

Environmental Research Centre

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A Review of Groundwater Levels in the South-East of Ireland

STRIVE

Environmental Protection Agency Programme

2007-2013

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A Review of Groundwater Levels in the South-East of Ireland

Review of Groundwater Level Data in the South Eastern River Basin District

Environmental Research Centre Report

Prepared for the Environmental Protection Agency and the Geological Survey of Ireland

by

Trinity College Dublin

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Executive Summary

Groundwater level monitoring, and the subsequent evaluation and interpretation of records, provides fundamental information on the nature of aquifers and the groundwater regime. Consistent monitoring over time allows hydrogeological trends to be identified and their implications assessed.

Groundwater level data have been collected in Ireland since the late 1960s. Typically, monitoring was conducted during the course of different projects implemented by the Geological Survey of Ireland (GSI) or local authorities. In the 1990s, the Environmental Protection Agency took responsibility for groundwater monitoring in Ireland and set up a new national monitoring network for groundwater quality and levels. In 2006, this network was reviewed and updated in accordance with European Union legislation. This report presents the analysis of groundwater level data available for the South Eastern River Basin District (SERBD).

On a national scale, the climate of the SERBD is reasonably dry. Effective rainfall was calculated using the Food and Agriculture Organization Penman–Monteith soil moisture budgeting method, in order to compare groundwater level variations.

The geology of the SERBD is extremely heterogeneous, comprising bedrock strata of principally Lower Palaeozoic, Devonian and Carboniferous age, with extensive and spatially variable overlying subsoil deposits. In general, groundwater flow in the bedrock is through secondary porosity and is dominated by fracture flow. The groundwater flow paths are likely to be shallow, predominantly in the upper layer of the aquifer, with enhanced weathering and open fractures. However, the karstified and dolomitised limestones may have permeable zones at greater depths. In contrast to the bedrock aquifers, sand and gravel aquifers provide an opportunity for intergranular groundwater flow. Tills are the most widespread subsoil deposit, and while they do not form aquifer units, they may influence any underlying aquifers.

Groundwater level data and monitoring point (MP) information for MPs within the SERBD have been collated into a publicly available database. Hydrographs with suitably long records have been analysed. For ease of discussion, the MPs have been divided into a number of groups. Comparison within and between groups provides an opportunity for insight into the various hydrogeological settings.

The phenomenon of rejected recharge is observed in the hydrographs of locally important aquifers as short-term recharge and recession events observed during winter and spring months when groundwater levels are elevated. Recharge events are observed during the summer months in hydrographs from the heavily karstified Nuenna Catchment. This may be due to the influence of localised summer effective rainfall or point recharge.

Analysis of seasonal groundwater levels showed that bedrock aquifers reach their annual maximum and minimum groundwater levels before gravel aquifers, and typically have a longer recession period. The difference is likely to be due to the discrepancy in storage between the fractured bedrock and gravel aquifers, as well as to the thick unsaturated zones overlying the featured gravel aquifers.

The aquifer storage property, specific yield, was calculated for a number of the settings using the average annual groundwater level variation. The values supported estimates from previous research on aquifers in the SERBD.

The report includes a review of work conducted by the GSI and the Geological Survey of Northern Ireland on the observed short-term groundwater level fluctuations in the SERBD, and elsewhere, due to global seismic events. This work was prompted by the observation of groundwater fluctuations coincident with the 2004 Saint Stephen's Day Indian Ocean earthquake.

An analysis of long-term groundwater level trends was undertaken to investigate if any impacts of climate change were evident in groundwater levels in the

SERBD. The analysis showed no consistent change in the timing of groundwater level minima or maxima in the SERBD. The data collected, however, may provide a useful baseline against which potential future trends may be measured.

Finally, a number of potential future research areas have been identified. The suggested areas include investigations into:

- The influence of subsoil properties on short-term hydrograph responses;
- The influence of groundwater drinking-water abstractions;
- The relationship between groundwater levels and spring flows; and
- Long-term groundwater level trends.

1 Introduction

1.1 Overview

Groundwater level data have been collected in Ireland since the late 1960s. Typically, this monitoring was conducted during the course of different projects, often implemented by the Geological Survey of Ireland (GSI) or local authorities. The GSI holds historical groundwater level records for over 150 monitoring points (MPs) in 10 counties. These records provide a good, though somewhat discontinuous, picture of groundwater levels in Ireland, and provide information on the nature of the aquifers and groundwater regime.

One of the tasks assigned to the newly formed Environmental Protection Agency (EPA) in the early 1990s was to prepare a national programme for the collection, analysis and publication of information on levels, volumes and flows of water in rivers, lakes and groundwaters in Ireland. Until this point, no organisation had any specific statutory responsibility for groundwater and there was no specific groundwater legislation in Ireland (Wright, 1994). Initially, groundwater levels were dipped at approximately quarterly frequency. In 2006, the EPA set up a new national monitoring network for groundwater quality and levels in accordance with European Union (EU) legislation, namely the Water Framework Directive (WFD) (2000/60/EC) (European Commission, 2000). The network comprises 305 MPs in the 26 counties of the Republic of Ireland. Groundwater levels are monitored at 107 MPs in 22 of the counties.

This report focuses on groundwater levels in the South Eastern River Basin District (SERBD), which comprises the river basins of the Suir, Nore, Barrow and Slaney Rivers, as well as a number of smaller coastal rivers. The SERBD comprises Counties Wexford, Kilkenny, Carlow and parts of Waterford, Tipperary, Laois, Kildare and Wicklow. Figure 1.1 outlines the main river catchments and towns of the SERBD as well as the location of GSI and EPA MPs.

1.2 Objectives

The overall objectives of this joint EPA–GSI–Trinity College Dublin (TCD) report were to collate and analyse the groundwater level data available for the SERBD. The analysis of the groundwater level data aims to provide insights into the hydrogeological situation and to enable a review of the value of monitoring in the region.

The analysis of groundwater level records will investigate:

1. Short-term and seasonal groundwater level trends, including:
 - The evaluation of groundwater level statistics;
 - The determination of aquifer properties from groundwater level variations;
 - A review of groundwater fluctuations caused by earthquakes; and
 - Brief summaries on groundwater level response to effective rainfall (EF), spring discharge and abstractions;
2. Long-term groundwater level trends, including the possible impacts of climate change; and
3. Surface water–groundwater interactions.

1.3 Report Outline

Following this introduction, Chapter 2 presents climate data for the SERBD and discusses the EF calculated for this project. Chapter 3 briefly outlines the physical setting of the SERBD. Chapters 4 and 5 present a general review of the geology and hydrogeology of the principal formations of relevance to the study. This is followed, in Chapter 6, by an introduction to the historic and current groundwater level monitoring networks in Ireland. Chapter 7 discusses the hydrographs with long data records and the analysis conducted for this report, while Chapter 8 contains a summary of the report and recommendations for further investigations.

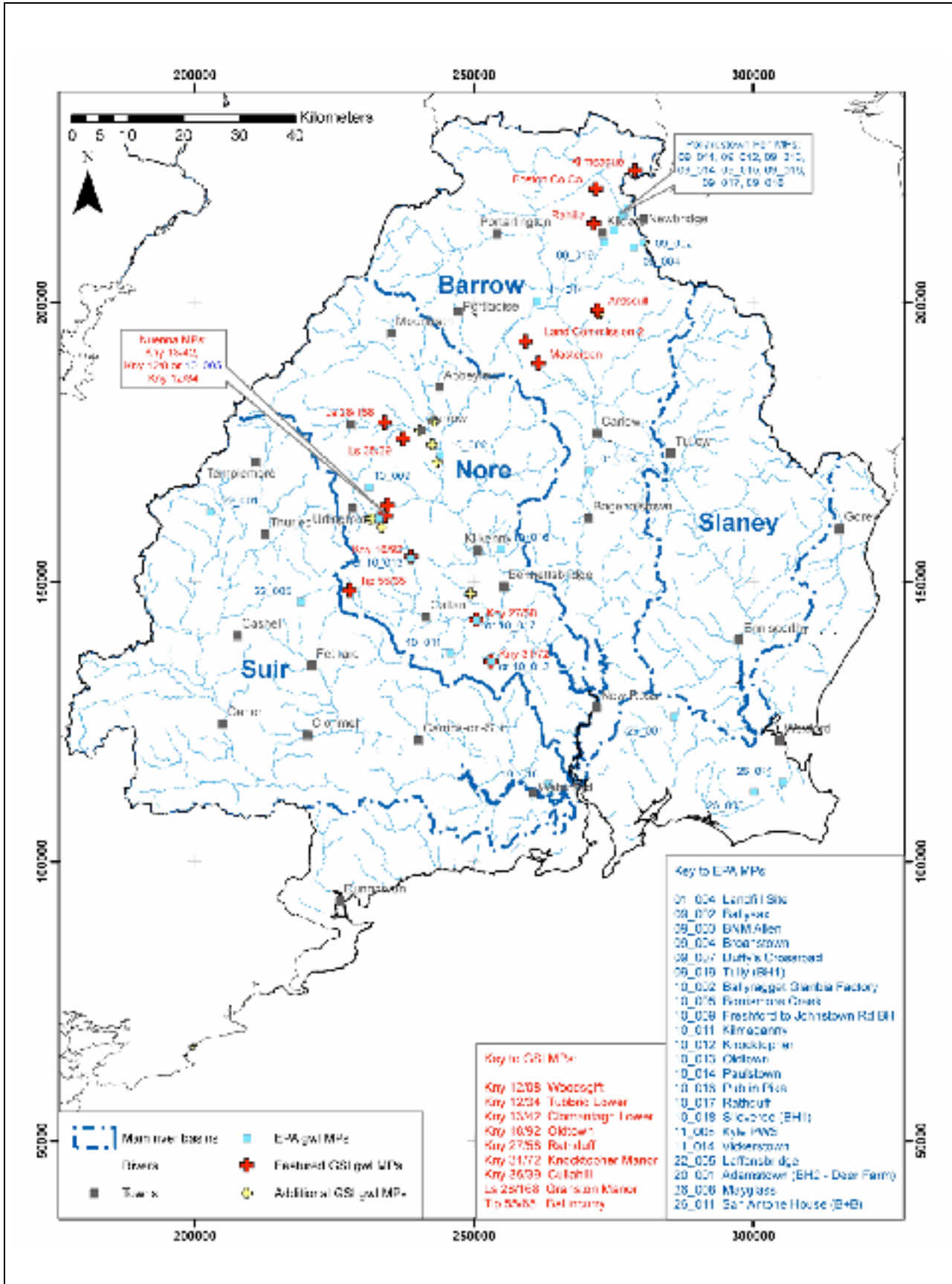


Figure 1.1. Main river basins in the South Eastern River Basin District and monitoring point locations.

Four appendices are included: (i) Appendix A outlines the translation between geological formations and the GSI's rock unit groupings; (ii) Appendix B outlines the GSI's historic groundwater level monitoring network;

(iii) Appendix C presents individual hydrographs for the EPA's current groundwater level monitoring network; and (iv) Appendix D presents individual hydrographs for the featured GSI MPs.

2 Climate

2.1 Precipitation

Rainfall is measured by Met Éireann at 61 rainfall stations throughout the SERBD. There are two synoptic stations within the SERBD: Oak Park (which replaced Kilkenny in March 2008) and Johnstown Castle (which replaced Rosslare in March 2008). At synoptic stations, meteorological elements, such as air temperature, rainfall, humidity, vapour pressure, wind speed, wind direction and atmospheric pressure, are recorded on an hourly basis. Daily evaporation, potential evapotranspiration (PE) and soil moisture deficits (SMDs) are calculated for these stations (<http://www.met.ie>).

The *Agroclimate Atlas of Ireland* (Collins and Cummins, 1996) shows the annual mean rainfall to be between 800 and 1,000 mm in the lowlands of the SERBD, 1,000 and 1,250 mm in upland areas (200–600 m), and in excess of 2,000 mm in mountainous areas (greater than 600 m). On a national scale, the

SERBD is a relatively dry region. Precipitation values in excess of 1,200 mm are typical over most of the rest of the country. Precipitation values in excess of 2,800 mm occur over the Connemara and Kerry mountains.

Table 2.1 outlines the details of rainfall stations close to groundwater level MPs, while Fig. 2.1 outlines the locations of the rainfall stations and groundwater level MPs.

Average annual rainfall has been calculated for each station over the periods outlined in Table 2.1. Missing rainfall data occur at all but the synoptic stations. Missing data for the Tullaroan and Thomastown stations have been infilled using an estimated relationship with the Kilkenny synoptic rainfall¹. Average annual rainfalls for the other stations were

1. Using a comparison between the average daily rainfall per month the following relationships were established between the Tullaroan/Thomastown rainfall and the Kilkenny rainfall: Thomastown rainfall = 1.10 × Kilkenny rainfall; Tullaroan rainfall = 1.29 × Kilkenny rainfall.

Table 2.1. Details of the rainfall stations close to monitoring points (MPs).

Rainfall station	X	Y	Elevation (m)	Start date	End date	Average annual rainfall (mm)	Nearest MPs
Kilkenny synoptic	249400	157400	66 ¹	Jan-70	Apr-08	845/823 ³	
Oak Park synoptic	273000	179500	61 ¹	Jan-07	Mar-09	842	
Tullaroan	233300	157800	2,75 ²	Jan-84	Aug-08	1,083	Clonmantagh Lower Borrismore Creek Oldtown Tubbrid Lower
Thomastown	254900	141500	45 ²	Dec-90	Nov-08	921	Rathduff Knocktopher
Fethard	223800	140300	1,78 ²	Jan-84	Dec-08	973	Ballincurry
Parknahown	234300	173900	1,00 ²	Jan-81	Aug-08	856	Granston Manor Cullahill
Castledermot	274500	187700	85 ²	Nov-83	Nov-91	794	Ardscull Masterson Land Commission 2
Naas	289400	219649	95 ²	Jul-68	Nov-91	802	Rahilla Boston Co. Co. Kilmeague

¹Data from Met Éireann.

²Elevations estimated from Ordnance Survey Ireland maps.

³Met Éireann long-term average (1961–1990).

