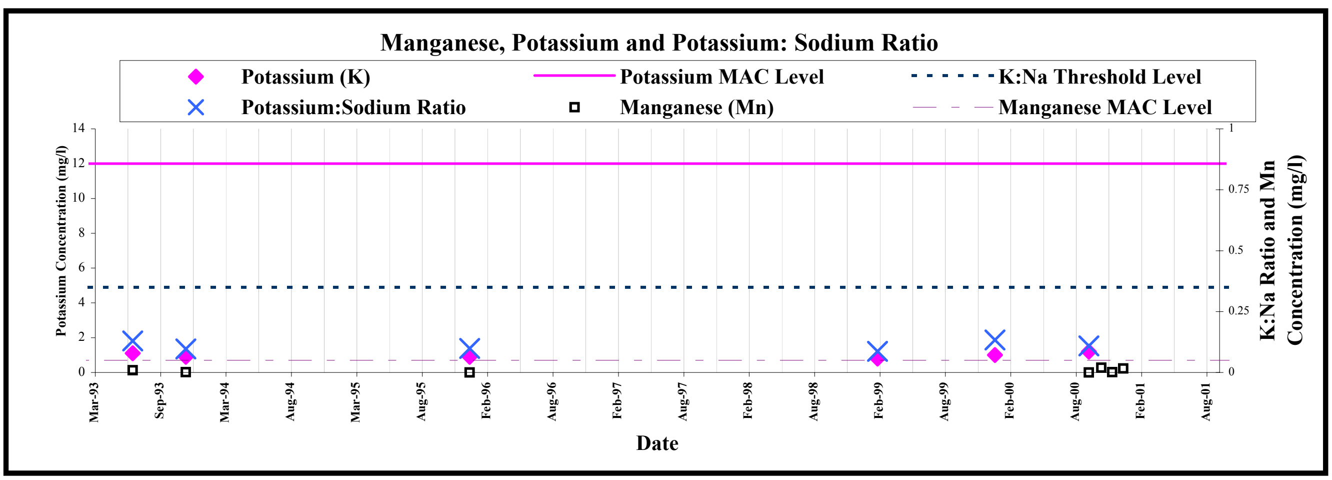


Kilmanagh GWS

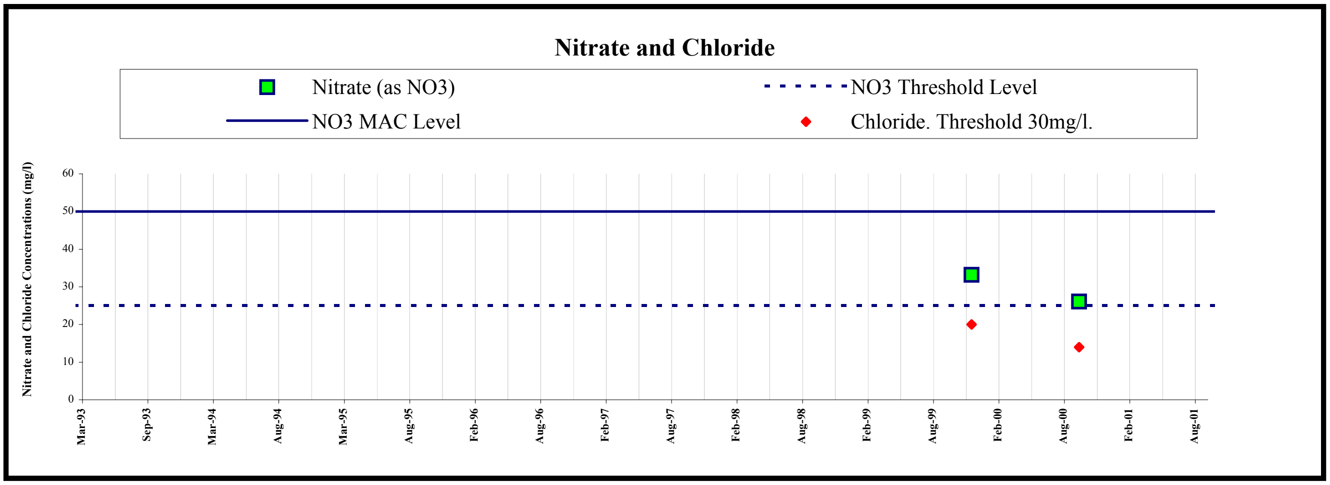
Key indicators of Agricultural and Domestic GroundwaterContamination.

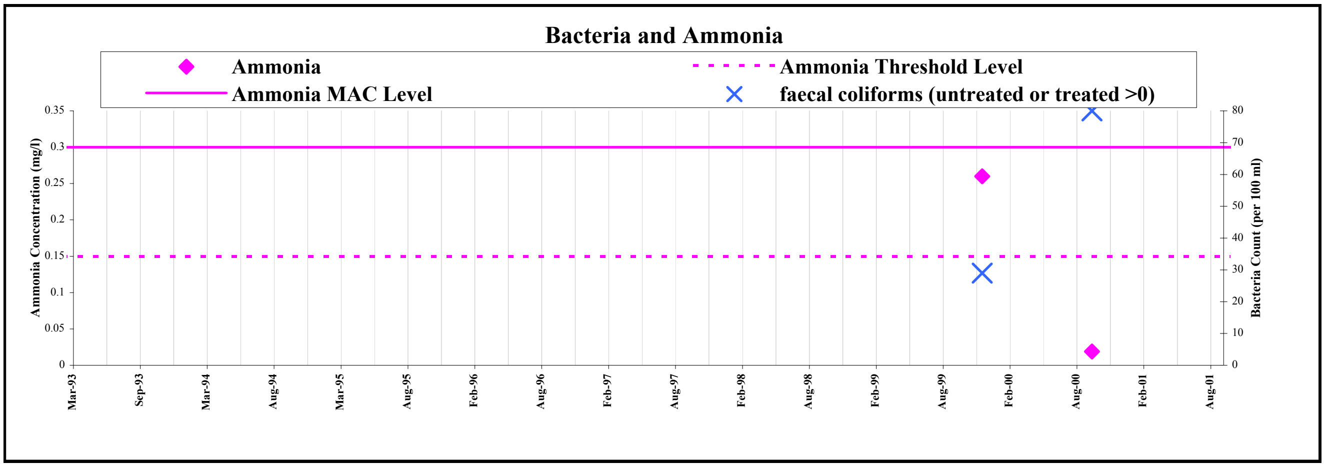


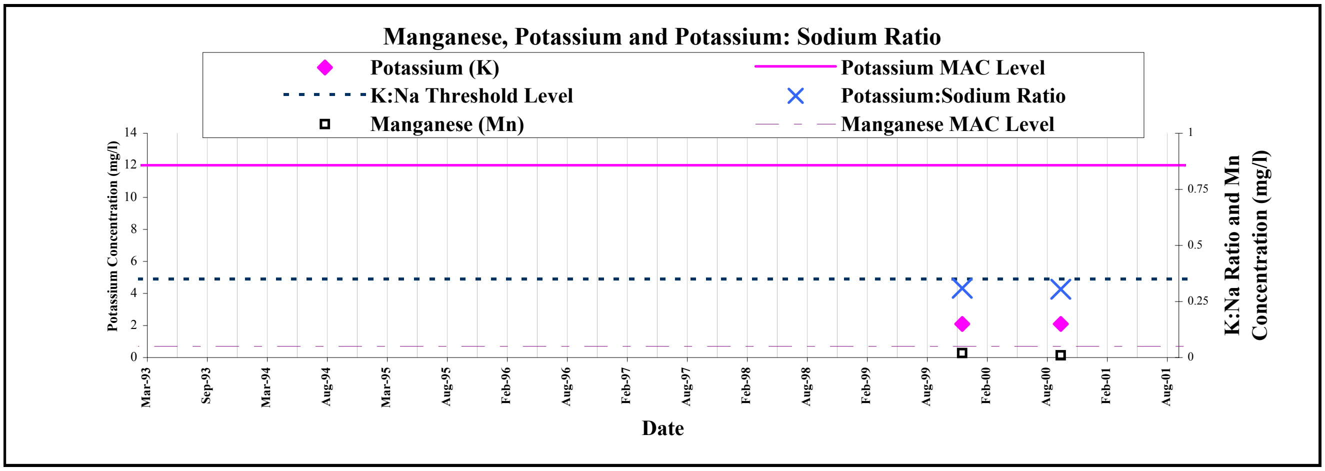




Kiloshulan Barna GWS
Key indicators of Agricultural and Domestic GroundwaterContamination.

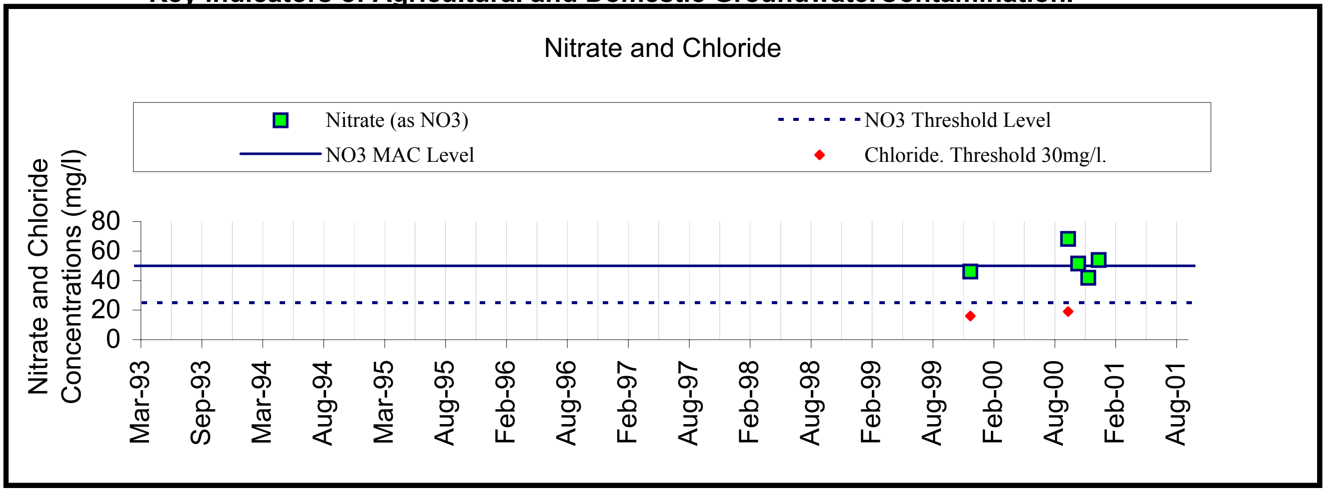


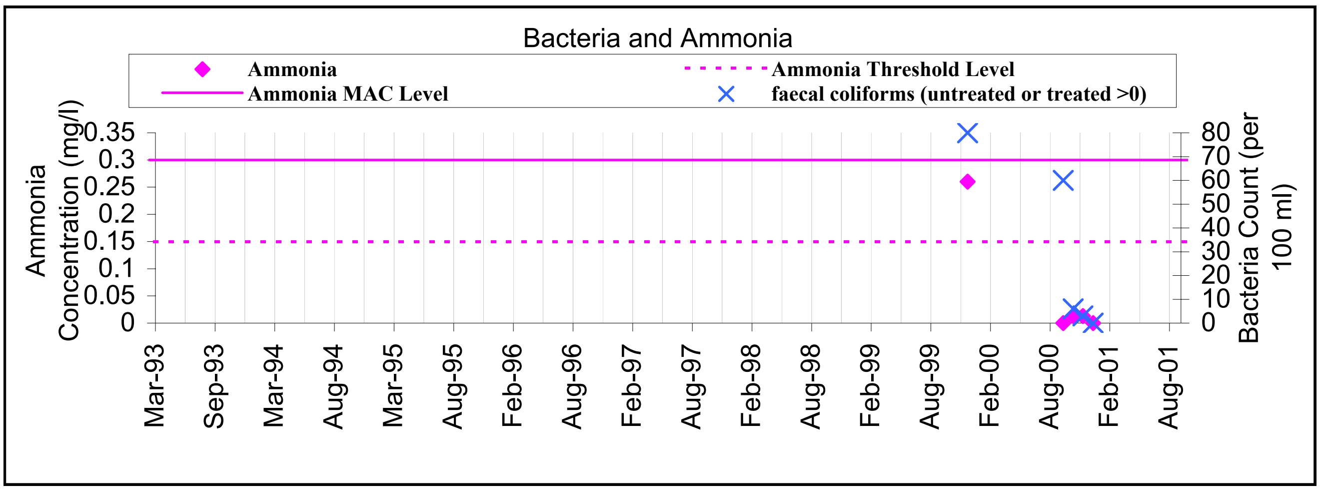


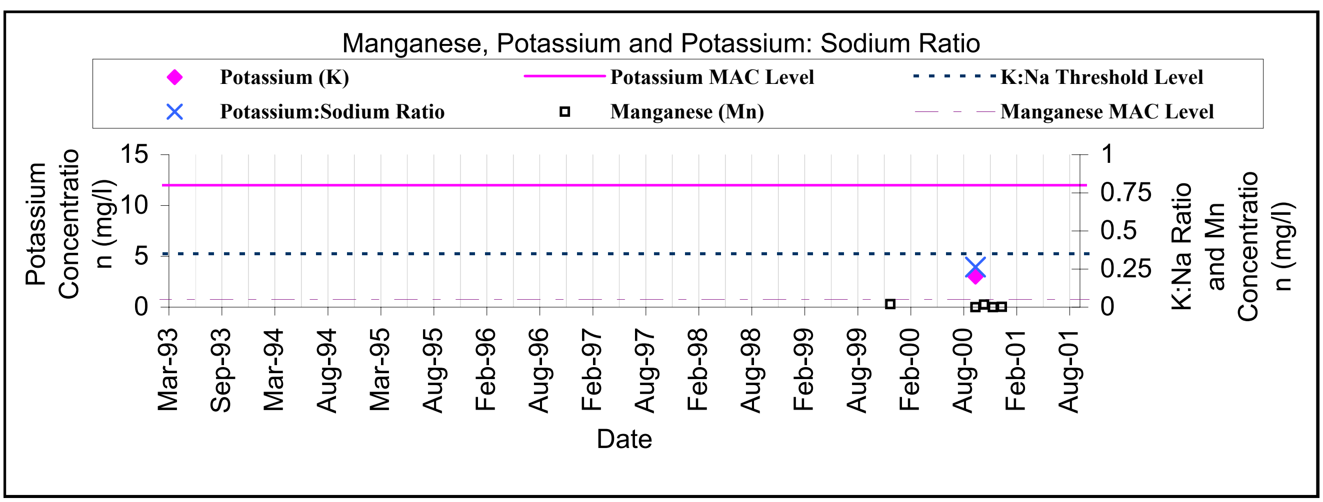


Kilree Stoneyford GWS

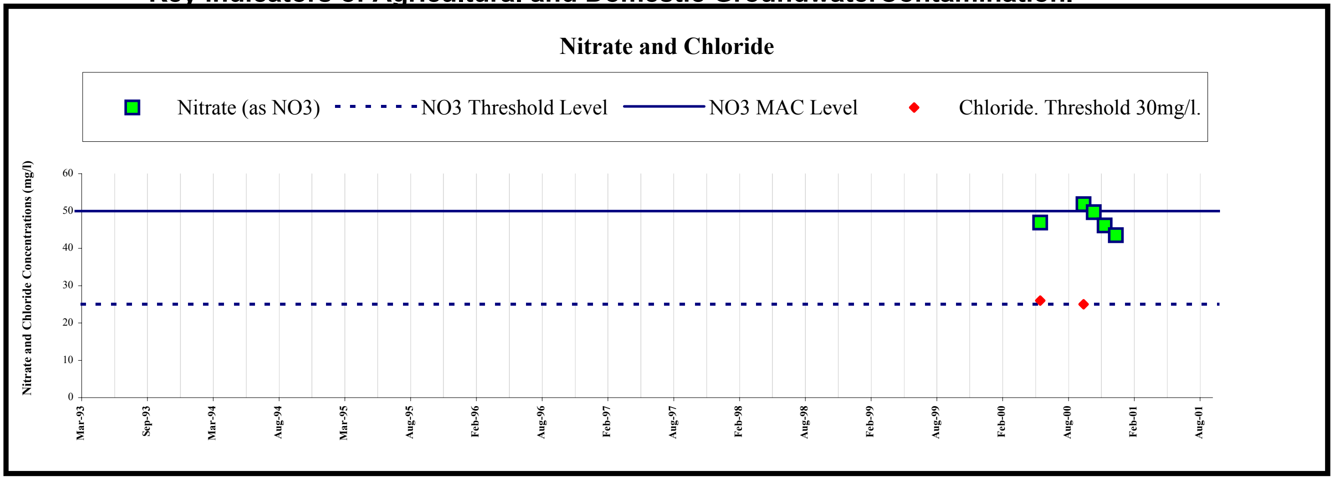
Key indicators of Agricultural and Domestic GroundwaterContamination.