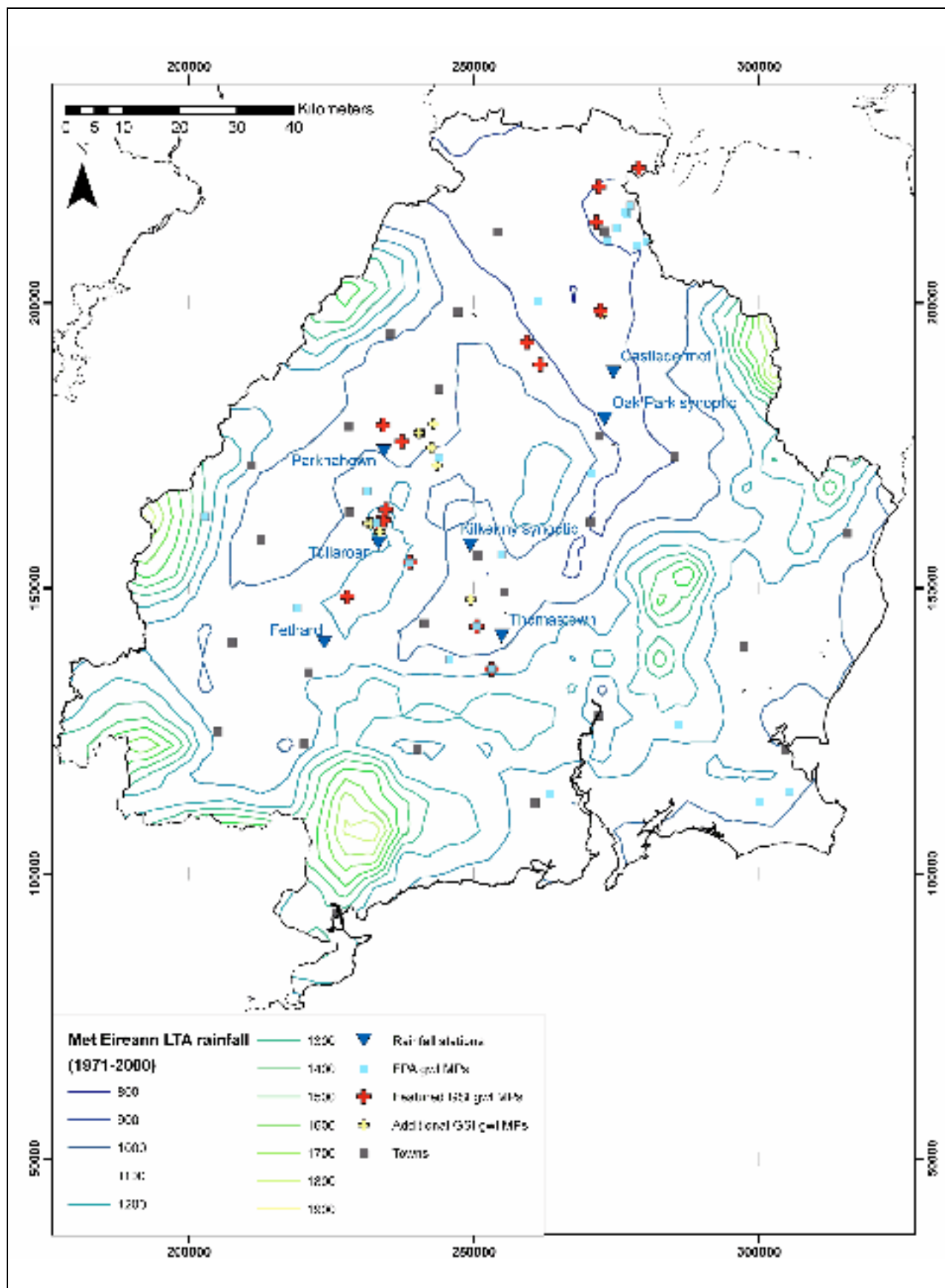


Figure 2.1. Rainfall in the South Eastern River Basin District and location of rainfall stations.

calculated using only those months with complete data.

Annual rainfall totals for Kilkenny, Tullaroan and Thomastown rainfall stations are shown in Fig. 2.2. This illustrates that periods of low annual rainfall occurred in 1971, mid- to late-1970s, late-1980s, early-1990s and mid-2000s and periods of high annual rainfall in 1994, 1998 and 2002.

In addition to the variations in annual rainfall, notable seasonal variations occurred with high summer rainfalls in 1985, 1997 and 2007. The 2007 summer rainfall (384 mm) was more than double the average summer rainfall for this station (184 mm).

Average monthly rainfalls for the Kilkenny synoptic station are included in Fig. 2.3 and show a variation between winter and summer rainfalls. The wettest month is typically October, with 92 mm of rain, and the driest month is typically April, with 54 mm of rain.

Keane and Collins (2004) state that for every 100 m increase in altitude, annual rainfall amounts increase by between 100 mm on eastern slopes and 200 mm on western slopes. This rainfall–elevation relationship suggests approximate annual rainfalls of between 1,300 mm and 1,800 mm on the upland areas of the SERBD.

2.2 Potential Evapotranspiration

Evapotranspiration is the combination of direct evaporation from land and water surfaces and plant transpiration. Met Éireann measures evaporation data, using a Class A pan, at 13 synoptic stations nationally, two of which are located in the SERBD. Met Éireann measures PE, using lysimeters, at two synoptic stations. Estimates of PE are calculated for each synoptic station using the Food and Agriculture Organization (FAO) Penman–Monteith formula (<http://www.met.ie>).

The *Agroclimate Atlas of Ireland* (Collins and Cummins, 1996) shows the annual PE in the SERBD to vary spatially between 450 mm and in excess of 500 mm. Potential evapotranspiration is relatively stable throughout the country, increasing with proximity to the coast.

A number of monthly and annual PE data sets for the Kilkenny synoptic station are shown in Table 2.2:

- Met Éireann daily data, averaged for this report, for the period 1970–2009;
- Met Éireann's long-term average (LTA) PE data (averaged over 1981–2000);
- Potential evapotranspiration data calculated by Daly (1994) using the Penman method; and
- Potential evapotranspiration data calculated by Misstea and Brown (2008) using the FAO Penman–Monteith method.

All sets of PE data show a minimum PE in winter, an increase during the spring to a maximum in the summer and a decline in the autumn.

The Met Éireann annual averages are approximately 15–20% higher than the other estimates of PE for the area shown in Table 2.2. The Met Éireann data and the other estimates are most similar in the summertime, where the Met Éireann monthly averages are approximately 10–20% higher than the other data sets; in the winter months, there is a larger proportional difference between the data sets, although actual PE values are small. At the time of writing, the reason for the discrepancy in PE values is unknown.

2.3 Effective Rainfall

Soil moisture budgets involve the calculation of soil moisture surpluses and deficits, and then actual evapotranspiration (AE), from precipitation and PE data. These models calculate the water that is potentially available for groundwater recharge (ER) as the difference between measured rainfall, estimated AE and the SMD (Misstea and Brown, 2008). In the current report, the FAO Penman–Monteith soil moisture budgeting method was used to calculate the ER. The reader is referred to Allen et al. (1998) for the methodology.

The FAO Penman–Monteith AE is calculated by applying a water stress factor (K_s) to the Penman–Monteith PE for the particular crop and soil under consideration. The stress factor is determined on a daily basis, depending upon PE, rainfall and the previous day's SMD for predetermined values of total

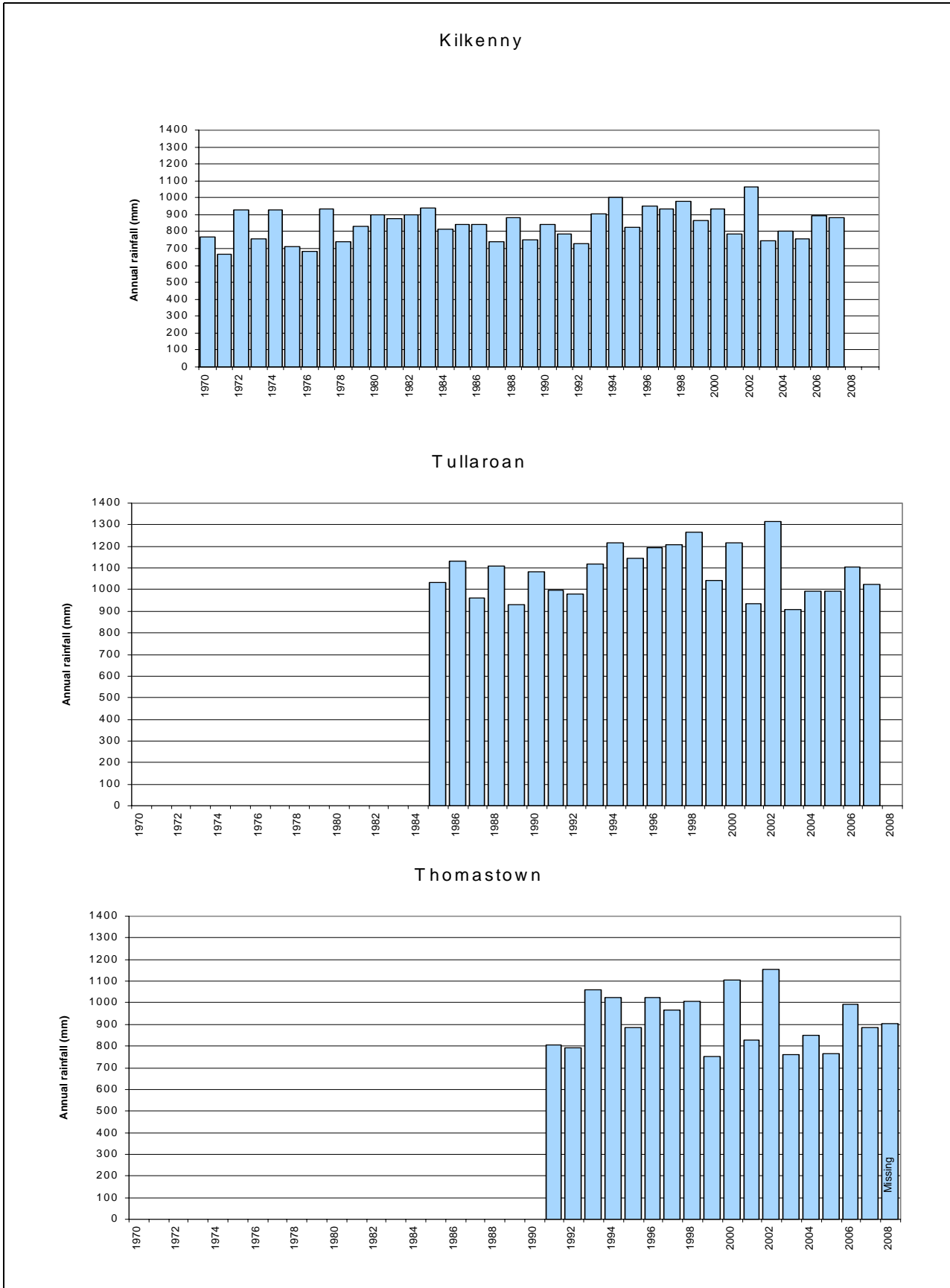


Figure 2.2. Annual rainfalls for Kilkenny, Tullaroan and Thomastown stations.

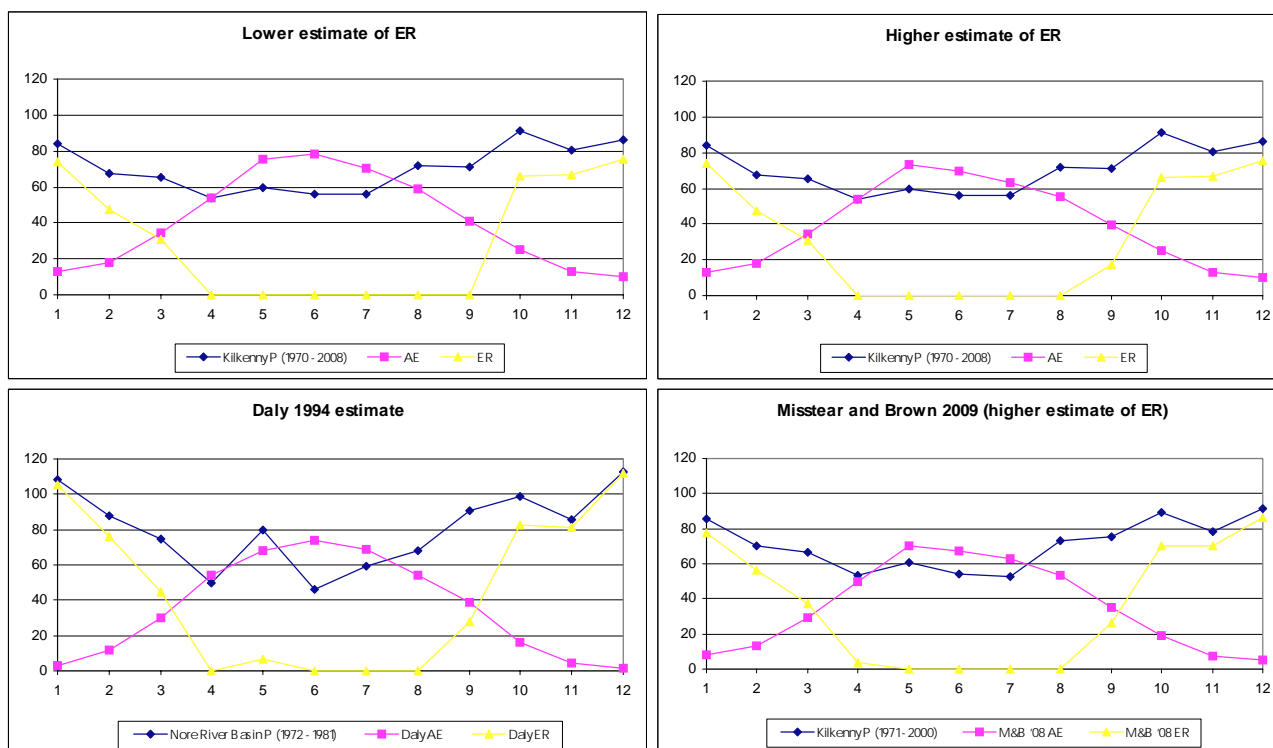


Figure 2.3. Comparison of monthly averages of rainfall, actual evapotranspiration and effective rainfall (ER).

Table 2.2. Comparison of monthly and annual averages of potential evapotranspiration (PE) for Kilkenny synoptic station.