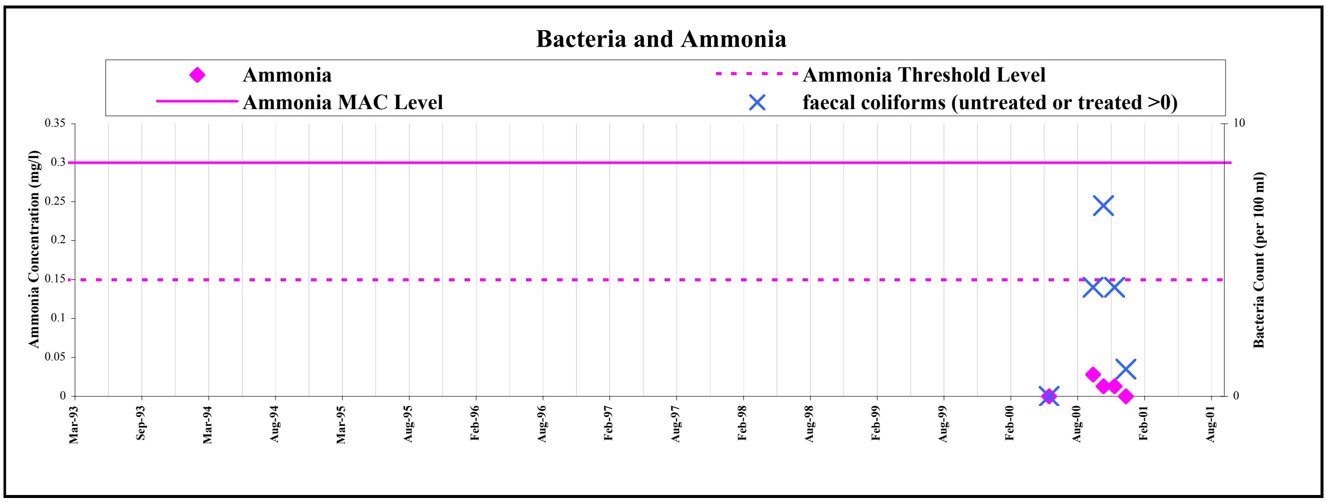


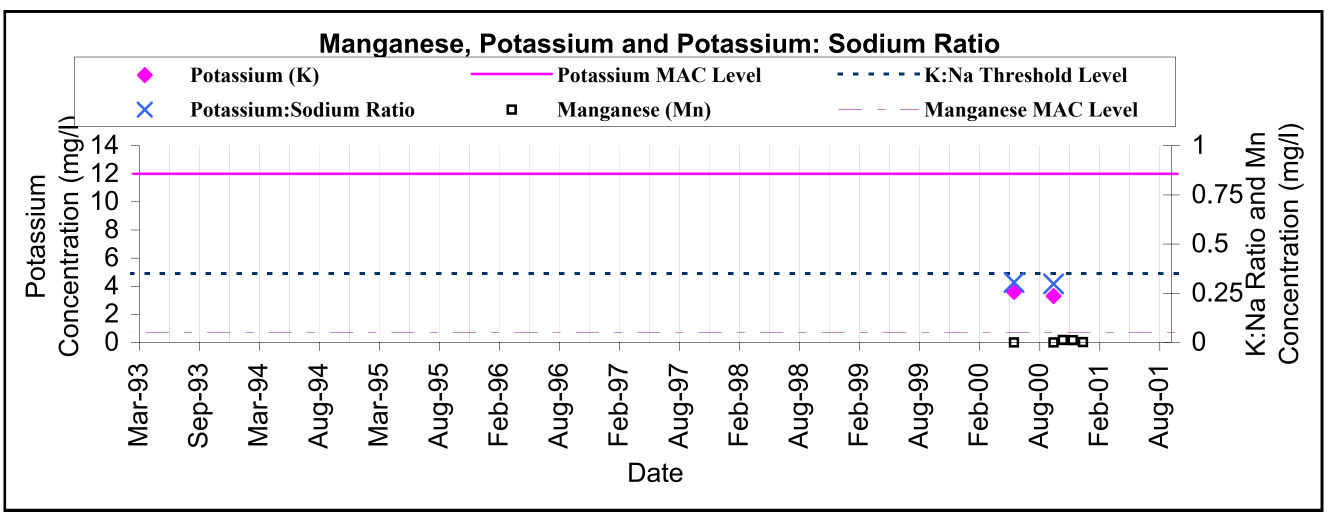




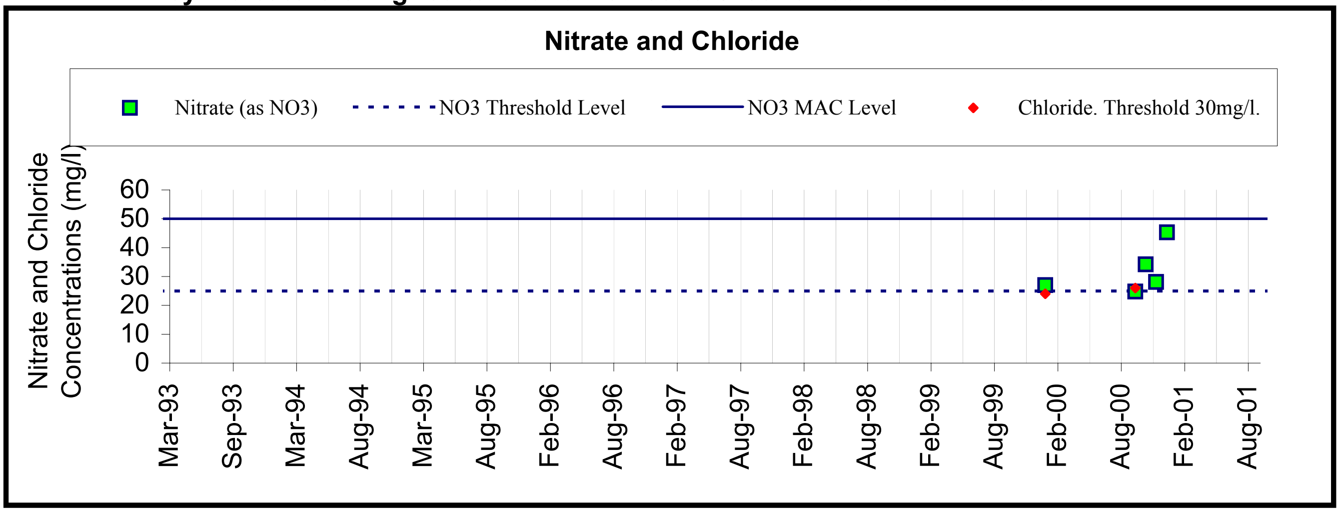
Maddoxtown GWS
Key indicators of Agricultural and Domestic GroundwaterContamination.

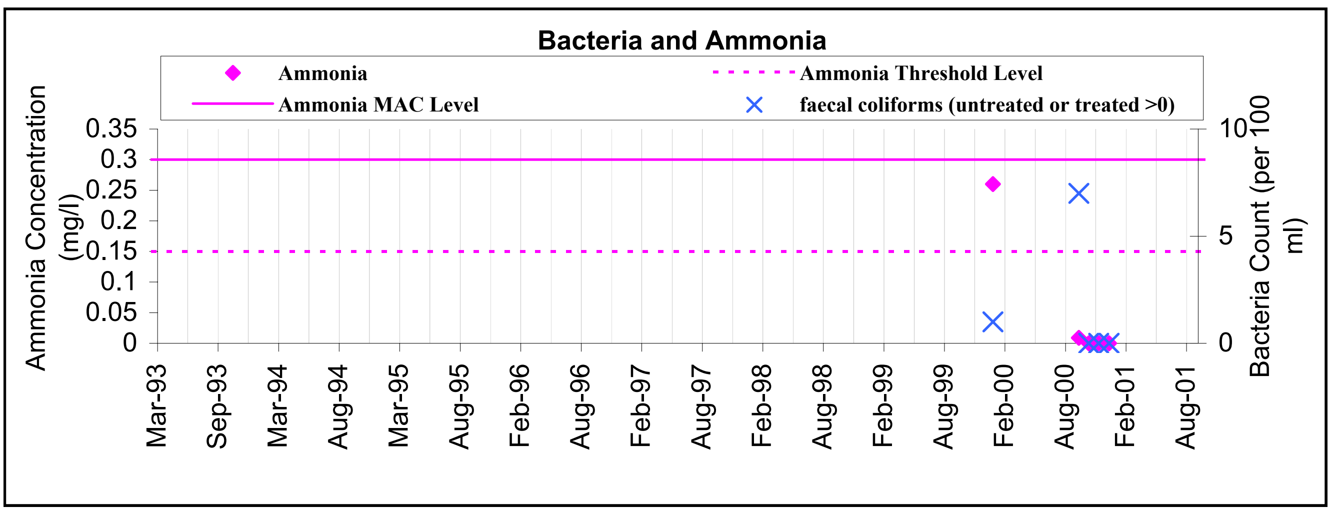






Newtown Kells GWS
Key indicators of Agricultural and Domestic GroundwaterContamination.





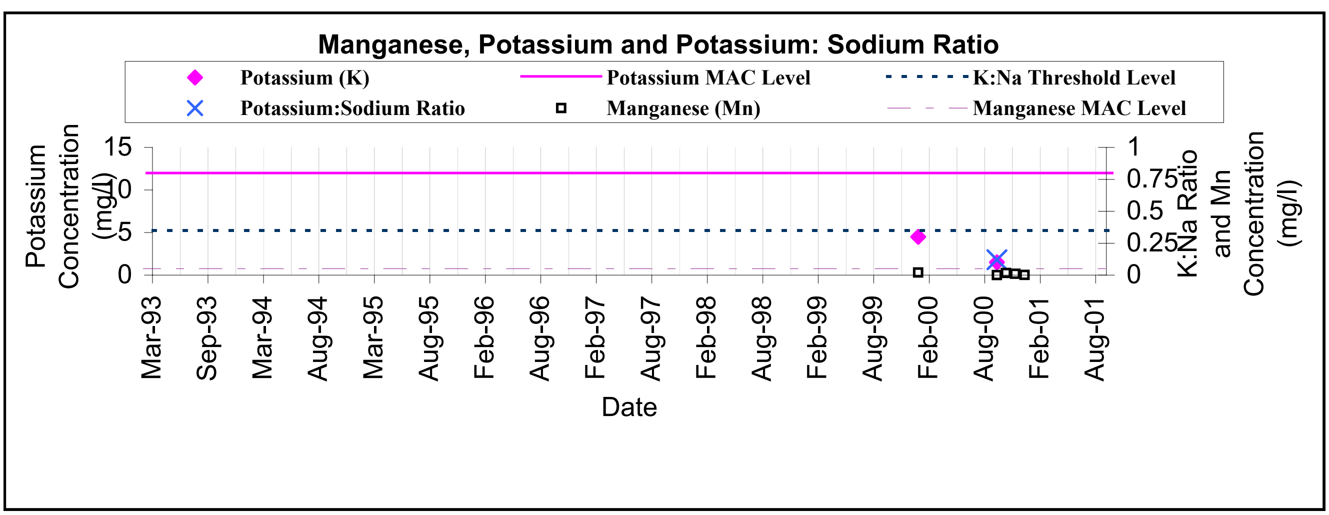
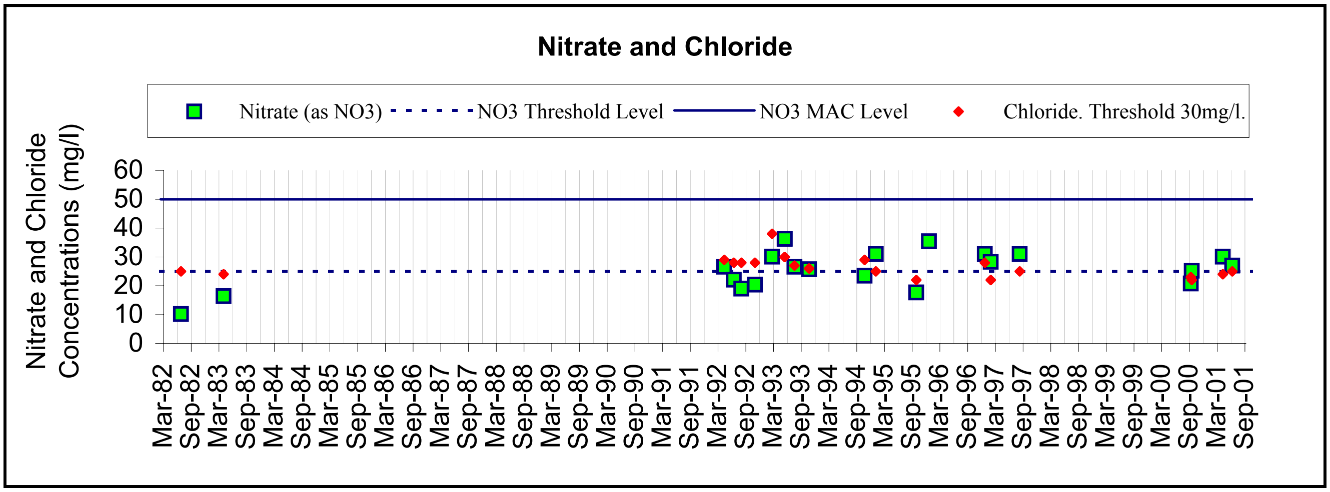
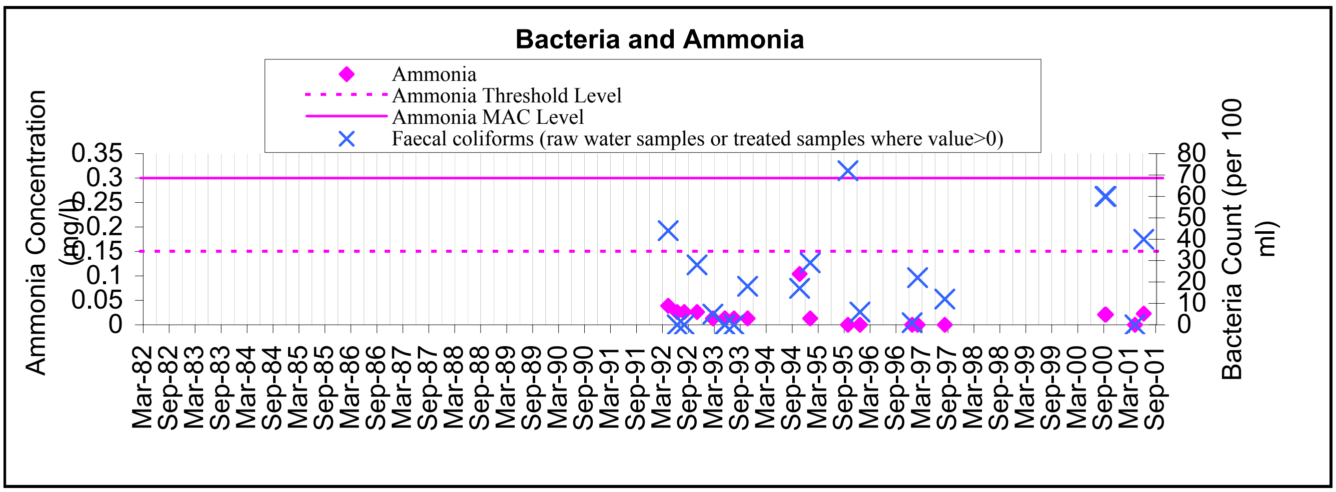


Figure 11.3-Paulstown Spring
Key indicators of Agricultural and Domestic GroundwaterContamination.





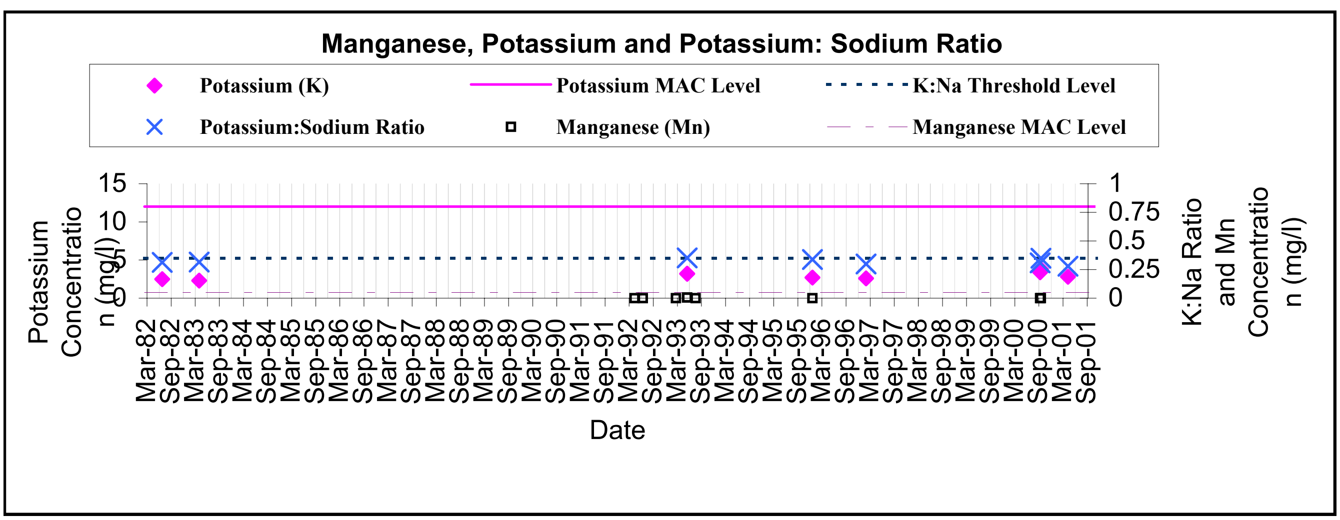
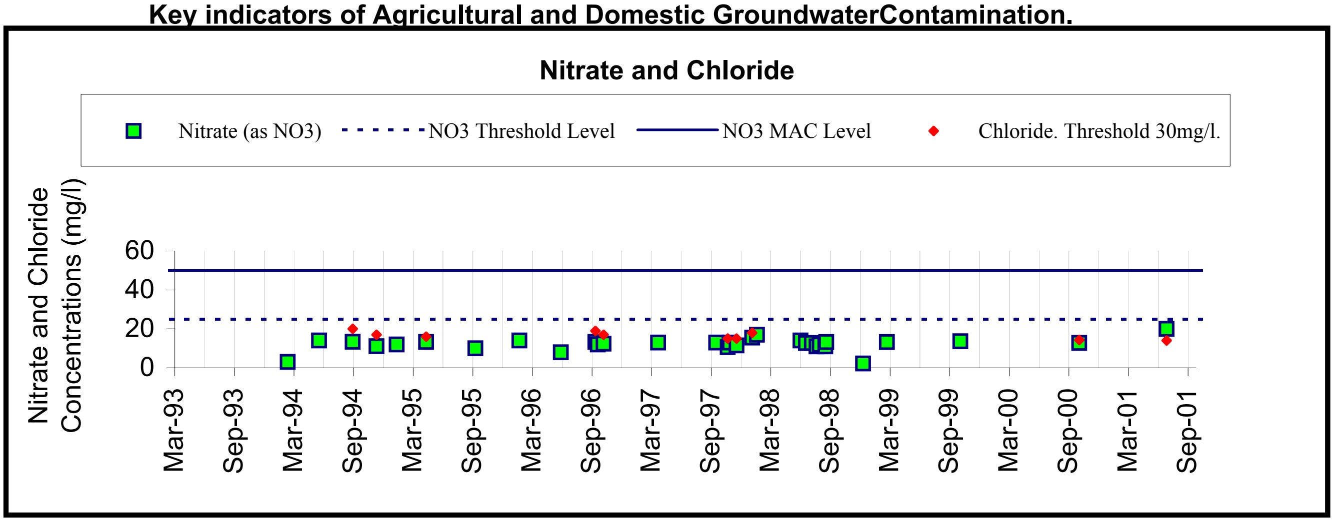
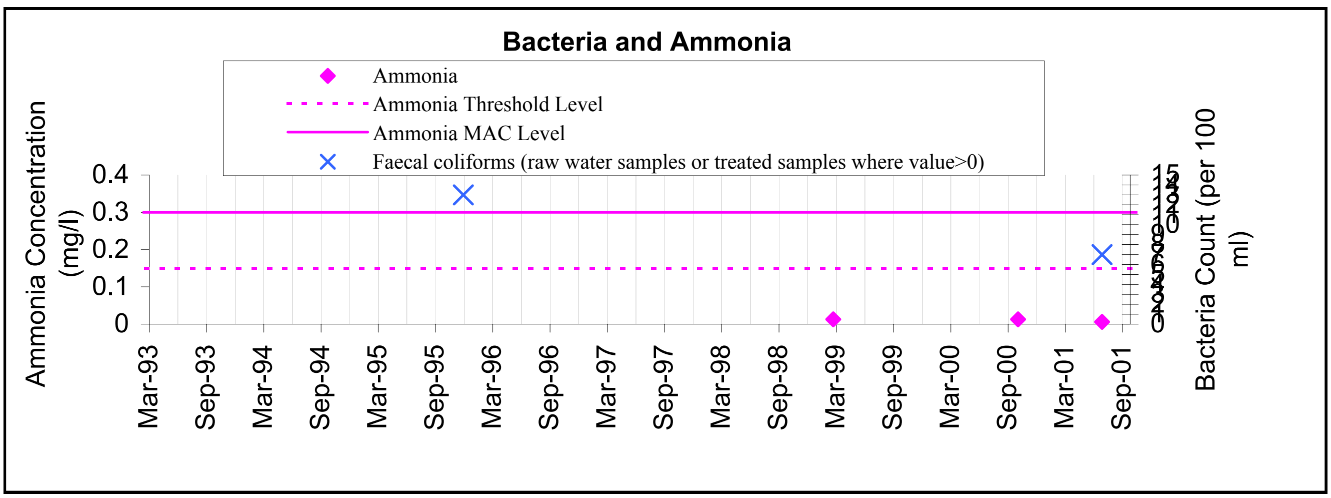


Figure 12.1-Piltown Springs (Combined discharge)
Key indicators of Agricultural and Domestic GroundwaterContamination.





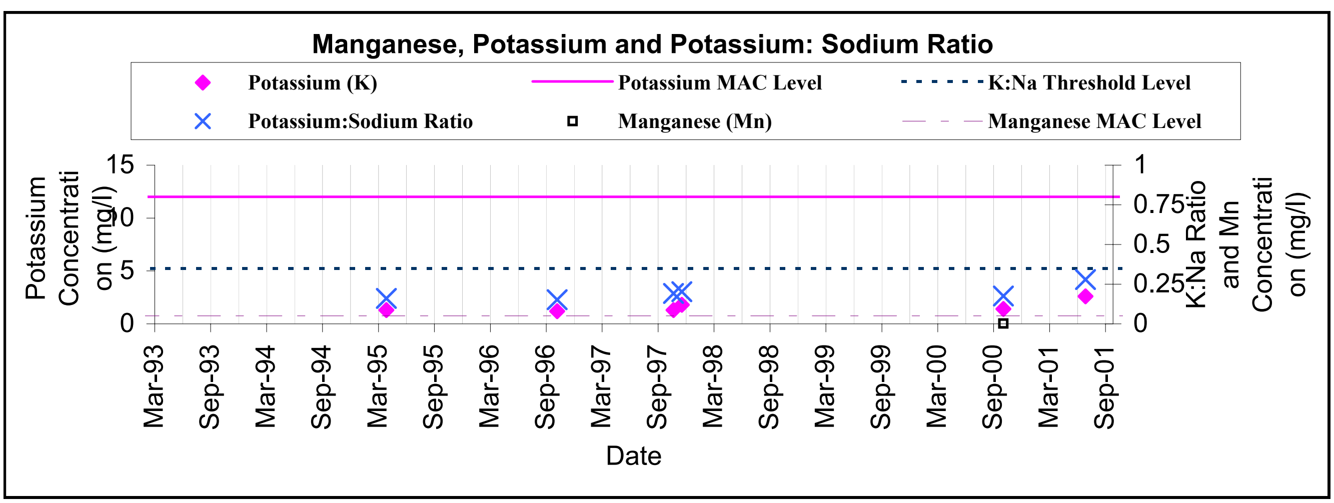
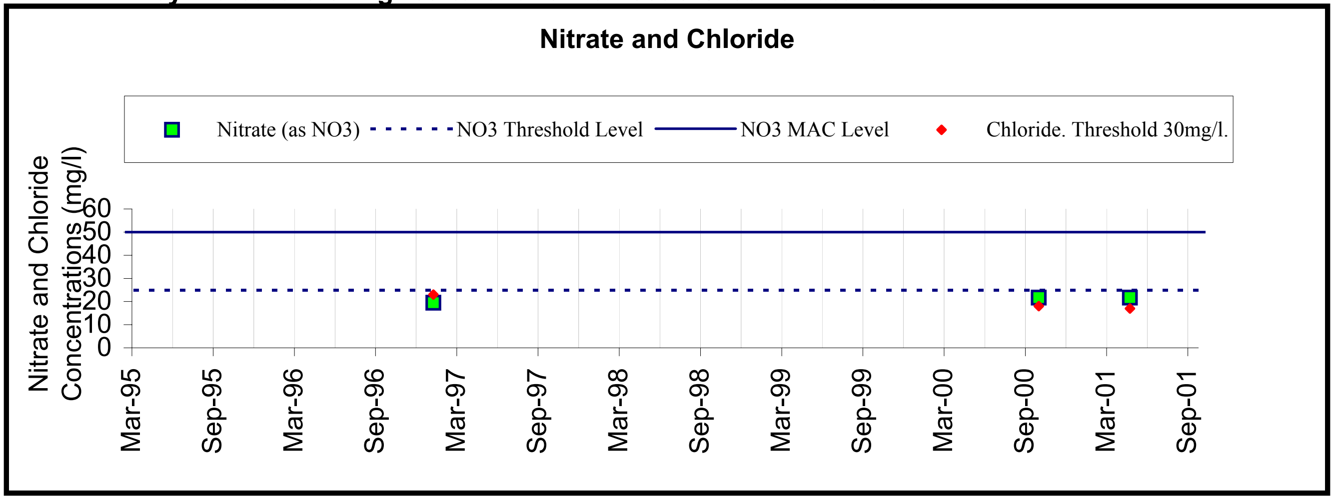
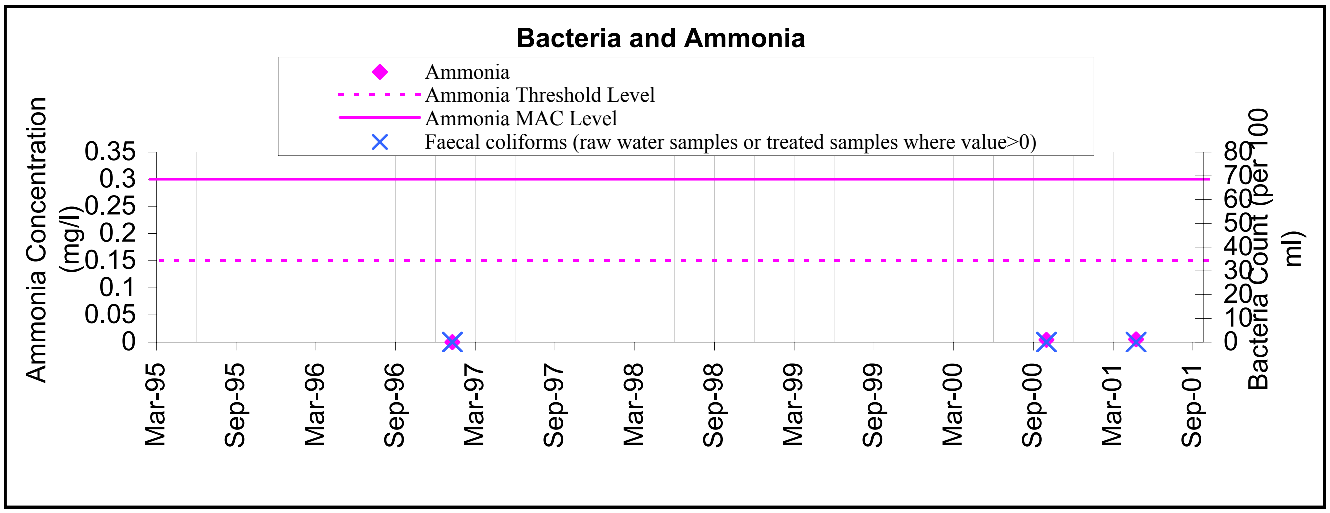