Month	Met Éireann ¹	Met Éireann LTA	Daly (1994)	Misstear and Brown (2008)
	Penman–Monteith PE (mm)		Penman PE (mm)	Penman–Monteith PE (mm)
January	12.7	13.5	3.1	7.9
February	18.4	19.2	11.7	13.2
March	34.6	34.5	30.1	29.3
April	54.3	53.3	54.3	49.9
May	75.8	74.9	69.8	71.5
June	83.5	80.9	81.2	75.3
July	86.7	86.7	74.2	78.4
August	72.7	72.6	62.1	66.3
September	47.1	47.3	39.6	40.8
October	25.9	25.9	16.4	19
November	12.6	13.3	4.1	7.6
December	10.5	11.0	1.3	5.3
Annual average	534.8	533.0	447.9	464.5
Analysis period	1970–2009	1981–2000	1972–1981	1971–2000

¹Met Éireann data averaged for this report.
LTA, long-term average; PE, potential evapotranspiration.

available water (TAW) and readily available water (RAW). Total available water is calculated using the rooting depth, water content at field capacity and wilting point, while RAW is calculated as a depletion factor of TAW (Misstear and Brown, 2008).

The majority of the MPs are located in moderate permeability limestone till subsoil (see Figs 5.2 and 5.3). These usually have less than 35% silt and clay and usually have less than 12% clay (GSI, 2002). Based on subsoil descriptions, these subsoils equate to sandy loam in the USA soil texture classification. The parameters used to calculate RAW and TAW for a sandy loam were taken from Allen et al. (1998) and are outlined in Table 2.3.

Applying these parameters gives TAW values between 110 mm and 150 mm and corresponding RAW values of 66 mm and 90 mm, respectively. The AE and ER calculated for this report are presented in Tables 2.4 and 2.5, respectively. The higher and lower estimates of AE and ER presented in these tables relate to the range in RAW and TAW. Met Éireann's estimate of AE and estimates of AE and ER from the literature outlined for Table 2.2 are included in Tables 2.4 and 2.5.

Met Éireann estimates AE from the PE and SMD data using a hybrid SMD model for three soil drainage classes: well drained, moderately drained and poorly drained (Schulte et al., 2005).

The AE annual averages calculated for this report are approximately 5–17% higher than the other values of AE presented in Table 2.4. This is likely to be due to

the higher PE values with which these data were calculated (see Section 2.2).

Misstear and Brown (2008) used soil moisture budgeting methods (FAO Penman–Monteith) to calculate AE and ER for the Kilkenny synoptic station. They found the mean annual AE to be between 91% and 95% of PE. Daly (1994) used a monthly soil moisture budget method and calculated ER by subtracting AE calculated for the Kilkenny synoptic station from rainfall values estimated for the whole Nore Catchment. Daly (1994) found the mean annual AE to be 95% of PE. The AE values calculated for this report are between 88% and 92% of PE.

All of the ER values show maximum ER in the winter months, a decrease during spring to a minimum of zero throughout the summer months, and an increase in the autumn months back to the winter maximum. This means that all rainfall during the summer months is consumed by evapotranspiration and is not available for recharge. Summer recharge, while rare, may occur due to either high and prolonged summer rainfall or to rainfall bypassing the soil zone, and thus soil moisture requirements, by, for example, point recharge mechanisms. Water becomes potentially available for widespread groundwater recharge in September or October.

Table 2.5 shows that the ER values calculated for this report are approximately 7–34% lower than the other values of ER presented in Table 2.5. This is likely to be due to the higher PE values with which these data were calculated (see Section 2.2). The greatest discrepancy

Table 2.3. Food and Agriculture Organization Penman–Monteith parameters (after Allen et al., 1998).

Parameter	Symbol	Minimum	Maximum
Water content at field capacity	θ_{FC}	0.18	0.28
Water content at wilting point	θ_{WP}	0.06	0.16
Difference between water content at field capacity and wilting point	$\theta_{FC} - \theta_{WP}$	0.11	0.15
Rooting depth for grazing pasture	Zr		1.0 ¹
Depletion factor between RAW and TAW for grazing pasture	p	0.6	

¹After Misstear and Brown (2008).
RAW, readily available water; TAW, total available water.

Table 2.4. Comparison of monthly and annual averages of actual evapotranspiration (AE) for Kilkenny synoptic station (mm).

Month	AE calculated for this report		Met Éireann calculated AE		Daly (1994)	Missteear and Brown (2008)	
	Lower estimate of AE	Higher estimate of AE	Well or moderately drained soil	Poorly drained soil	AE	Lower estimate of AE	Higher estimate of AE
January	12.6	12.6	13.2	13.3	3.1	7.9	7.9
February	18.3	18.3	18.8	19.1	11.7	13.2	13.2
March	34.7	34.7	33.2	34.6	30.1	29.3	29.3
April	54.3	54.3	47.9	51.8	54.3	49.9	49.9
May	73.5	75.6	59.0	64.1	68.2	70.3	71.5
June	69.5	78.2	58.7	62.6	74.1	67.5	73.5
July	63.1	70.6	57.9	61.3	69	63.1	70.7
August	55.3	58.7	51.8	53.9	53.9	53.1	58
September	39.5	40.7	36.1	38.1	38.7	35.2	36.6
October	25.2	25.3	24.1	24.8	16.4	18.8	18.8
November	12.6	12.6	12.7	12.9	4.1	7.6	7.6
December	10.4	10.4	10.7	10.7	1.3	5.3	5.3
Annual average	468.8	491.9	423.8	447.0	424.9	421.2	442.3
Analysis period	1970–2009		1979–2008		1972–1981	1971–2000	

Table 2.5. Comparison of monthly and annual averages of effective rainfall (ER) for the Kilkenny synoptic station.

Month	ER calculated for this report		Daly (1994)	Missteear and Brown (2008)	
	Higher estimate of ER	Lower estimate of ER	ER	Higher estimate of ER	Lower estimate of ER
January	73.8	73.8	105.3	77.3	77.3
February	47.6	47.6	76.0	56.7	56.7
March	31.1	31.1	44.3	37.1	37.1
April	0.0	0.0	0.0	3.6	3.7
May	0.0	0.0	6.9	0.0	0.0
June	0.0	0.0	0.0	0.0	0.0
July	0.0	0.0	0.0	0.0	0.0
August	0.0	0.0	0.0	0.0	0.0
September	17.5	0.0	27.8	26.0	4.9
October	66.2	60.6	82.7	70.3	70.2
November	67.1	67.1	81.5	70.6	70.6
December	75.1	75.1	111.7	86.5	86.5
Annual average	378.5	355.4	536.2	428.1	407.0
Analysis period	1970–2009		1972–1981	1971–2000	

is with Daly's (1994) data. As outlined above, Daly (1994) calculated ER using rainfall values estimated for the whole Nore Catchment rather than just the Kilkenny synoptic station. Both this report and that of Misstear and Brown (2008) used rainfall values only from the Kilkenny synoptic station. This difference may account for the greater discrepancy between ER calculated for this report and Daly's (1994) estimates, as Kilkenny rainfall is relatively low compared with the rest of the catchment (see Table 2.1 and Fig. 2.1).

Figure 2.3 presents monthly averages of the rainfall, AE and ER calculated for this report and from Misstear

and Brown (2008) and Daly (1994). This shows the similarity in trends between the three estimates.

The calculated higher monthly estimate of ER is presented in this report against the groundwater hydrographs in Figs 7.1–7.7 and in Appendices C and D. The choice of the higher estimate of ER ensures that all likely ER events are displayed. The ER plotted against the hydrographs is for the Kilkenny synoptic station, rather than for the rainfall station nearest to the MP. This is due to the large number of data gaps and relatively short data record for the rainfall stations compared with the Kilkenny synoptic station.

3 Physical Setting

3.1 Topography

Figure 3.1 presents the topography of the SERBD. The study area is bounded to the north-east by the Wicklow Mountains (highest point 927 m), to the north-west by the Slieve Bloom to Silvermines range, to the south-west by the Galtee Mountains (highest point 920 m) and the Comeragh and Monavullagh Mountains (highest point 792 m), and to the south-east by the coast. Other notable landforms within the study area are the Castlecomer Plateau (up to 600 m), the Slieveardagh Hills (up to 600 m), Slievenamon (up to 600 m) and the Blackstairs Mountains (highest point 796 m).

The main lowlands of the study area are the:

- Thurles to Mountrath Lowlands (to the west of the Castlecomer Plateau and Slieveardagh Hills), which lie typically between 130 and 100 maOD²;
- Callan to Carlow Lowlands (to the east of the Castlecomer Plateau and the Slieveardagh Hills), which lie typically between 90 and 30 maOD; and

2. maOD, metres above Ordnance Datum.

- Coastal lowlands (to the east of the Blackstairs Mountains), which lie typically between 60 maOD and sea level.

3.2 Surface Water Networks

The Rivers Suir, Barrow and Nore rise in the Slieve Bloom to Silvermines Mountains. The three rivers take different courses before converging in the Waterford Estuary. The River Suir flows south from its source past the Galtee Mountains, then east past Slievenamon before flowing into the Waterford Estuary. The River Nore initially flows north-east along the length of Slieve Bloom, then south-east between the Castlecomer Plateau and the Slieveardagh Hills before flowing into the Waterford Estuary. The King's River, a major tributary of the River Nore, rises in the Slieveardagh Hills and flows into the River Nore just upstream of its transition into the Waterford Estuary. The River Barrow flows east from the eastern flanks of Slieve Bloom, then flows south-east and south between the Castlecomer Plateau and the Wicklow Mountains before flowing into the Waterford Estuary.

The River Slaney rises in the Wicklow Mountains and flows south-east into the Wexford Estuary.

The EPA monitors the flow of rivers at 134 hydrometric stations within the SERBD.

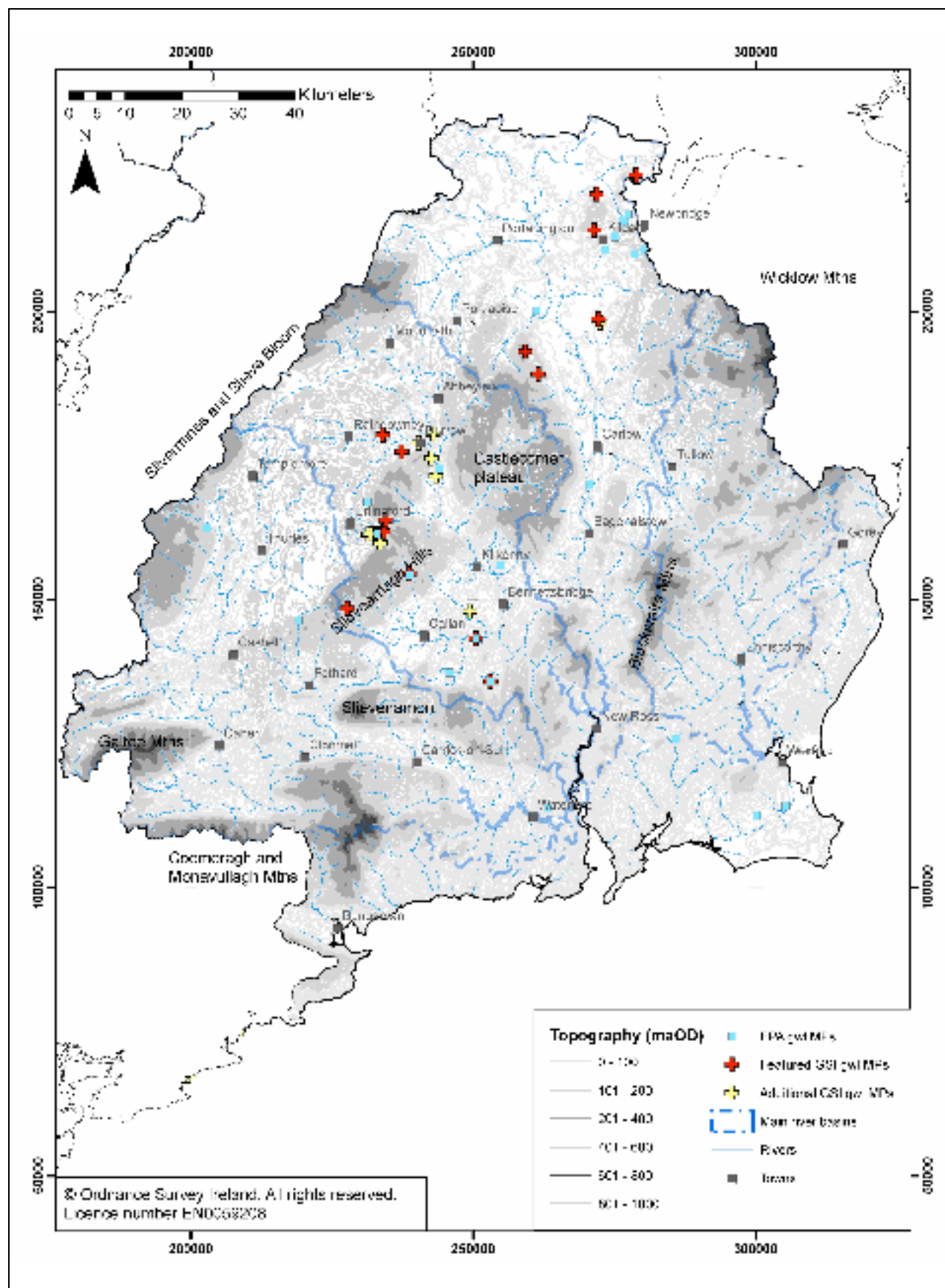


Figure 3.1. Topography of the South Eastern River Basin District.

4 Geology

4.1 Introduction

The study area is underlain by extremely heterogeneous strata, principally of Lower Palaeozoic, Devonian and Carboniferous age, with extensive, and spatially variable, overlying subsoil deposits.

The majority of geological information in this section comes from the GSI reports accompanying the GSI's 1:100,000 geological map sheets covering the area of the SERBD (specifically Tietzsch-Tyler et al., 1994; Archer et al., 1996). Table 4.1 outlines the bedrock stratigraphy and highlights hydrogeologically important strata. Figures 4.1 and 4.2 show the distribution of the bedrock units and subsoils, respectively. For simplicity, Fig. 4.1 shows the bedrock geology as the GSI's grouped rock units (GSI, 2005a). The relationship between the formations and groups discussed in the text and the grouped rock units may be found in Appendix A. Geological borehole log information, where included, refers to groundwater level MPs, the locations of which are shown in Fig. 1.1.