Figure 13.2-Thomastown (Well 5-Nore Creamery)
Key indicators of Agricultural and Domestic GroundwaterContamination.





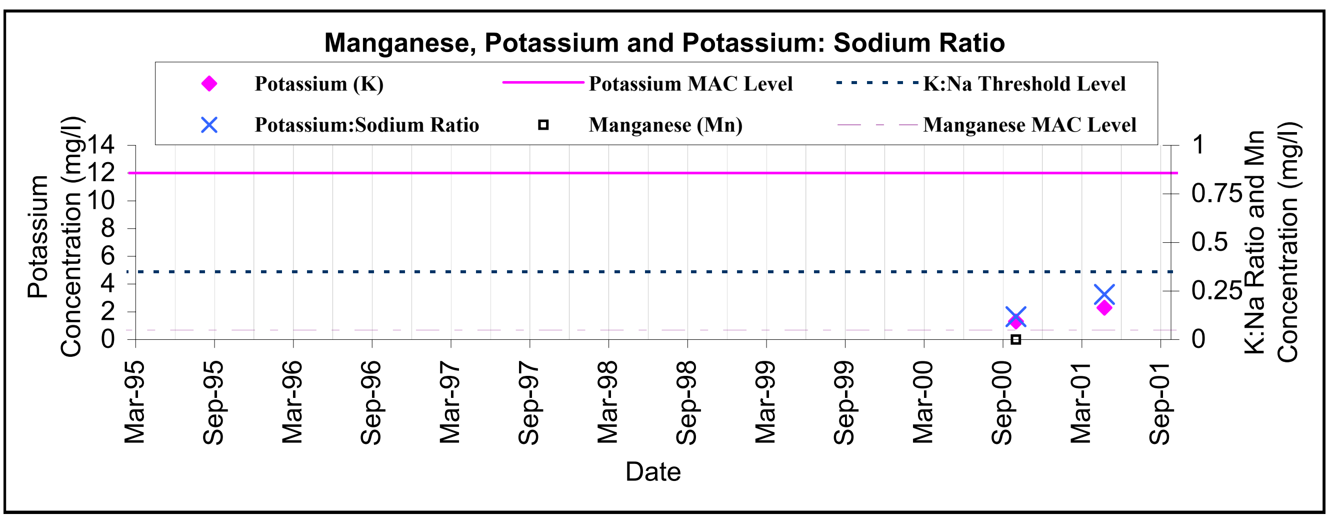
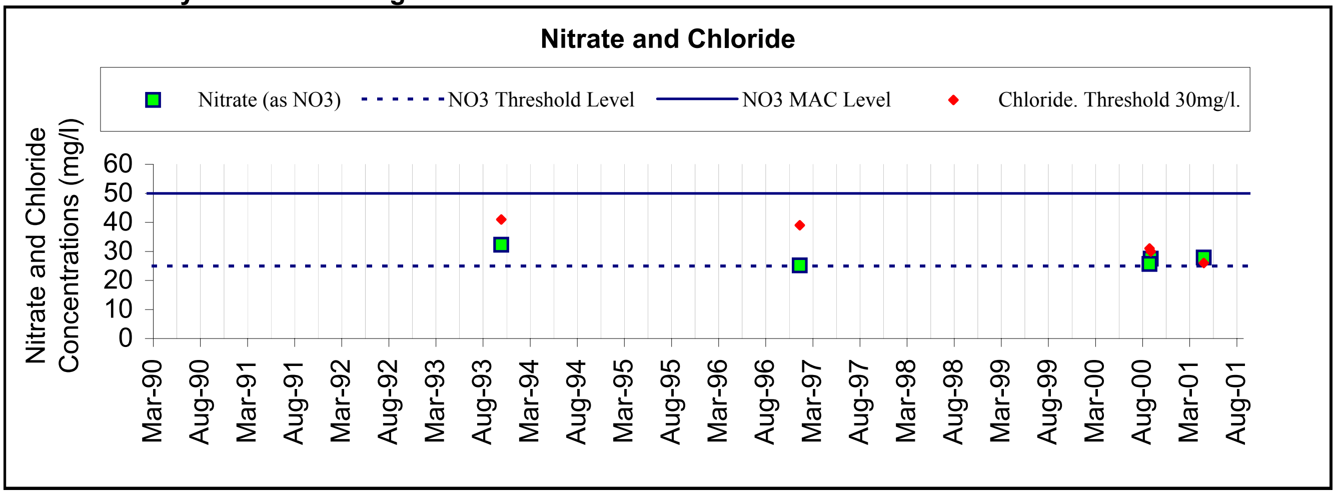
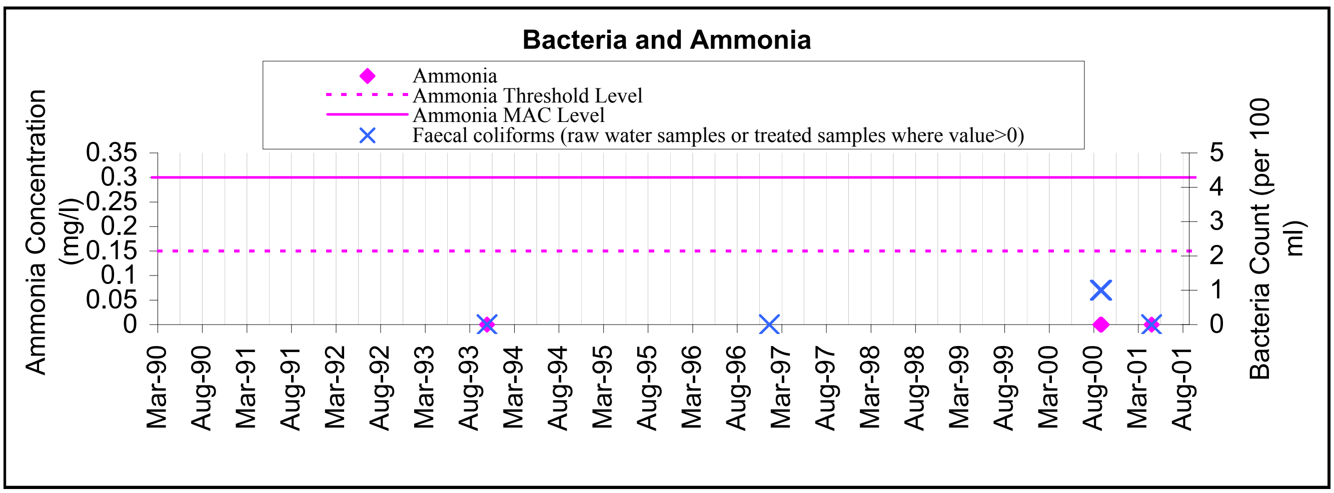
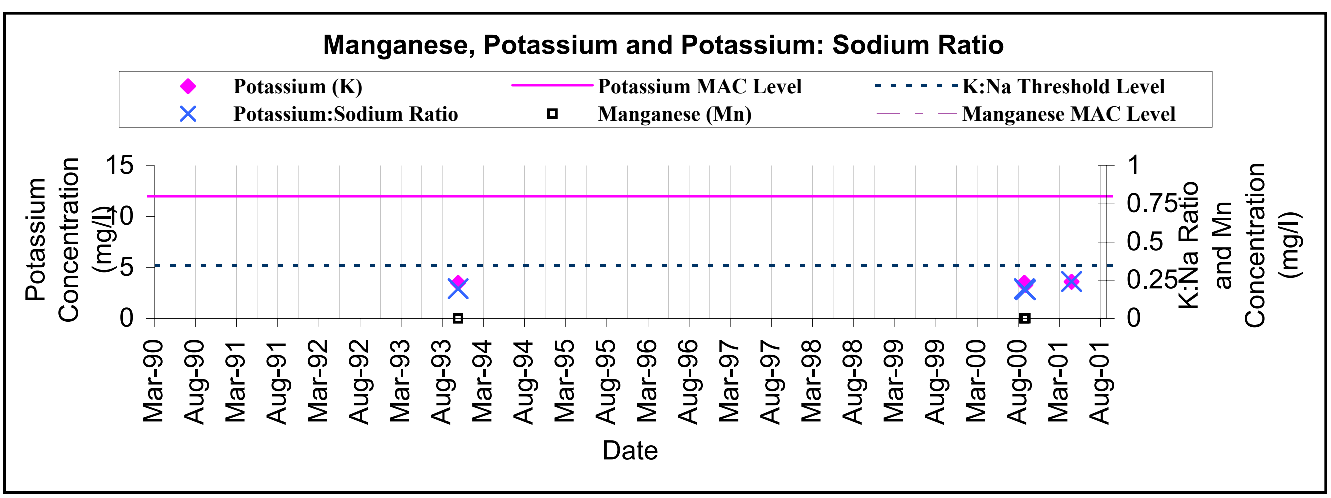


Figure 13.2-Thomastown (Well 9-GAA Grounds)
Key indicators of Agricultural and Domestic GroundwaterContamination.