4.2 Lower Palaeozoic Strata

The Lower Palaeozoic strata outcrop in the east of the study area and underlie the majority of Counties Wexford, Waterford and Wicklow and the east of Counties Carlow, Kilkenny and Kildare. They are also exposed via inliers in the Galtee, Slieve Bloom and Slievenamon Mountains. The deposits comprise metasedimentary and volcanic rocks associated with the evolution of the Iapetus Ocean. They are folded with a north-east to south-west trend and are extensively faulted; therefore, they are typically steeply dipping and include overturned beds (Archer et al., 1996).

4.3 Devonian Strata

Devonian strata unconformably overlie the Lower Palaeozoic rocks as a result of uplift during the Caledonian Orogeny (Silurian to Devonian). The

deposits comprise the sandstones and conglomerates of the Old Red Sandstone and large intrusive granite bodies.

The Old Red Sandstone is exposed on the flanks of the southern and western uplands. The granite bodies, which form part of the Leinster Granite Batholith, underlie the majority of County Carlow and extend north-eastwards to Dublin Bay.

The Old Red Sandstone comprises shallow water, fluvial or lacustrine, deposits eroded from the Caledonian uplands. In most places the succession commences with a breccia or conglomerate, followed by repeated fining-upwards sequences composed of conglomerates and coarse sandstones, followed by fine-grained red beds. The Kiltorcan Formation forms an important aquifer within the Old Red Sandstone. It contains micaceous sandstones interbedded with silty mudstones and conglomerates (Archer et al., 1996).

The Old Red Sandstone's thickness varies throughout the SERBD, from 50 m depth near Ballyragget in Co Kilkenny to over 3,000 m in the central Comeraghs (Daly, 1982). The Kiltorcan Formation is about 235 m thick at Kiltorcan (Archer et al., 1996) near the Knocktopher Manor Borehole (Kny 31/72).

The Old Red Sandstone is folded into a series of east-west trending Variscan age folds. The strata have variable dips (ranging from 5° to 70° around Slievenamon).

A borehole log for the Knocktopher Manor Borehole (Kny 31/72) (Daly, 1994) was derived from samples of chippings and geophysical investigations. It shows 4 m of till subsoil overlying 10.9 m of the Porter's Gate Formation (interbedded mudstones, sandstones and limestones) overlying 35 m of the Kiltorcan Formation (sandstones with occasional siltstones and mudstones).

Table 4.1. Stratigraphy of bedrock geology (after Daly, 1994 and Tietzsch-Tyler et al., 1994). (Fm, formation)

Geological age		Group	Outcrop distribution	Hydrogeologically significant formations	Lithology		
Carboniferous	Westphalian		Deltaic cycles of coals and thick sandstones	Slieveardagh Hills/Castlecomer Plateau	Lickfinn Coal Fm	Sandstone and silty shales with coal seams	
		Namurian		Sandstones, shales and limestones	Slieveardagh Hills, Durrow Syncline, flanks of Castlecomer Plateau	Bregaun Flagstone Fm	Micaceous sandstone and siltstones
					Killeshin Siltstone Fm	Silty shale with few sandstone beds	
					Luggacurran Shale Fm	Shales with muddy cherts, limestones with ironstone ribs	
	Dinantian	Visean		Visean Limestones	Urlingford to Mountrath and Callan to Bennettsbridge Lowlands	Clogrennan Fm	Crinoidal, cherty limestone with local algal laminations
						Ballyadams Fm	Thick-bedded crinoidal limestone with clay wayboards
						Durrow Fm	Fossiliferous limestone, shales and oolites
						Aghmacart Fm	Peloidal and micritic limestone with algal laminations
						Urlingford to Mountrath Lowlands	Crosspatrick Fm
					Waulsortian Mudbank Complex	Flanks of Slieve Bloom and Galtee Mountains	Waulsortian Limestones
				Sub-Waulsortian Limestones	Flanks of Castlecomer Plateau and Slievenamon, Slieve Bloom Mountains	Ballysteen Fm	Bioclastic limestones becoming increasingly muddy upwards
						Ballymartin Fm	Muddy bioclastic limestones interbedded with calcareous shales
Lower Palaeozoic	Devonian		Lower Carboniferous Sandstones and Shales	Flanks of Slievenamon, Galtee Mountains and Slievenamuck	Ballyvergin Fm	Non-calcareous mudstone with interlaminated siltstone	
					Porter's Gate Fm	Calcareous sandstone, shales and thin limestones	
			Old Red Sandstone	Flanks of Slievenamon, Galtee Mountains and Slievenamuck	Kiltorcan Fm	Coarse-grained white–yellow sandstone, conglomerate and mudstone	
			Tullow and Blackstairs Granites	Carlow and Wicklow			
			Metasedimentary and volcanics	Wexford, Wicklow, Waterford, east of Carlow, Kilkenny and Kildare Slievenamon, Slieve Bloom and Galtee Mountains	Campile Fm	Ordovician volcanics	

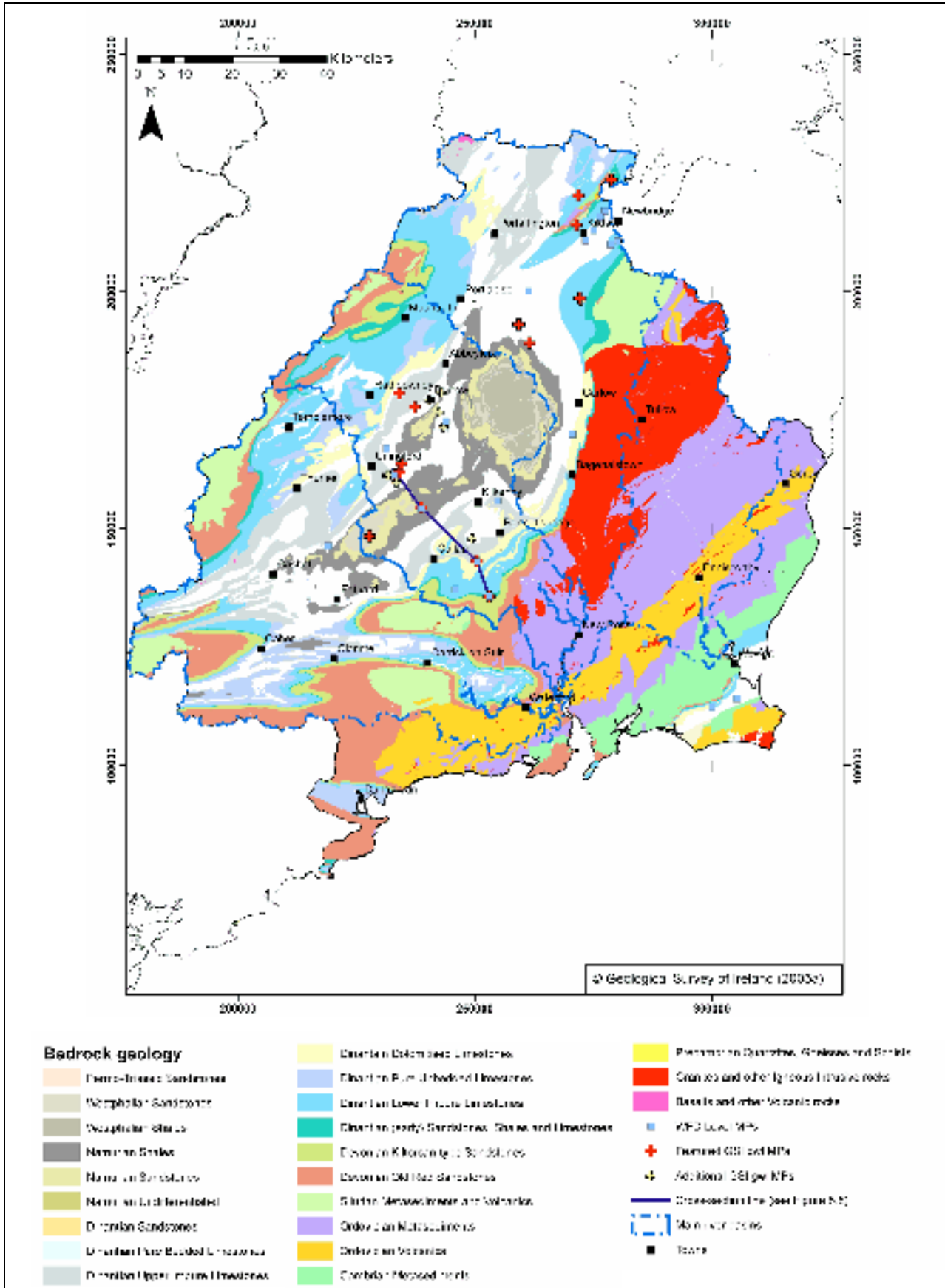


Figure 4.1. Bedrock geology of the South Eastern River Basin District.

4.4 Carboniferous Strata

4.4.1 *Dinantian strata*

4.4.1.1 *Lower Carboniferous Sandstones and Shales*

The Lower Carboniferous Sandstones and Shales (also known as the Lower Limestone Shales) rest conformably on the Old Red Sandstone and mark the onset of a marine transgression. The strata comprise a series of sandstones, siltstones and mudstones (Tietzsch-Tyler et al., 1994). They outcrop predominantly on the flanks of Slievenamon, Slievenamuck and the Galtee Mountains.

The Porter's Gate Formation, at the base of the Lower Carboniferous Sandstones and Shales, includes sandstones, shales and thin bioclastic limestones. The overlying Ballyvergin Shale Formation is a thin (maximum thickness 10 m) distinctive shale horizon, which marks the transition from the Lower Carboniferous Sandstones and Shales to the overlying Carboniferous limestone sequence (Tietzsch-Tyler et al., 1994).

The thicknesses of the Lower Carboniferous Sandstones and Shales are greatest in the south of the Nore River Basin. The Porter's Gate Formation is typically between 30 m and 80 m thick (Daly, 1994).

4.4.1.2 *Sub-Waulsortian Limestones*

The Sub-Waulsortian Limestones (also known as the Sub-Reef Limestones) correspond to the Lower Impure Limestone rock unit. The strata outcrop on the flanks of the Castlecomer Plateau, Slievenamon and the Slieve Bloom to Silvermines mountainous uplands.

The Sub-Waulsortian Limestones, namely the Ballymartin and Ballysteen Formations, conformably overlie the Lower Carboniferous Sandstones and Shales. They mark the onset of a thick sequence of Dinantian interbedded limestones and shales deposited in sub-tidal conditions.

The Ballymartin Formation comprises muddy bioclastic limestones interbedded with calcareous shales. The formation weathers very readily and, as a result, there are few good outcrops; therefore, it is often mapped together with the underlying Ballysteen Formation (Archer et al., 1996). The Ballysteen Formation comprises bioclastic argillaceous limestones

interbedded with shales, becoming increasingly muddy upwards. Oolitic limestones are found at several intervals throughout the formation, including the Lisduff Oolite Member. This member is a thick-bedded cross-bedded, well-jointed oolite that may be up to 100 m in thickness (Daly, 1994). The Ballysteen Formation is equivalent to the Boston Hill Formation in Counties Kildare and Wicklow (McConnell et al., 1994).

There is a reduction in the thickness of the Sub-Waulsortian Limestones from north to south and from west to east. They range from 500 m at Borris-in-Ossory to about 300 m at Bennettsbridge (Daly, 1994). In the SERBD, much of the upper section of the Ballysteen Formation has been extensively dolomitised (Daly, 1994).

4.4.1.3 *Waulsortian Limestones*

The sequence of Dinantian marine limestones continues with the Waulsortian Limestones and equivalent successions. The Waulsortian Limestone outcrops to the west of Kilkenny. To the east there are a number of laterally equivalent successions including the Butlersgrove Formation (formerly termed the Middle Limestones). For further information on these successions, the reader is referred to Tietzsch-Tyler et al. (1994).

The Waulsortian accumulations or banks consist of massive, but subtly bedded, often steep-sided mounds, which coalesce into a thick unit. The dominant lithology is often a very fine micrite with large sparry masses. These limestones are often, inappropriately, termed 'reef' limestones.

These limestones predominantly outcrop in the lowlands of the study area. Topographically they are expressed as both abrupt and rounded hills, sometimes reflecting the original mound forms (Tietzsch-Tyler et al., 1994; Archer et al., 1996).

The massive and early-lithified Waulsortian was rigid enough to support open pathways for fluids expelled from the underlying Old Red Sandstone and other rocks, so it is frequently wholly converted to dolomite. It is also the preferred host for most of the base metal deposits in this part of Ireland (Tietzsch-Tyler et al., 1994; Archer et al., 1996).

4.4.1.4 Visean Limestones

The Visean Limestones occur in the lowlands of the study area. Depending upon location, these limestones have been grouped into a number of different successions, but generally they record a sequence of shallow-water, continental-shelf limestones. Table 4.1 outlines only the Rathdowney–Hollycross Visean succession (Succession 7) as most MPs are located in this succession. For further information on the different Visean successions, the reader is referred to Archer et al. (1996).

The Rathdowney–Hollycross Formation is divided into five formations, namely the Crosspatrick, Aghmacart, Durrow, Ballyadams and Clogrennan Formations (many of these names have been newly introduced). Previously, the Durrow, Ballyadams and Clogrennan Formations were known as the Cullahill Formation (Daly, 1994).

The Crosspatrick Formation comprises a pale crinoidal to micritic limestone, with much chert and some shale. The Aghmacart Formation comprises dark fine-grained peloidal and micritic limestones, with algal laminations, thin shales and oolitic and bioclastic intervals. The Durrow Formation comprises fossiliferous limestones, shales and oolites, with a few micrites. The Ballyadams Formation comprises pale thick-bedded crinoidal limestone with clay wayboards. The Clogrennan Formation comprises crinoidal, cherty limestones, with local algal laminations (Archer et al., 1996).

The Crosspatrick Formation is up to 60 m thick, but its thickness is quite variable, reflecting the topography of the underlying Waulsortian mounds. The Aghmacart and Durrow Formations are each up to 200 m thick. The Ballyadams Formation is at least 200 m thick and the Clogrennan Formation is at least 100 m thick.

Borehole logs for the Granston Manor pumping and observation boreholes (Ls 28/170 and Ls 28/168, respectively) (Daly, 1994) are based on samples of chippings and geophysical logs. They show approximately 7 m of clay and sand subsoils overlying up to 31 m of partially dolomitised Crosspatrick Formation.