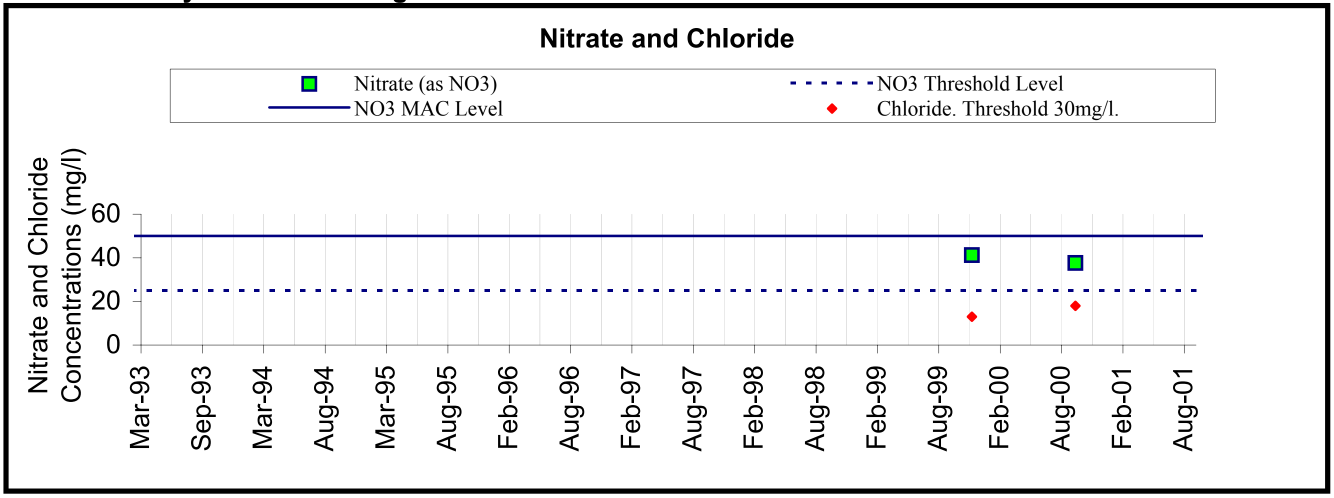


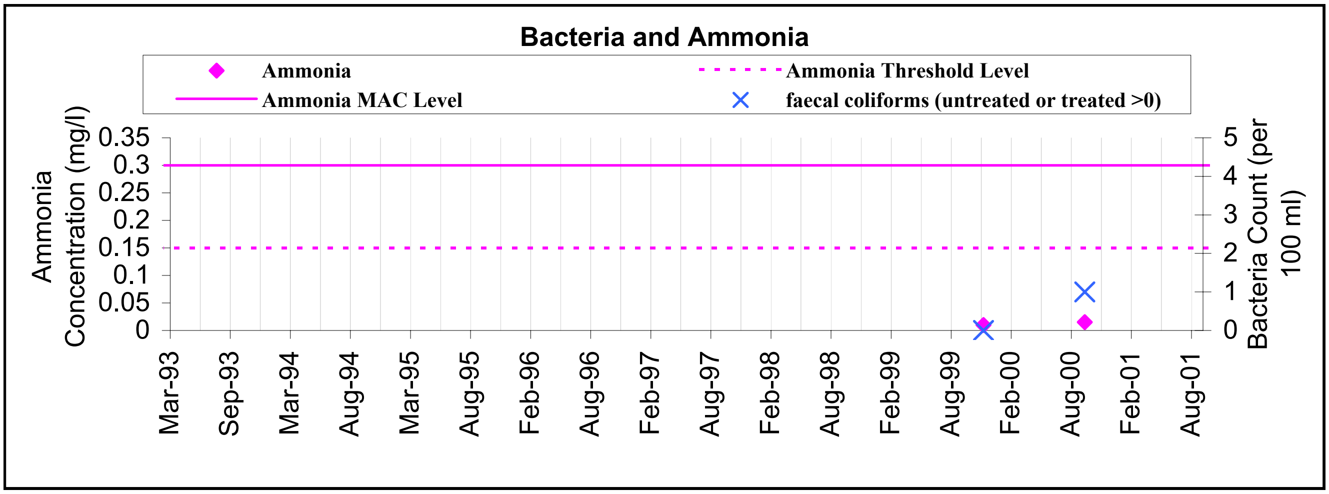


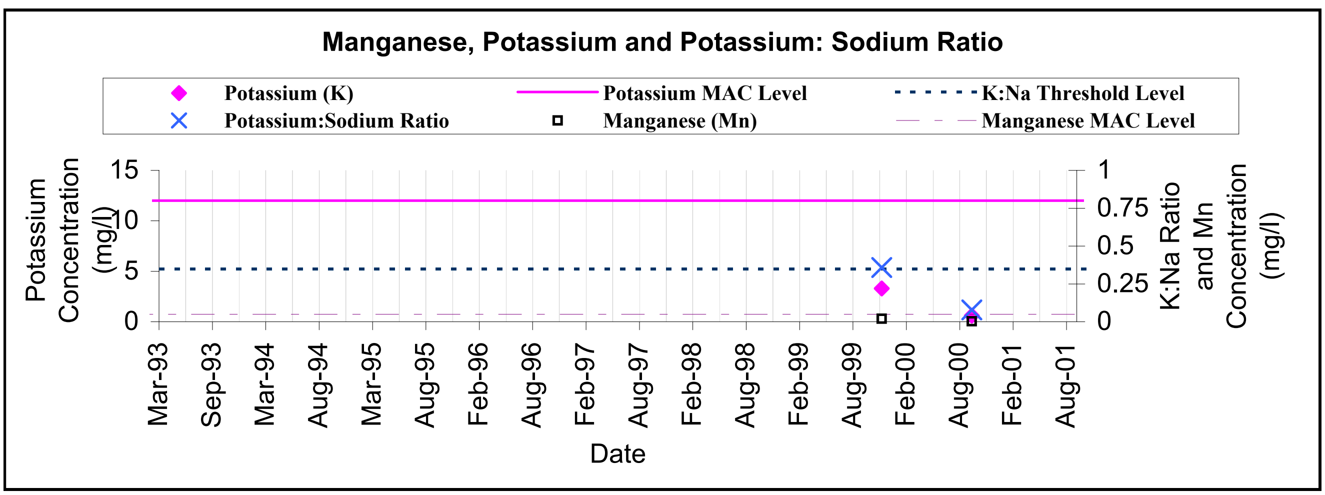


Tubbrid Lower GWS

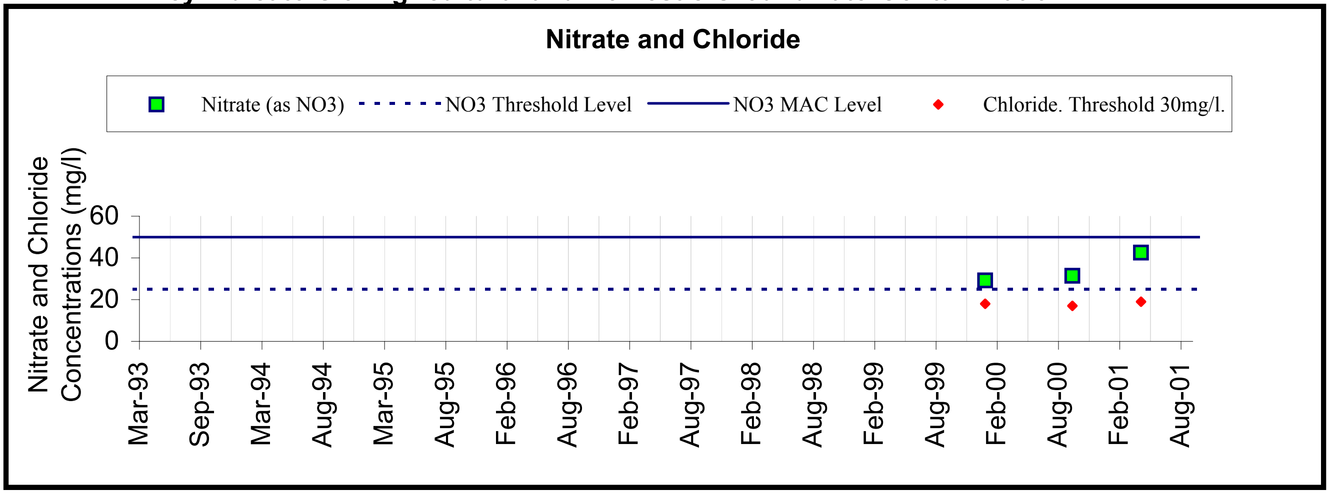
Key indicators of Agricultural and Domestic GroundwaterContamination.