An unlabelled geophysical log for the Woodsgift Borehole (Kny 12/8) (unpublished GSI records) located in the Ballyadams Formation is consistent with interbedded limestones and shales and suggests that the limestone becomes less pure with depth.

The Ballyadams Formation is dolomitised where it outcrops to the south and east of the Castlecomer Plateau. The Visean Limestones outcropping in the lowlands to the north-west of the Slieveardagh Hills are not significantly dolomitised. The Ballyadams and Clogrennan Formations both contain karst weathering features.

4.4.2 Namurian strata

The Namurian strata unconformably overlie the Visean Limestone sequence. The unconformity represents a period of non-deposition and a change from shallow tropical seas to a quiet deep-water environment (Tietzsch-Tyler et al., 1994). The outcrop of the Namurian rocks is mostly confined to the Castlecomer Plateau and the Slieveardagh Hills.

Again, depending upon location, the successions of the Namurian strata vary. Table 4.1 outlines the Castlecomer and Slieveardagh succession as it is represented by the groundwater level monitoring network. For details on the other successions, the reader is referred to Archer et al. (1996). The Castlecomer and Slieveardagh succession is divided into three formations, namely the Luggacurren Shale, Killeshin Siltstone and Bregaun Flagstone Formations.

The Luggacurren Shale Formation comprises a condensed succession of black cherty shale and thin limestone. The Killeshin Siltstone Formation comprises a dark silty shale, with a few sandstone bands. The Bregaun Flagstone Formation is a flaggy micaceous sandstone and siltstone, often slumped, and dark shaly siltstones above (Archer et al., 1996).

The Killeshin Siltstone is known to be nearly 300 m thick in the Castlecomer and Slieveardagh coalfield areas and is believed to thin to the south and west (Archer et al., 1996).

4.4.3 Westphalian strata

The Westphalian strata outcrop in the centre of the Castlecomer Plateau and Slieveardagh Hills, where

they conformably overlie the Namurian rocks. The successions in the two areas are different but consist of shallow deltaic deposits. There was considerable coal-mining activity in both areas in the nineteenth and twentieth centuries (Daly, 1982).

Table 4.1 outlines the Slieveardagh succession, which includes only the Lickfinn Coal Formation. For details on the Castlecomer succession, the reader is referred to Archer et al. (1996). The Lickfinn Coal Formation comprises sandstones and silty shales, with up to eight coal seams. The two principal sandstone units are the Glengoole Sandstone and the lower Main Rock Sandstone (Archer et al., 1996).

The geophysical logs for two boreholes on the Slieveardagh Hills (including Ballincurry Tip 55/65) indicate that the Main Rock Sandstone unit is between 6 m and 16 m and that the Glengoole Sandstone unit is approximately 6 m thick (Daly, 1980).

4.4.4 Post-Carboniferous strata

A small outcrop of Permo-Triassic New Red Sandstones (Killag Formation), south-west of Wexford, is the only Post-Carboniferous solid geology in the study area. It is likely that most of the study area was emergent after the Carboniferous Period until the late Cretaceous when it is inferred that most of the country was covered by a chalk sea (Tietzsch-Tyler et al., 1994). Any chalk deposition at this time was subsequently removed in the Tertiary Period, a period of extensive erosion in this area. The Tertiary Period is important hydrogeologically as it was probably the period of most significant karstification (Daly, 1994).

4.5 Structure

The structure of the SERBD may be divided into three separate regions (Daly, 1982):

1. The Lower Palaeozoic rocks are characterised by Caledonian folding. They comprise large north-east to south-west trending anticlines and synclines, with additional deformation due to granite intrusion. The later Variscan deformation has had little effect on these strata.
2. The Upper Palaeozoic strata north of the Slievenamon are situated in a large syncline, the

Southeast Carboniferous Basin, which is an extensional structural basin of Variscan age but Caledonian orientation (i.e. north-east to south-west). The Dinantian Limestones dip gently (5–15°) below the overlying Namurian and Westphalian strata of the Castlecomer Plateau and the Slieveardagh Hills, which occupy the centre of the syncline.

3. The Upper Palaeozoic strata, south of Slievenamon, have been folded into a series of steeply dipping synclines, e.g. synclines at Carrick-on-Suir, Dungarvan and south of Caher. Their orientation is Variscan, i.e. east–west trending folds. In general these rocks are heavily faulted, usually in a north–south direction.

There has been widespread and extensive faulting of the Devonian and Carboniferous strata. The dominant trends are north-west, north, north-east and east–north-east. The displacement along many of the larger faults is variable, but of the order of 20–200 m. This is important hydrogeologically, as it separates some of the principal aquifers into unconnected or partially connected units. Closely spaced drilling in the Nore River Basin has invariably shown that there is additional faulting. Hence, it is considered that the strata at the top of the Old Red Sandstone and at least the lower half of the Dinantian strata are regularly faulted (at least every 0.5–1 km) along strike. The displacement along many of these minor faults is of the order of a few to tens of metres (Daly, 1994).

The Namurian and Westphalian strata in the Castlecomer Plateau are displaced by north–south trending faults, indicating east–west compression, and two sets of ENE–WSW³ trending tear faults. The vertical displacement along the tear faults is of the order of 50–125 m, thus dividing the aquifer unit into three separate blocks (Misstear et al., 1980).

4.6 Subsoils (Quaternary Deposits)

Over most of the SERBD, the bedrock is overlain by unconsolidated deposits dating from the Quaternary Period (last 2.6 million years), referred to here as

3. ENE, east–north-east; WSW, west–south-west.

subsoils. Figure 4.2 presents the distribution of the different subsoil types within the SERBD.

The study area has been glaciated on multiple occasions since the beginning of the Quaternary Period (2.6 Ma). During the most recent glaciation, ice from the Midlands spread south and south-eastwards across the study area and merged with ice flowing onshore, south and south-westwards from the Irish Sea Basin (Tietzsch-Tyler et al., 1994). Thus, tills derived from Irish Sea Basin muds (Irish Sea Tills) have been deposited across land close to the east Wexford coast.

4.6.1 Tills

Tills are the dominant and most widespread subsoil material. They are comprised of ground-down debris deposited by or from glacier ice, and are typically derived from the underlying bedrock material at any locality (see Figs 4.1 and 4.2). For example, the Namurian and Westphalian bedrock strata within the SERBD are typically overlain by shale and sandstone till, the Dinantian strata are typically overlain by limestone till, and the Devonian sandstones are typically overlain by sandstone tills. In the southernmost area of the SERBD, the bedrock is overlain by erratic till derived from neighbouring shales or shales and sandstones combined.

The GSI groundwater well database indicates that the thickness of the tills in the study area is typically less than 10 m. The tills typically become thinner with increasing elevations so that bedrock is often exposed in the uplands. The Irish Sea Tills on the eastern Wexford coast (Fig. 4.2) are an exception as they can be greater than 30–40 m in thickness (Robert Meehan, Talamhireland, personal communication, 2009).

Often the till sequences are quite complex, for example a borehole log for the Rathduff Borehole (Daly, 1994) indicates 18 m of clay, sand, limestone till and gravel overlying the dolomitised limestones at this location (see Fig. 1.1).

4.6.2 Alluvium, sands and gravels

Alluvium of Holocene age (i.e. last 11,700 years) is associated with the main river channels. Generally, there are up to 2 m depth of alluvium along the main river floodplains (Daly, 1994). The alluvium is often

flanked by glaciofluvial sands and gravels dating from the last glaciation. The sands and gravels sometimes underlie 'recent' alluvium under the river floodplain itself but also extend beyond the modern floodplains (reflecting the extent of former glacial outwash plains). Some of the sand and gravel deposits are substantial enough to be classified as aquifers (see Section 5.2):

- **Mid-Kildare Sand and Gravel Aquifer**
This aquifer, which extends into the north-east of the study area, is one of the most extensive sand/gravel bodies in Ireland (GSI, 2004). The deposit is located in a north-east to south-west orientated shallow limestone trough. The glaciofluvial deposits are typically between 20 m and 40 m in thickness, with an estimated maximum thickness of 110 m (proven in a mining exploration borehole, Robert Meehan, Talamhireland, personal communication, 2009). The sediment stratigraphy exhibits extensive lateral variability. The dominant subsoil type is sandy GRAVEL or gravelly SAND with occasional clay horizons (Missteart et al., 2009). The aquifer covers an area of approximately 200 km².

The Rahilla Borehole is located in the western edge of the aquifer. The borehole log shows two gravel units, 23.5 and 3 m thick, separated by limestone till (Ward, 1993).

- **Nore River sands and gravels**
The Nore River sands and gravels extend along the Nore River Valley from north of Abbeyleix to south of Kilkenny (GSI, 2006). The deposits are up to 30 m in thickness (Daly, 1982). The sands and gravels are generally very coarse and poorly sorted, but frequently include some lenses of better sorted material (Daly, 1994).
- **Barrow Valley sands and gravels**
The extent of this aquifer is determined by the area of sand and gravel deposits, which are situated in the Barrow River Valley from Athy to a few kilometres south of Bagenalstown. In the Barrow Valley, the deposit ranges from 10 m to 25 m thick. Water levels appear to be generally less than 2 m below ground surface, indicating that the saturated thickness of the deposit is generally greater than 5 m (<http://www.gsi.ie>).

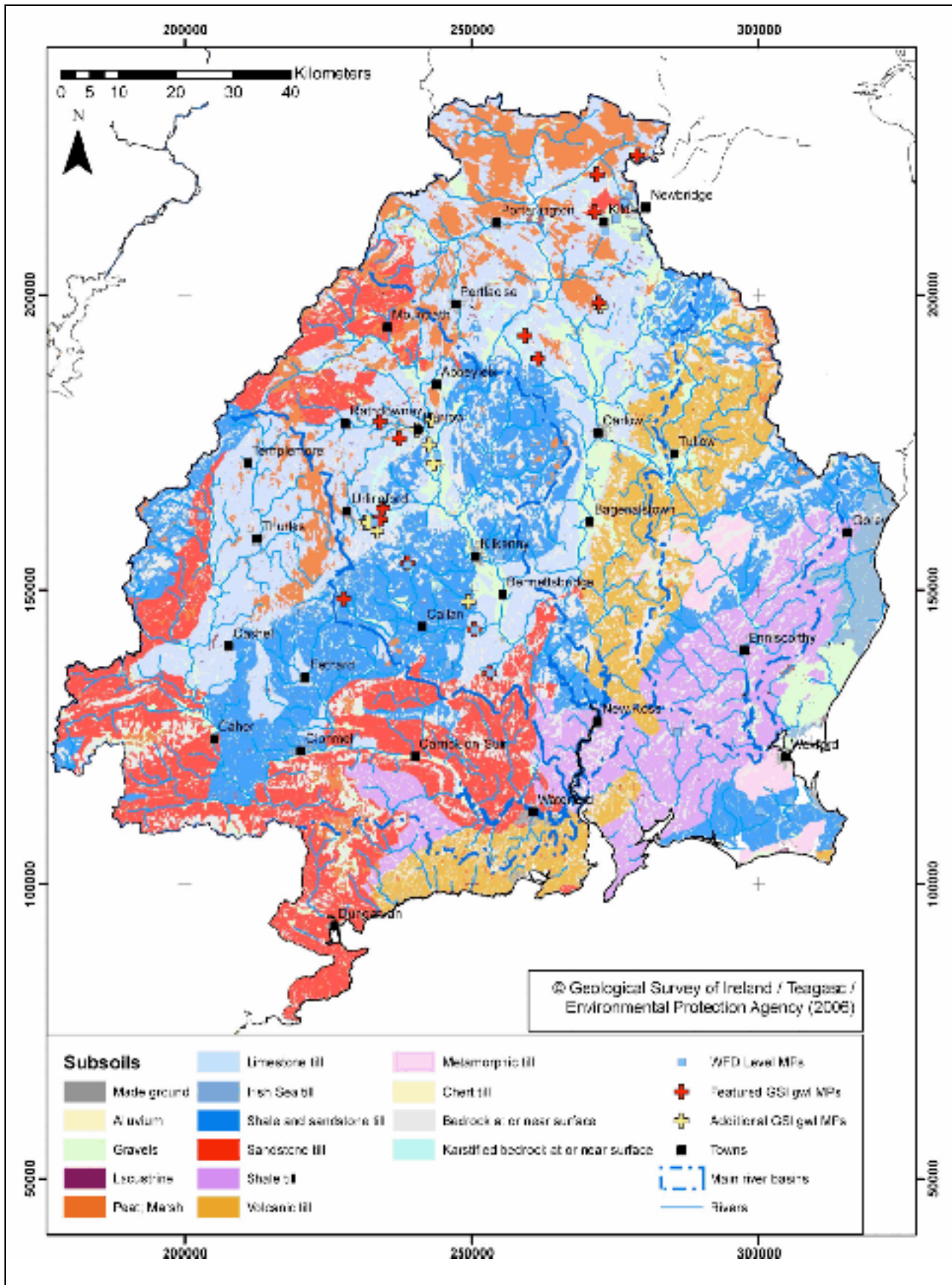


Figure 4.2 Subsoils of the South Eastern River Basin District.

The Barrow River Gravel Aquifer consists of interbedded sands and gravels, and sands and clays. The sands and gravels are very coarse but poorly sorted and are similar to deposits in the Nore River Basin. There are frequent tills above and below individual sands and gravel units (<http://www.gsi.ie>).

- **Kilmanagh River gravels**

This sand and gravel deposit is located along the Kilmanagh River, a tributary of the River Nore, on the south-east side of the Slieveardagh Hills. The aquifer is approximately 28 km² in area and extends from Tullaroan in the north to Callan in the south.

A geological log for the Oldtown Borehole, located in the Kilmanagh River gravels, shows there to be 18 m of subsoil overlying the Namurian Sandstones and Shales at this location. The subsoils predominantly comprise sand and gravel deposits, with a clay band from 5 to 6 mbgl⁴ and boulder clay from 15 mbgl (Daly, 1982).

Other glaciofluvial deposits of note include:

- **Screen Hills Moraine**

Located north-east of Wexford, the Screen Hills Moraine is a classic example of kame-and-kettle moraine; these deposits are up to 100 m thick (Tietzsch-Tyler et al., 1994);

- **Recessional moraines**

Moraine deposits associated with glacial halt stages in Blessington, Oakpark and Clopook–Ballinakill are typically 20–40 m thick (Daly, 1994).

4.6.3 Peat

There are extensive post-glacial peat deposits in the north, north-west and west of the study area. In the north of the study area, these peat deposits can be up to 10 m deep, with thick underlying lacustrine deposits (Robert Meehan, Talamhireland, personal communication, 2009). Peat deposits in the Nore River Basin can be up to 5 m thick (Daly, 1994).

4. mbgl, metres below ground level.

5 Hydrogeology

5.1 Introduction

The solid geology underlying the SERBD is heterogeneous. In general, alteration, cementation and intensive structural deformation mean that groundwater flow will be through secondary porosity and will be dominated by fracture flow. In a typical fractured hydrogeological system, the occurrence of open water-bearing fractures is greatest at shallow depths. Typically, the hydraulic conductivity declines with depth as fractures become tighter and less common. Therefore, the groundwater flow paths are likely to be shallow, predominantly in the upper layer of the aquifer with enhanced weathering and open fractures (Robins and Misstear, 2000). However, the karstified and dolomitised limestones may have permeable zones at greater depths, relating to earlier periods of alteration.

Extensive subsoil deposits overlie the solid geology. In contrast to bedrock aquifers, sand and gravel aquifers provide an opportunity for intergranular groundwater flow, which may, in some cases, be of regional importance. Tills are the most widespread subsoil deposit and, while they do not form aquifer units, they may influence the hydraulic conditions of, and the proportion of recharge reaching, any underlying aquifers.

5.2 Aquifer Properties

Figure 5.1 shows the distribution of aquifer types within the study area, Table 5.1 outlines the properties of the aquifer units within the study area and Box 5.1 outlines the GSI's aquifer classification system.

The regionally important aquifers in the study area are (GSI, 2006):

- Ordovician volcanics;
- Devonian to Early-Carboniferous Kiltorcan Sandstone Aquifer (including sandstones of the overlying Porter's Gate Formation);

- Dinantian Dolomitised Limestones (Waulsortian, Butlersgrove and Milford Formations and equivalent horizons);
- Dinantian Karstified Limestones (Ballyadams and Clogrennan Formations); and
- Quaternary Sand and Gravel aquifers.

The locally important aquifers in the study area are the:

- Devonian to Early-Carboniferous Kiltorcan Sandstone Aquifer – in upland areas;
- Waulsortian Limestone, where it is not dolomitised or highly fractured;
- Dinantian Crosspatrick Formation;
- Dinantian Argillaceous Limestones (Ballysteen Formation);
- Westphalian Sandstones (Lickfinn Coal Formation and equivalent horizons); and
- Quaternary Sand and Gravel aquifers.

The poor aquifers in the study area are the:

- Lower Palaeozoic strata, excluding Ordovician Volcanics;
- Leinster Granites; and
- Namurian Sandstones and Shales.

5.2.1 Regionally important aquifers

5.2.1.1 Ordovician Volcanics

The Ordovician Volcanics are classified as a regionally important fissured aquifer (Rf).

The dominant hydraulic conductivity, or permeability, in these strata is secondary, along joints developed during the Caledonian and Variscan orogenies. Well logging in south-east County Kilkenny indicates that developed fissures occur down to 50 m. It is likely that there will be very little natural flow in these aquifers at depth (Daly, 1982).

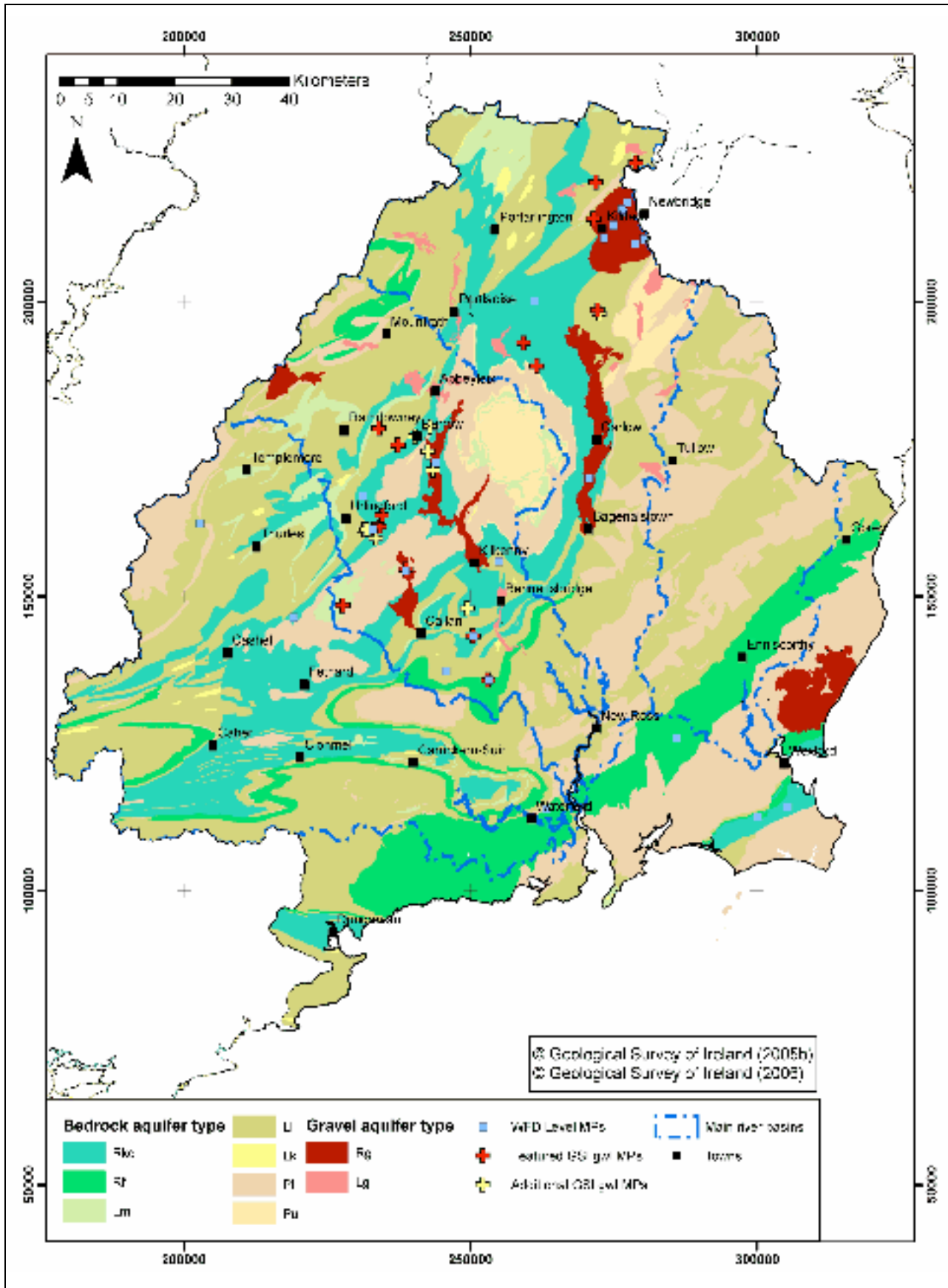


Figure 5.1. Aquifer types of the South Eastern River Basin District.

Table 5.1. Properties of the aquifer units within the study area. (Fm, formation; for aquifer category codes, please refer to Box 5.1.)

Geological age	Group	Aquifer name	Hydrogeologically significant formations	Aquifer category	Thickness (m)	Well yield ³ (m ³ /day)		Specific capacity ³ (m ³ /day/m)		Transmissivity ³ (m ² /day)		Hydraulic conductivity ⁵ (m/day)	Specific yield ⁶ (-)		
						Typical	Range ⁴	Typical	Range	Typical	Range				
Carboniferous	Westphalian	Sand and gravel ¹		Lg		500	200–1,000	200	50–1,000	400	100–2,000	1–250	0.05–0.15		
		Deltaic cycles of coals and thick sandstones	Westphalian Sandstones ¹	Lickfinn Coal Fm/ Clay Gall Sandstone Fm	Lm	<350/250–320	200–500	100–1,100	10–50	5–50	5–15	1–500	0.001–50	0.01	
	Namurian	Sandstones, shales and limestones	Namurian Sandstones and Shales ^{1,7}	Bregaun Flagstone Fm	PI	390–460	20–50	10–200	1–5	0–15				0.005–0.01	
				Killeshin Siltstone Fm	PI										
	Dinantian	Visean Limestones	Karstified Limestones ^{1,7}	Luggacurran Shale Fm	Pu	225–400	20–500	10–2,000	5–100	1–3,000	200	5–3,000	0.1–100	0.005–0.05	
				Clogrennan Fm	Rkd/Lk										
				Ballyadams Fm	Rkd/Lk										
				Durrow Fm	LI										
				Aghmacart Fm	LI										
			Crosspatrick Fm ¹	Crosspatrick Fm	Lm	<60	250–400	100–500	10–20	10–50	20–40	10–100	0.1–10	0.01–0.02	
		Waulsortian Mudbank Complex	Waulsortian Limestones	Rkd, Lk (LI)	50–220	1,000	300–3,000	100	10–350	250	20–800	0.1–20	0.02–0.04		
		Sub-Waulsortian Limestones	Dolomitised Limestones ^{1,7}	Ballysteen Fm	Rkd, Rf (LI)	300–500	(20–40)	(10–150)	(2–10)	(0–100)					(0.01–0.03)
				Ballymartin Fm	Rf, Lm (LI)										
				Ballyvergin Fm		3–5									
Lower Carboniferous Sandstones and Shales	Kiltorcan Sandstone ¹		Porter's Gate Fm	Rf	30–80										
			Kiltorcan Fm	Rf	20–230	500	50–1,300	40	2–270	60	10–500	0.1–10	0.01–0.02		
Old Red Sandstone															
Devonian	Tullow and Blackstairs Granites		Granites	PI/LI											
Lower Palaeozoic	Metasedimentary and volcanics strata	Ordovician Volcanics ²	Campile Fm	Rf	400–1,500	200–2,000		5–200		15 to >500		0.01			

¹After Daly (1994).²After Daly (1982).³Derived from pumping tests on wells that are mainly partially penetrating.⁴Tests are not practical where the yield is less than 10 m³/day.⁵An average value over the productive section of pumped wells.⁶Obtained from pumping tests, core measurement or hydrograph analysis.⁷Boreholes failing to provide a minimum domestic supply (10 m³/day) are not uncommon in these formations.

Box 5.1. Aquifer Classification

Based on the hydrogeological characteristics and on the value of the groundwater resource, all of the Republic of Ireland's land surface is divided into nine aquifer categories. Eight of the aquifer categories are defined in Groundwater Protection Schemes (DELG/EPA/GSI, 1999), and they are as follows:

Regionally Important (R) Aquifers

1. Karstified bedrock (Rk)
2. Fissured bedrock (Rf)
3. Extensive sand & gravel (Rg)

Locally Important (L) Aquifers

4. Bedrock which is Generally Moderately Productive (Lm)
5. Bedrock which is Moderately Productive only in Local Zones (LI)
6. Sand & gravel (Lg)

Poor (P) Aquifers

7. Bedrock which is Generally Unproductive except for Local Zones (PI)
8. Bedrock which is Generally Unproductive (Pu)

During the course of the National Aquifer Classification Programme (completed in 2004) undertaken for the Water Framework Directive, a further aquifer category was established:

9. Locally important karstified bedrock (Lk)

Note that, depending on the degree and nature of the karstification, regionally important karstified bedrock aquifers (Rk) may be further characterised as either:

- Regionally important karstified bedrock aquifers dominated by conduit flow (Rkc); or
- Regionally important karstified bedrock aquifers dominated by diffuse flow (Rkd).

The volcanic units close to outcrop are unconfined but the aquifer becomes confined as it dips under the overlying interbedded sediments (Daly, 1982).

5.2.1.2 Kiltorcan Sandstone Aquifer

The Kiltorcan Sandstone Aquifer is classified as a regionally important fissured bedrock aquifer (Rf). Due to a higher proportion of sandstone, it is expected that the permeability of the aquifer will be greatest in the upper half of the Kiltorcan Formation and at the base of the Porter's Gate Formation (Daly, 1988).

The secondary porosity and permeability of the Kiltorcan Sandstone Aquifer is produced by fracturing and, to a lesser extent, weathering. In the Kiltorcan

Sandstone Aquifer, fracturing tends to be restricted to the sandstone units. Fractures, and hence permeability and porosity, are more extensive in the south and are more intense around major structural features such as faults and anticlines (Daly, 1988).

Fracturing is likely to be considerably reduced at depth and may be absent in the centre of large synclines where the sandstones are in compression. A borehole log for Knocktopher Manor (Kny 31/73, i.e. the pumping borehole to which Kny 31/72 is an observation borehole) (Daly, 1994) shows major inflows between 35 m and 39 m and between 42 m and 52 m. Evidence from other boreholes has established

that productive fracturing extends to depths of over 100 m.

Many of the minerals of the Kiltorcan Sandstone Aquifer are susceptible to chemical weathering. Weathering is pronounced along fractures and results in the sandstone being friable. The total porosity of the sandstone is normally less than 5%; however, in heavily weathered sections the porosity may be in excess of 10% (Daly, 1988).

Pumping tests, conducted in 1980, on two boreholes at Knocktopher Manor (Kny 31/72 and Kny 31/73) gave transmissivity estimates of 1,910 m²/day and 1,789 m²/day, respectively, and storage coefficient estimates of 3.9×10^{-6} and 7.2×10^{-4} , respectively, for the confined conditions (Daly, 1994).

The rock formations above and below this aquifer confine it over much of its extent. In the more low-lying outcrop areas, where the overlying subsoils are often thicker, the aquifer may be confined by till or in continuity with sands and gravels. Daly (1987) describes artesian conditions in this aquifer to the east of Callan. Water-table maps for this aquifer indicate that the main discharge areas are in the Knocktopher/Ballyhale area and at Thomastown in South Kilkenny, and at Rushin Crossroads in the Slieve Bloom area (Daly, 1994).

5.2.1.3 Dinantian Dolomitised Limestone Aquifer

The Dinantian Dolomitised Limestone Aquifer is classified as either Rkd or Lk, depending upon the extent of dolomitisation. The aquifer comprises the Sub-Waulsortian Limestones, Waulsortian Limestones, the Crosspatrick Formation and the Aghmacart Formation where dolomitised (Daly, 1994). Where not dolomitised, the formations are classified as LI and are dealt with in Section 5.2.2. Of these units, only the Crosspatrick Formation has significant and consistent permeability in the absence of dolomitisation (Daly, 1993).