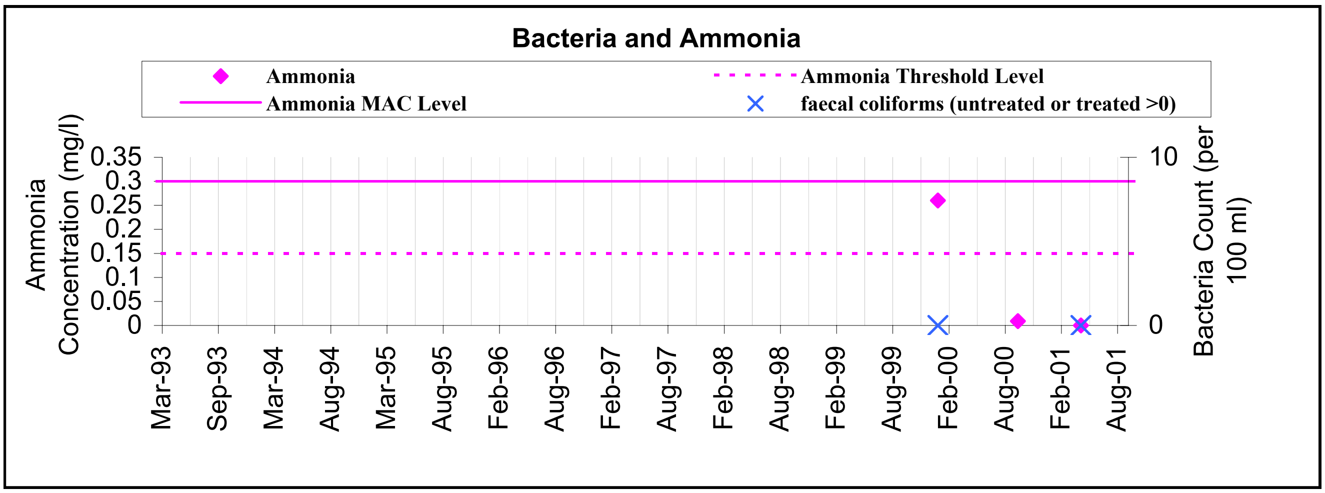


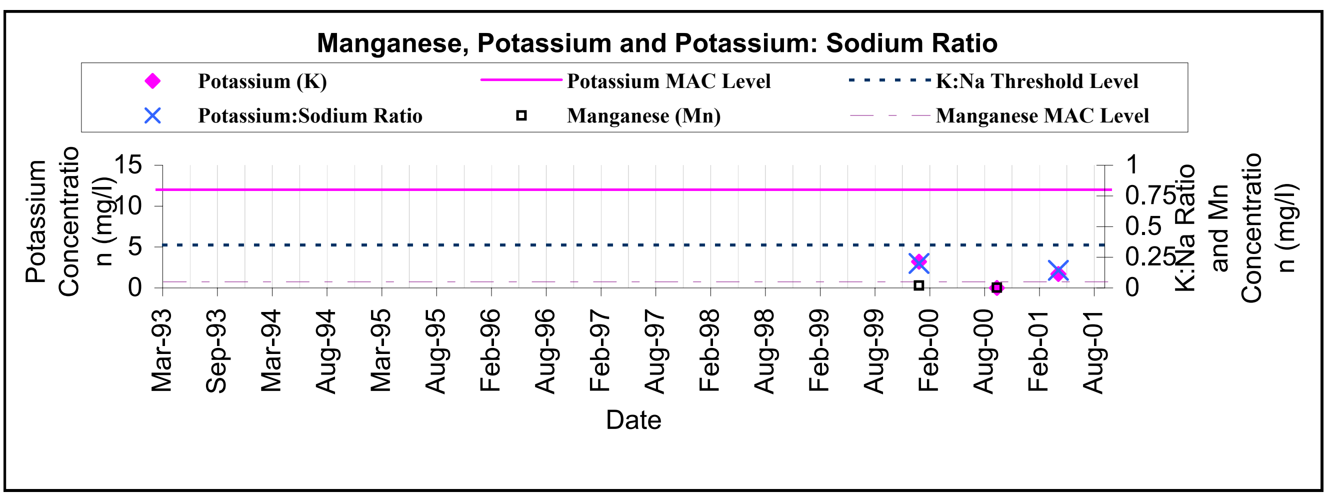




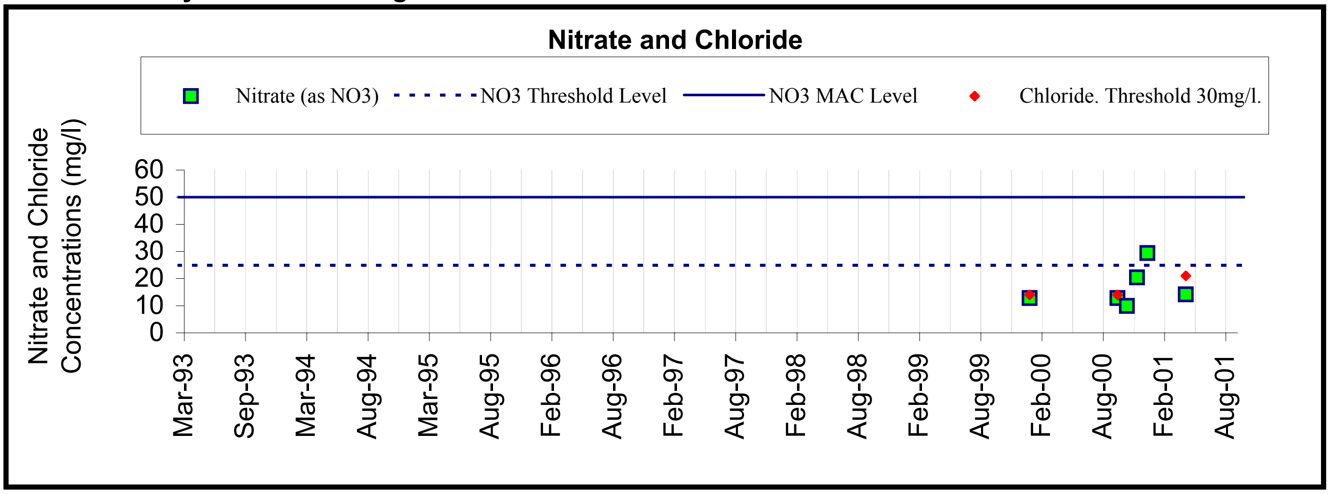
Tullahouht GWS
Key indicators of Agricultural and Domestic GroundwaterContamination.

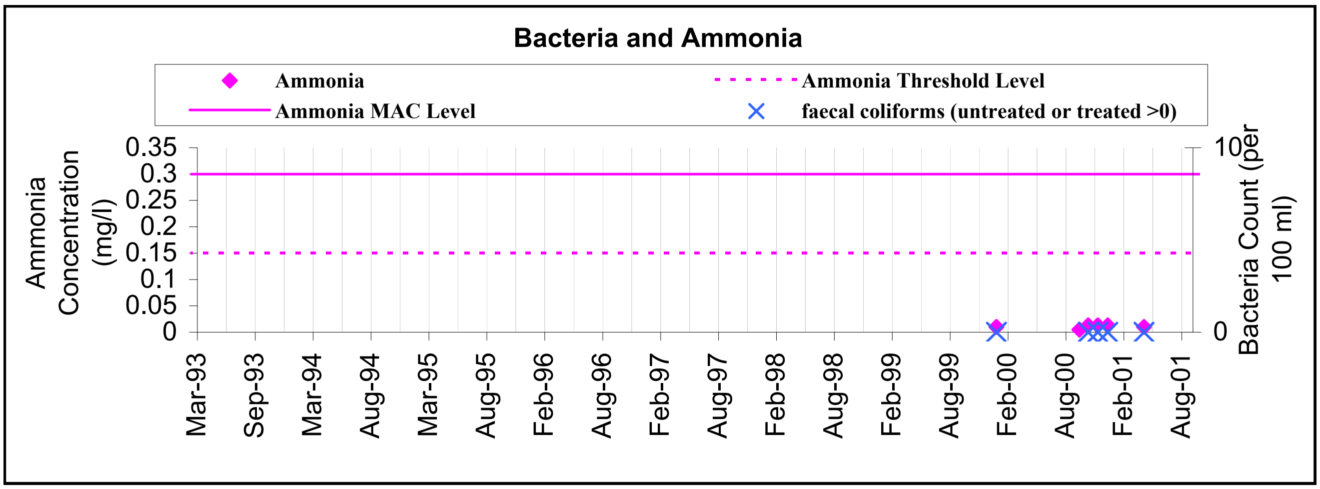






Tullaroan GWS
Key indicators of Agricultural and Domestic GroundwaterContamination.