Dolomitisation is the replacement of calcite with dolomite. It is important hydrogeologically because it results in an increase in porosity (and permeability), as the crystal lattice of dolomite occupies about 13% less space than that of calcite (Freeze and Cherry, 1979).

The extent of the dolomitisation within the SERBD is quite variable. Dolomitisation appears to decrease from east to west. In the east (Callan to Bennettsbridge Lowlands), the boundary of the aquifer, i.e. the extent of the dolomitisation, can extend from the Aghmacart Formation, through the Crosspatrick Formation and Waulsortian Limestones to the Sub-Waulsortian Limestones. In the west (Urlingford to Mountrath Lowlands), however, the aquifer is restricted to the Waulsortian Limestones (Daly, 1993).

The interpretation of geophysical logs for the Rathduff Borehole (Daly, 1994) shows 18 m of subsoils overlying 7 m of limestone, with occasional dolomitised horizons, overlying 33 m of dolomitised limestones, with occasional undolomitised limestones.

Daly (1994) suggests that this aquifer may have significant amounts of deep (>200 m) groundwater flow, based on the following:

- The aquifer is continuous at depth;
- There is significant permeability at depth;
- Head difference between the Urlingford to Mountrath Lowlands and the Callan to Bennettsbridge Lowlands is in excess of 30 m and could provide the hydraulic drive;
- Large springs discharging in the Callan to Bennettsbridge Lowlands; and
- Slightly elevated temperatures of some discharges of water from this aquifer in the Callan to Bennettsbridge Lowlands.

5.2.1.4 Dinantian Karstified Limestone Aquifer

The Dinantian Karstified Limestone Aquifer is classified as Rkd or Lk, depending upon the extent of karstification. The secondary permeability and porosity is developed by karstification of the Visean Limestones.

The Dinantian Karstified Limestone Aquifer is bounded by the underlying locally important Aghmacart Formation and the overlying generally unproductive Luggacurren Shale Formation. However, only karstified sections of the intervening strata are classified as part of the aquifer. Daly (1994) describes the limit of karstification development as the lowest

level to which the strata could have drained in geological history. He suggests this level to be around 30 maOD in the Urlingford to Mountrath Lowlands and close to 0 maOD in the Callan to Bennettsbridge Lowlands. The aquifer is not believed to have any significant permeability where it lies beneath the Namurian strata (Daly, 1994).

Cawley (1990) investigated the hydrology and hydrogeology of the Nuenna/Borrismore Catchment, a minor tributary of the Nore River. Three aquifer zones were identified and the aquifer properties for each zone are presented in Table 5.2. Cawley also modelled a significant proportion of groundwater discharge, particularly in winter, as ‘quickflow’; this supports other evidence of conduit flow in this aquifer (Daly, 1994)

There are numerous karst features within this aquifer. In the Nuenna Catchment, which includes the Woodsgift, Clomantagh Lower and Tubbrid Lower cluster of MPs (see Fig. 1.1 for location), there are many mapped karst features within the GSI karst features database. For example, within a 10-km radius of these MPs there are: one cave, two enclosed depressions, 28 springs (located where the subsoil is thin or permeable), seven swallow holes (located especially along the Namurian–Dinantian contact south-east of Johnstown) and one turlough. In contrast, where the aquifer is exposed to the north of the Castlecomer Plateau (where the Land Commission and Masterson Boreholes are located), there are fewer mapped karst features, e.g. three springs and three caves within a 10-km radius of the boreholes.

An unlabelled geophysical log for the Woodsgift Borehole (Kny 12/8) (unpublished GSI records) indicates inflows from fissures or fractures at depths of 19.2 mbgl, 25.4 mbgl and 30.0 mbgl.

This aquifer discharges via numerous springs close to the main river channels or directly into the rivers themselves. The aquifer discharges in the Nore just north of Bennettsbridge (Daly, 1994), in the Nuenna via a number of springs including the Boiling Well at Clomantagh, in the Suir Catchment at the Kiltinin Castle Springs, which flow into the Anner River, and in the Barrow Catchment via sands and gravels between Carlow and Leighlinbridge (Daly, 1982).

5.2.2 Locally important aquifers

5.2.2.1 Dinantian Crosspatrick Formation

The Crosspatrick Formation is classified as an Lm aquifer. This long narrow limestone aquifer occurs in the Urlingford to Mountrath Lowlands. It is not well defined in the Callan to Bennettsbridge Lowlands owing to extensive dolomitisation and, therefore, is included as part of the Dinantian Dolomitised Limestone Aquifer. Where not dolomitised, this formation forms part of the Dinantian Pure Bedded Limestone rock unit.

In the south-west and centre of the Urlingford to Mountrath Lowlands, the aquifer is bounded at the base by the Dinantian Dolomitised Limestone Aquifer with which it is in hydraulic continuity. In the north-east, it is bounded at the base by the Sub-Waulsortian Limestones. The Aghmacart Formation, an LI aquifer, forms the upper boundary (Daly, 1994).

Over the outcrop area, the hydraulic conditions vary from unconfined, with hydraulic continuity to the overlying sands and gravels, to being confined by thick till. It becomes confined down dip where it is likely to be much less permeable unless dolomitised (Daly, 1994).

At the Granston Manor Borehole the formation is partially dolomitised. The geological log (Daly, 1994) notes water inflows at 6 mbgl coincident with sand

Table 5.2. Aquifer properties within the Nuenna/Borrismore Catchment (after Cawley, 1990).

Zone	Transmissivity (m ² /day)	Specific yield (%)	Well yield (m ³ /day)
Recharge zone	1–5	0.5–1.0	<50
Intermediate zone	120–150	1.0–2.5	<750
Discharge zone	150–750	3.0–5.0	<2,000

subsoils, 10 mbgl coincident with loose rock at the top of the bedrock and a major inflow at 24 mbgl coincident with a large fracture.

The aquifer is recharged in more elevated areas, where Quaternary deposits are thin and permeable, and discharges into small streams (Daly, 1994).

5.2.2.2 *Westphalian Sandstones*

The Westphalian Sandstones are classified as an Lm aquifer. Due to the overlying clays, shales and siltstones, the sandstone aquifer units are confined apart from at, or near, an outcrop.

Pumping tests conducted on two boreholes in the Slieveardagh Hills (including the Ballincurry Borehole Tip 55/65) gave transmissivity values of between 10 m²/day and 101 m²/day. There were artesian conditions in the Ballincurry Borehole (Tip 55/65); test results gave an average storage coefficient of 4.4 × 10⁻⁴. Safe yields for the two boreholes were calculated to be 360 m³/day and 900 m³/day, respectively (Daly, 1980). The hydraulic conditions of the Westphalian Sandstones within the Slieveardagh Hills and the Castlecomer Plateau are mostly confined (Daly, 1980; Daly et al., 1980).

5.2.2.3 *Lower Carboniferous*

The Sub-Waulsortian and Waulsortian Limestones, where not dolomitised, the Durrow Formation, where not karstified, and the Aghmacart Formation are classified as locally important aquifers. The areas underlain by these strata are frequently poorly drained, especially in the Urlingford to Mountrath Lowlands (Daly, 1994).

5.2.3 *Poor bedrock aquifers*

The early Palaeozoic strata and the Leinster Granites are mostly classified as poor bedrock aquifers, as are all the Namurian strata.

Much of the potential recharge to these strata is rejected and throughput is low. Groundwater flow is generally restricted to the upper weathered zone, to more permeable beds of limited extent or to fault zones. There are shallow, short localised flow systems, often with very little continuity between them. The slope of the water table generally reflects the surface topography (Daly, 1994).

5.3 **Subsoils**

5.3.1 *Quaternary Sand and Gravel aquifers*

There are a number of regionally and locally important sand and gravel aquifers within the study area (see Fig. 5.1).

The Mid-Kildare and Kilmanagh Sand and Gravel Aquifers are classified as regionally important aquifers (Rg). A number of other sand and gravel deposits in the study area associated with the main channels of the Nore, Barrow and Suir are also substantial enough (>10 km² in area and >5 m saturated thickness) to be classified as Rg aquifers. Smaller deposits within the study area are classed as locally important sand and gravels aquifers (typically 1–10 km² in area).

In contrast to the bedrock aquifers, sand and gravel aquifers have primary porosity and flow is intergranular. The hydraulic conditions in these deposits are quite variable, depending upon lithology and stratigraphy. Confined and unconfined conditions are often found within a short distance and the aquifers are frequently in continuity with rivers and the underlying aquifers. As such, the sands and gravels can represent an important source of additional storage for the underlying aquifers (Daly, 1982). Due to the limited extent of some of these deposits, flow paths are often short and groundwaters discharge into streams with which they are in contact (Daly, 1994).

5.3.2 *Subsoil permeability and groundwater vulnerability*

Even subsoils which do not form aquifer units may be of hydrogeological importance. For example, depending upon thickness, and particularly permeability, subsoils may influence the hydraulic conditions of, and the proportion of recharge reaching, the underlying bedrock aquifers.

Maps of the subsoil permeability and groundwater vulnerability within the SERBD are presented in Figs 5.2 and 5.3, respectively. The majority of the uplands area, above 200 m elevation, has bedrock overlain by less than 3 m of subsoil (denoted in grey in Fig. 5.2). Groundwater in these areas is classified as extremely vulnerable. This situation covers 36% of the study area.

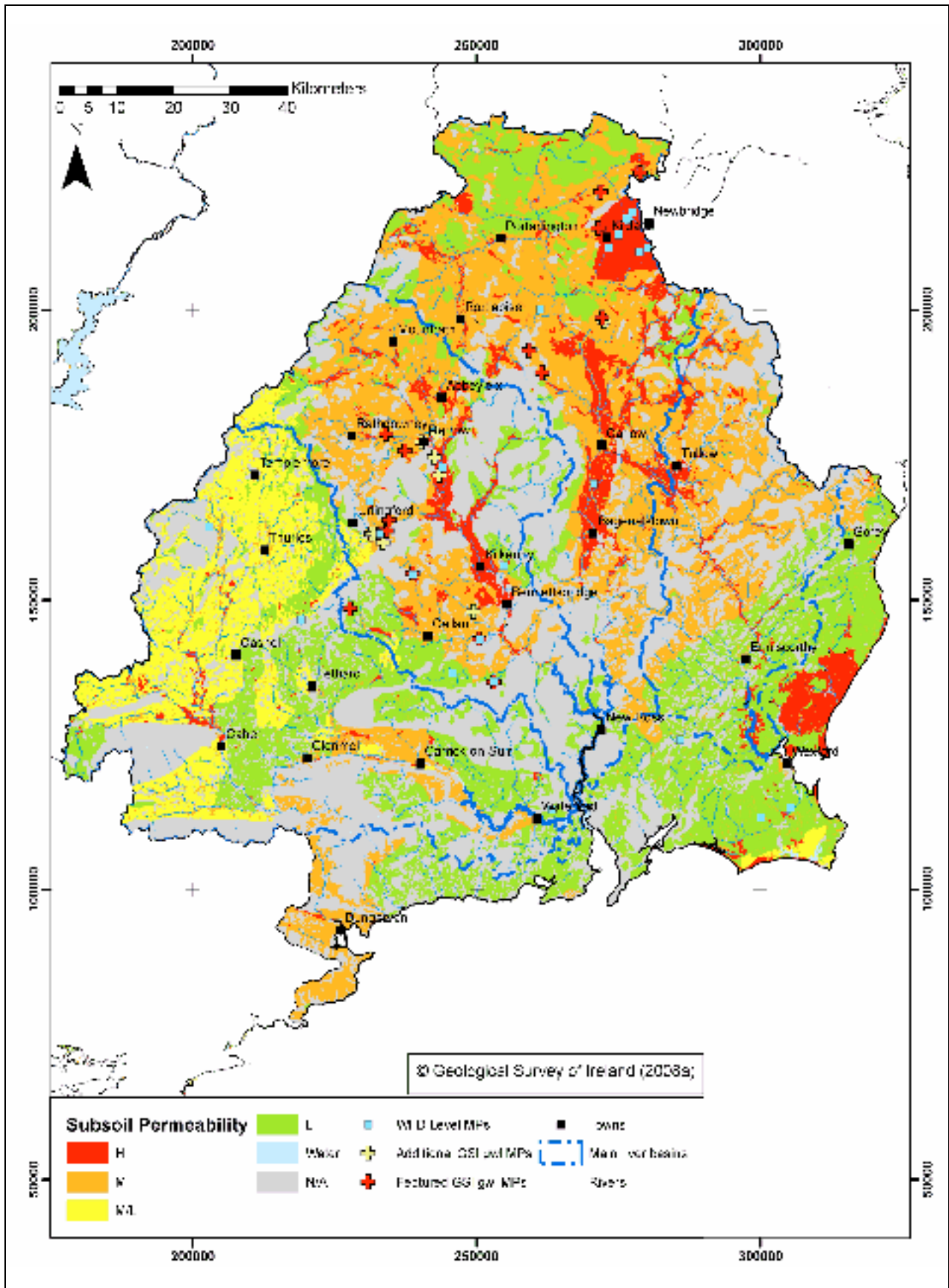


Figure 5.2. Subsoil permeability of the South Eastern River Basin District.