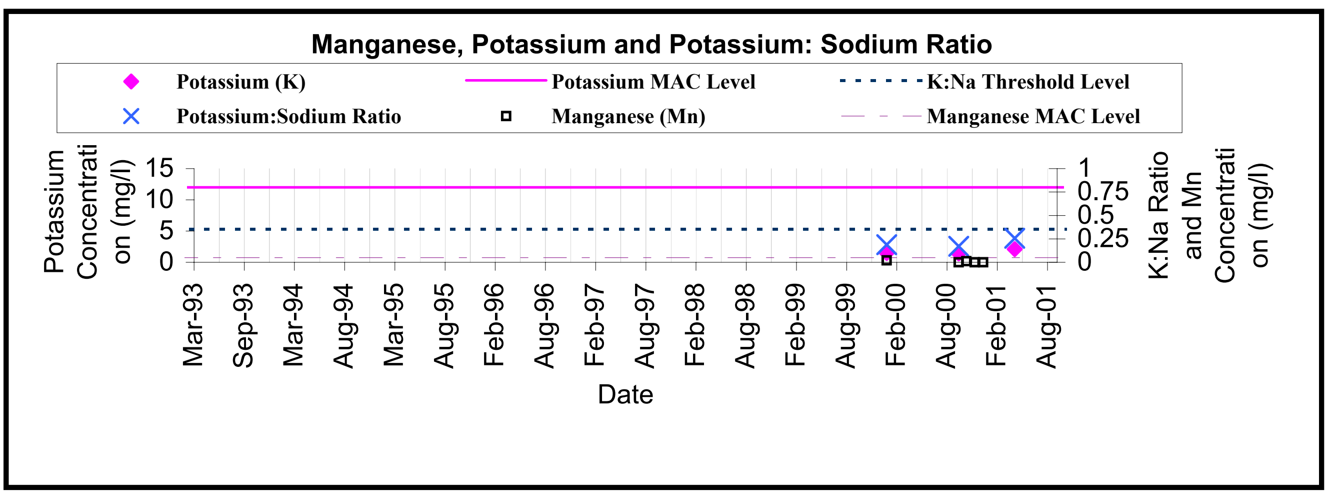
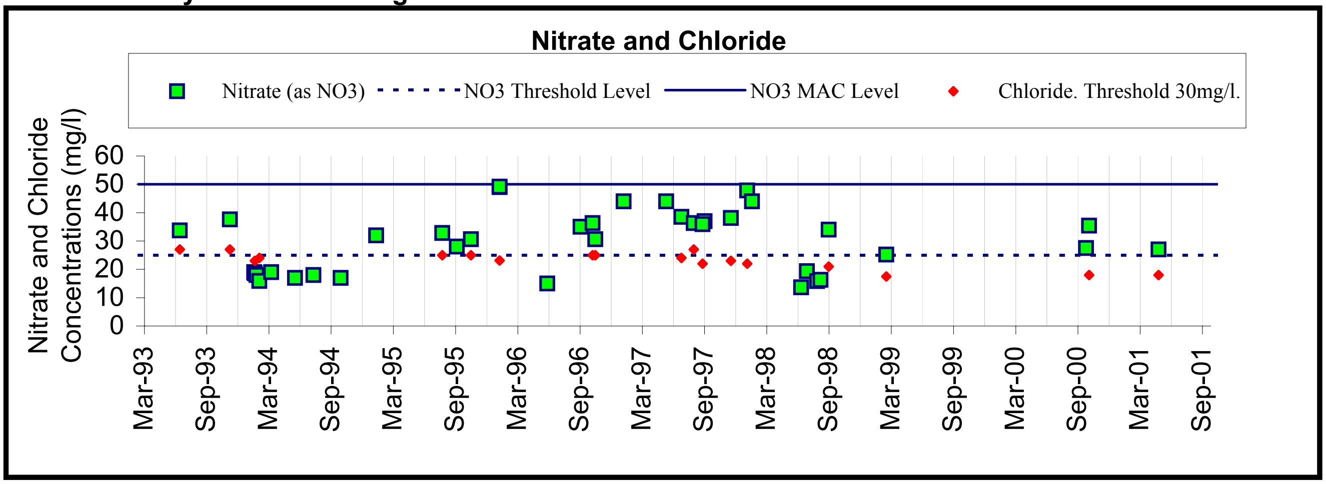
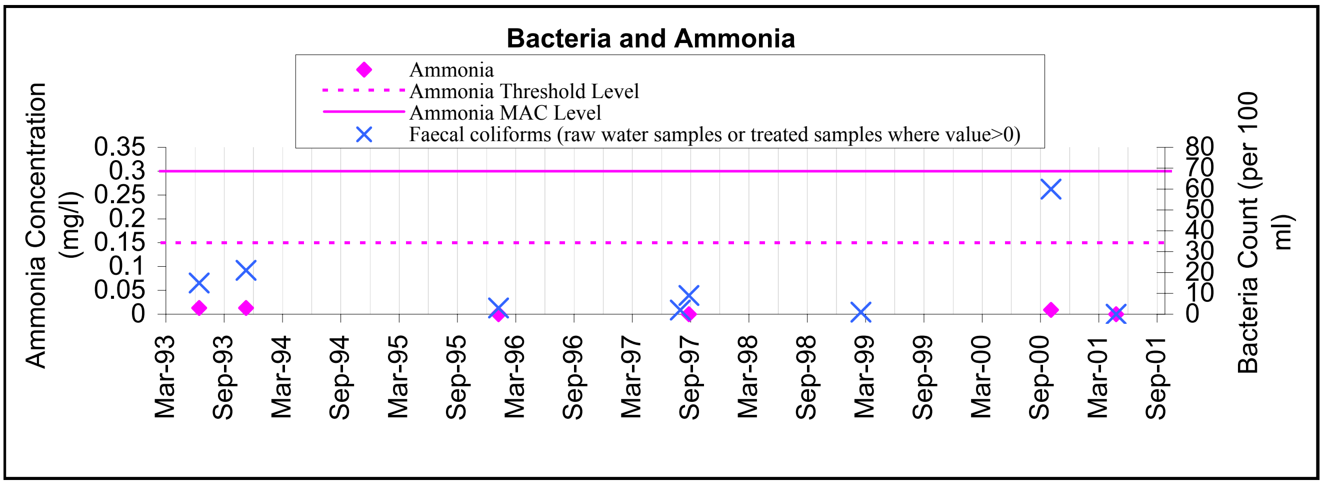
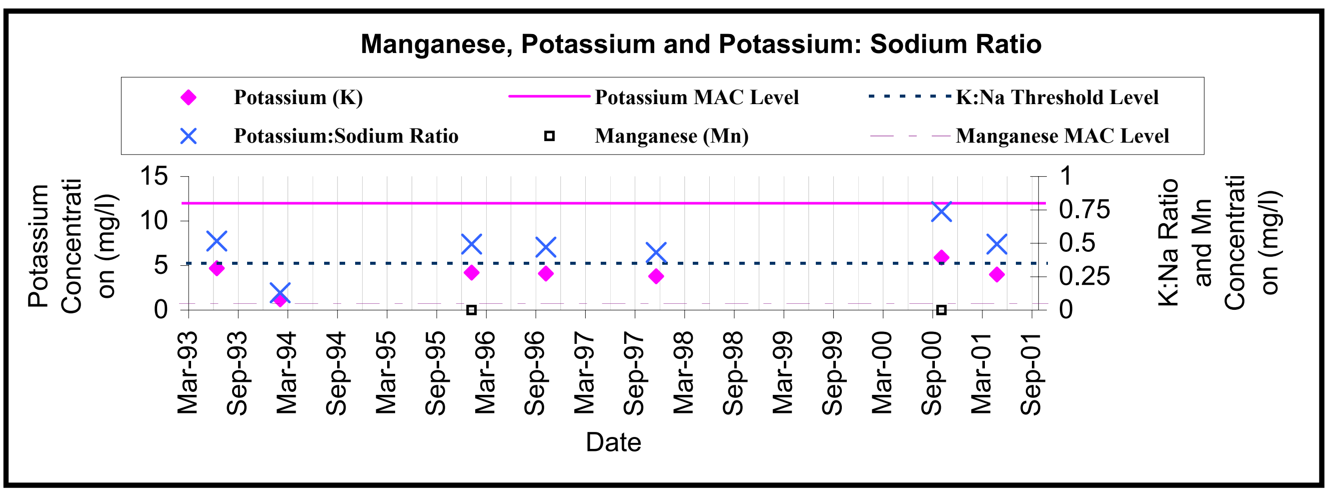


Figure14.1- Urlingford Springs
Key indicators of Agricultural and Domestic GroundwaterContamination.

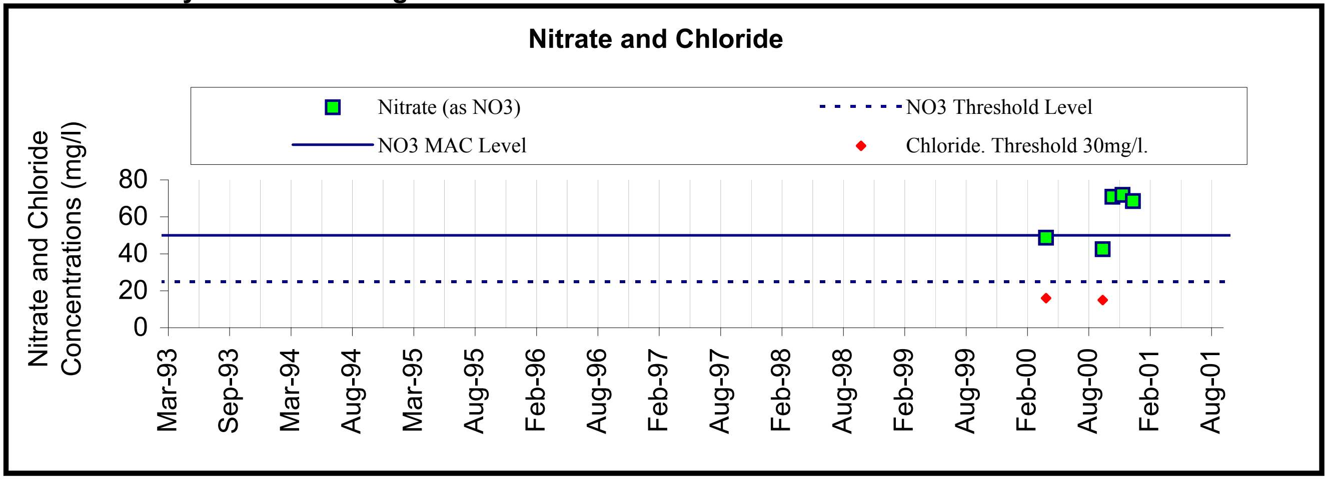


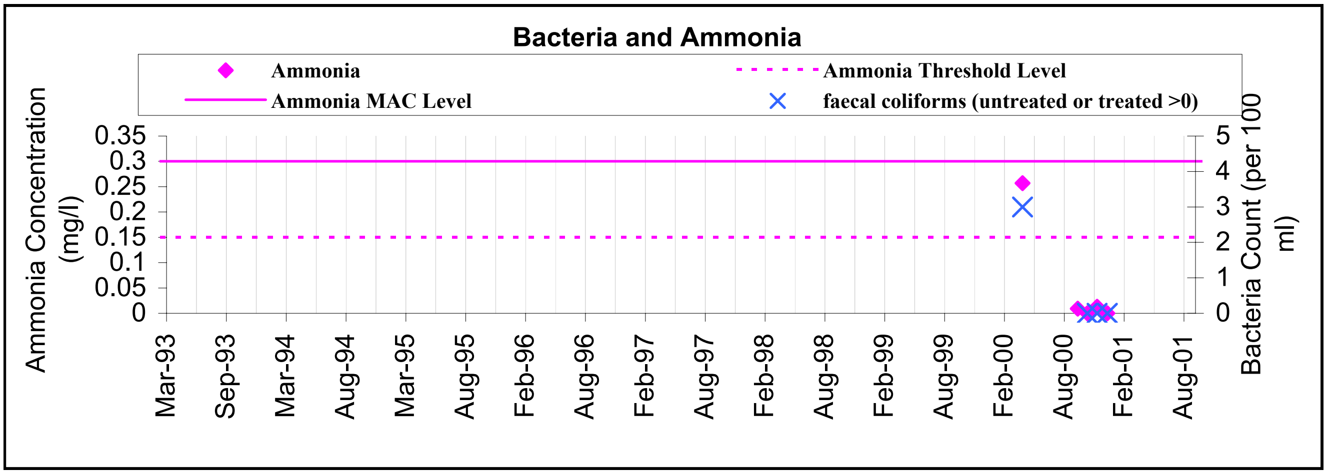


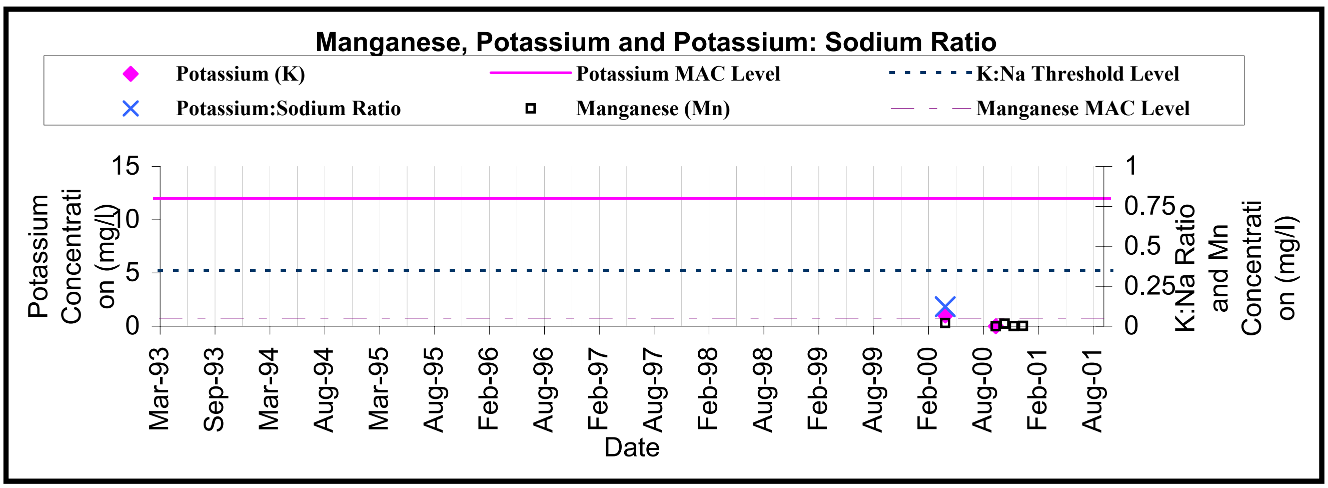


Windgap GWS

Key indicators of Agricultural and Domestic GroundwaterContamination.







Windgap (Domestic well)
Key indicators of Agricultural and Domestic GroundwaterContamination.