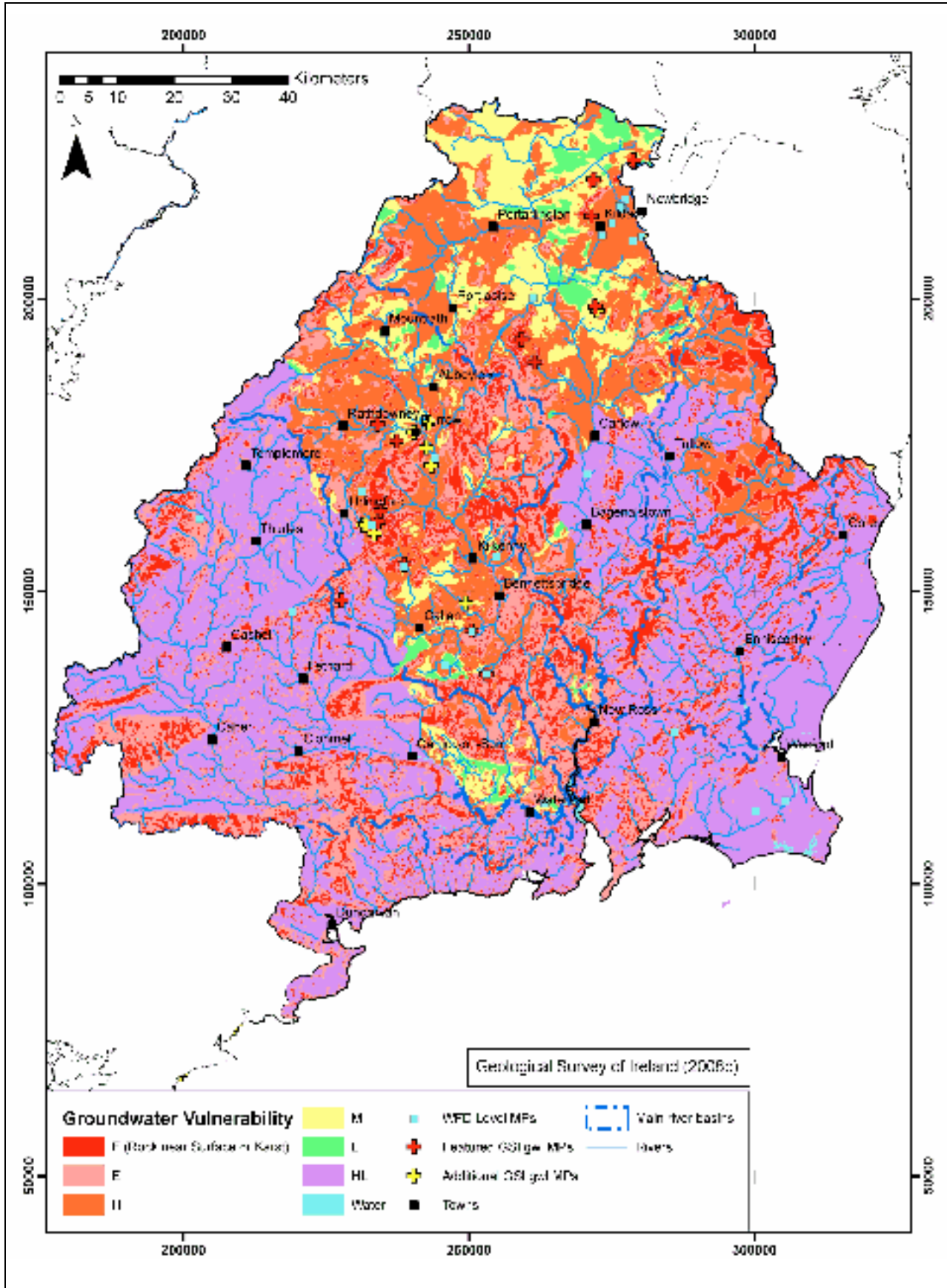


Figure 5.3. Groundwater vulnerability of the South Eastern River Basin District.

The gravels and alluvium associated with the main river channels are classified as being of high permeability, as well as the Curragh Sand/Gravel Aquifer and the Screen Hills Moraine. Seven per cent of the bedrock of the study area is overlain by high permeability subsoils.

The shale and sandstone tills associated with the Slieveardagh Hills, the Castlecomer Plateau and the Lower Palaeozoic strata are classed as low permeability deposits, as well as the peat deposits in the north and north-west. Even a thin layer of peat, especially non-cutover lowland peat, can have a significant influence in reducing potential recharge (Misstear et al., 2009). Twenty-three per cent of the study area is overlain by low permeability subsoils.

The remaining subsoils (34%) are classified as moderate or moderate/low permeability (where the permeability mapping is not complete).

5.4 Recharge

The influence of subsoils on groundwater recharge in an Irish setting was investigated by Fitzsimons and Misstear (2006) using a simple numerical model. The results of this work were used in the preparation of a set of recommended values for recharge coefficients, for a variety of hydrogeological situations in Ireland, and were contained in a report produced by the Working Group on Groundwater (2005).

The Working Group on Groundwater report (2005) provides guidance on assessing the impacts of groundwater abstractions during the initial phase of characterisation of groundwater bodies and groundwater-dependent terrestrial ecosystems for the EU WFD. The report recommends that, for initial characterisation, recharge should be estimated by multiplying the estimated effective rainfall value by the recharge coefficient. In areas underlain by poor aquifers, a recharge 'cap' should be applied. Further details are given in Box 5.2.

A recharge map of Ireland was developed using the resulting recharge values. The recharge map for the SERBD is presented in Fig. 5.4.

Misstear and Brown (2008) developed a quantified link between recharge and groundwater vulnerability using a number of case studies. From previous studies, it was recognised that the most important linkage to study was that between subsoil permeability and recharge. Three of the four case studies lie within the SERBD. The recharge coefficients calculated from the case studies were:

- 81–85% for the high permeability subsoils of the Curragh (Mid-Kildare) Gravel Aquifer (Misstear et al., 2009);
- 41–54% for the moderate permeability subsoils within the Callan to Bennettsbridge Lowlands (or 36–60% for the full sub-catchment, which includes high and low permeability subsoils as well as moderate permeability subsoils); and
- 55–65% for the moderate permeability subsoils of the Galmoy Mine area.

5.5 Conceptual Model

A schematic cross-section conceptual model which extends from the Nuenna Catchment, through the Slieveardagh Hills and into the Callan to Bennettsbridge Lowlands is shown in Fig. 5.5. The cross section extends from the Namurian Sandstones and Shales, through the Dinantian Karstified and Dolomitised Limestone Aquifers and into the Devonian–Dinantian Kiltorcan Sandstone Aquifer, and includes the Kilmanagh River Gravel Aquifer (see Fig.4.1 for location of cross section). The cross section 'dog-legs' to include the Woodsgift, Clomantagh Lower, Oldtown, Rathduff and Knocktopher Manor MPs. The cross section is based on geological maps and cross sections presented in Archer et al. (1996) and Daly (1994) and on the geological logs for the above-mentioned MPs.

Included on the cross section are three typical hydrographs of aquifers located from the recharge to the discharge zone. It should be noted that aquifer units are likely to be limited in extent due to faulting and the nature of fracture flow; therefore, the hydrographs in Fig. 5.5 do not represent a regional groundwater flow.

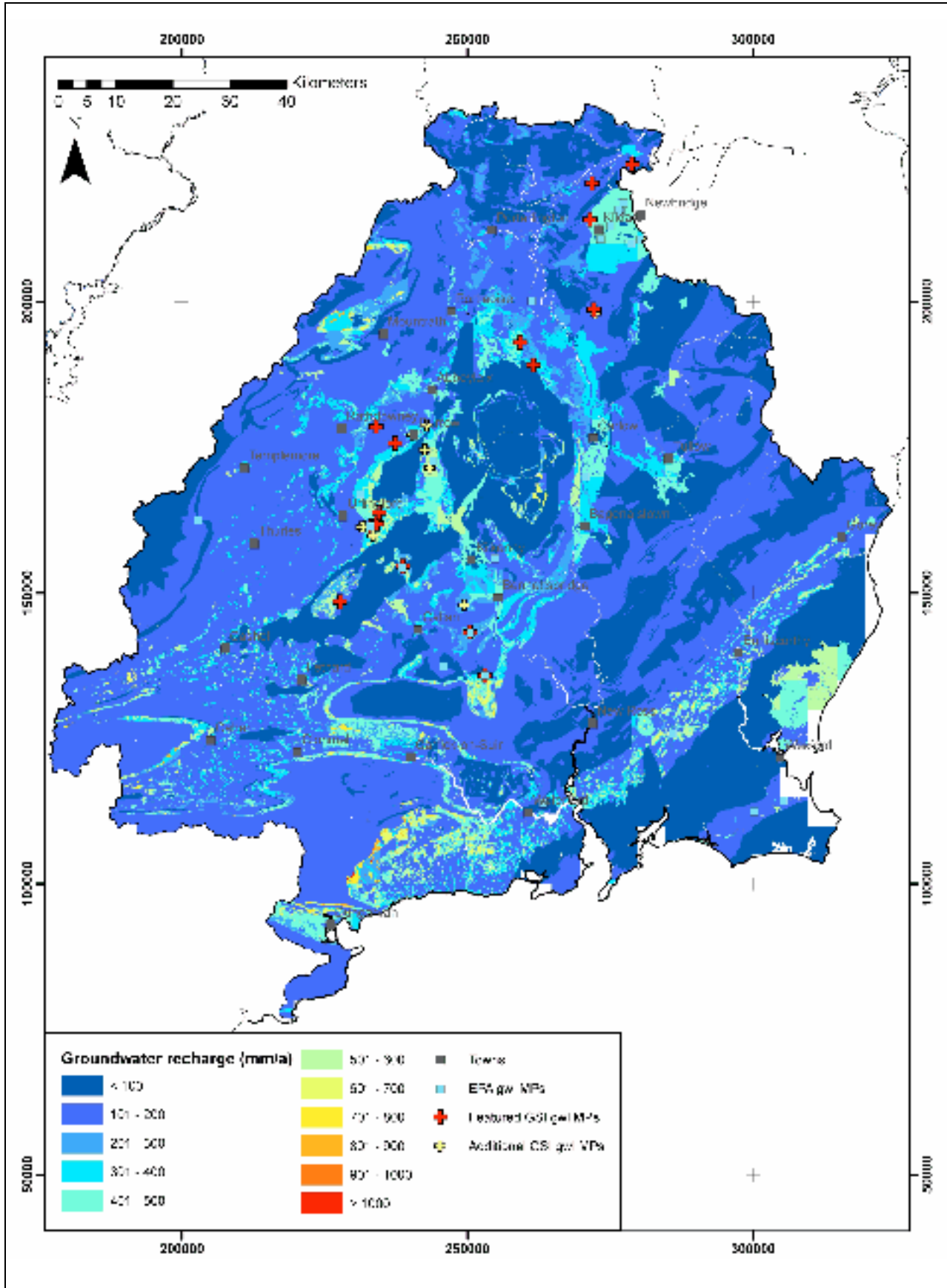


Figure 5.4. Recharge map for the South Eastern River Basin District.

Box 5.2. Recharge Coefficients

The proportion of effective rainfall (ER) that becomes recharge is referred to as the recharge coefficient. This depends largely on the permeability and thickness of the subsoils and unsaturated bedrock overlying the groundwater, as well as on the presence of 'wet' and 'dry' soils or peat.

Recharge estimation methodology (recommended for the initial characterisation):

- Estimate effective rainfall.
- Multiply effective rainfall by the appropriate recharge coefficient to give the potential recharge.
- In areas underlain by poor aquifers, apply a maximum recharge 'cap' (see below). This takes account of the limited capacity of such aquifers to accept recharge.
- Where point recharge is present, use information on the local situation to estimate its significance and the likely catchment area of the point.
- If possible, corroborate results with an assessment of base flow from local rivers.

Where further characterisation is required, a more comprehensive assessment of recharge will be necessary, which will require more detailed analysis of ER and base flow.

Recharge caps

- In areas underlain by poor aquifers (PI and Pu), the maximum recharge should be taken as 100 mm/year.
- In areas underlain by locally important aquifers that are generally unproductive except for local zones (LI), the maximum recharge should be in the range of 150–200 mm/year, depending upon local knowledge.

6 Groundwater Level Network

6.1 Groundwater Level Monitoring – Historic

Groundwater levels have been monitored in Ireland since the late 1960s. Historically groundwater levels were monitored during the course of various projects often implemented by the GSI or county councils. Typically, the latter were focused on the protection of drinking-water supplies and investigating the impacts of source pollution events and have not been used in this report. A summary of the GSI's historic groundwater level monitoring is included in Appendix B. This summary was compiled in the late-1990s by Geoff Wright and outlines the extent of the GSI's groundwater level monitoring in Ireland.

The long-term historic groundwater level monitoring data for this report were derived from a small number of projects:

- **GSI monitoring in Counties Kildare and Laois**
The first regular groundwater monitoring in Ireland was conducted in Counties Kildare and Laois by Bob Aldwell of the GSI. A number of MPs in the limestone bedrock and subsoil deposits were monitored from 1968 to the early-1990s. The MPs were dipped weekly to 1975, then fortnightly to 1983, and less frequently thereafter (Wright, 1994).

Monitoring points analysed in the current report from this group are: Ardscull DW, Rahilla, Kilmeague, Boston Co. Co., Masterson and Land Commission 2 (see Fig. 1.1 for locations).

- **GSI investigations in the Nore River Basin**
In the 1970s, the GSI began a detailed hydrogeological investigation of the Nore River Basin. The overall objectives were to provide an understanding of the hydrogeology of the basin, enable the results to be extrapolated to adjacent areas of similar geology and hydrology and to provide experience in carrying out hydrogeological investigations in Ireland (Daly, 1994).

Data from a large number of MPs, many drilled for the project, in all productive formations in the basin, are available for the 1970s. The MPs were initially dipped, but between 1975 and 1981 chart recorders (see Fig. 6.1(a)) were fitted to a number of boreholes (Wright, 1994). A small number of these MPs are still operating and have been assimilated into the EPA WFD monitoring programme.

Monitoring points analysed in the current report from this group are: Knocktopher Manor, Oldtown, Woodsgift, Rathduff, Ballincurry, Cullahill, Granston Manor, Clomantagh Lower and Tubbrid Lower (see Fig. 1.1 for locations). The first four MPs listed have been assimilated into the EPA WFD monitoring network.

- **County council monitoring in County Wexford**
Manual monitoring of groundwater levels was carried out by Wexford County Council in 40 boreholes throughout the county from the early-1980s. Most of these MPs are associated with the Council's large abstraction schemes at Fardystown, Adamstown and Gorey (O'Sullivan, 1992; Wright, 1994).

Analysis of data from these MPs has not been included in the current report. However, two of these MPs, which are still operating, have been included in the EPA WFD monitoring programme, namely Mayglass and San Antone House.

Only groundwater level MPs with more than 10 years of data were chosen from projects outlined above. The only exception to this procedure is the Ballincurry MP which was included, despite having only 5 years of data, as a suitable alternative within the Westphalian Sandstone Aquifer was not available. Figure 1.1 shows the locations of the GSI's historic MPs. Table 6.1 gives details of the historic MPs analysed in this report and their hydrographs are presented in Appendix D.

Table 6.1. Historic groundwater level monitoring points (MPs).

Name	GSI (EPA) MP code	County	X	Y	Geology	Aquifer type ²	Subsoils	Subsoil permeability	Vulnerability	Operator	Type of MP	Type of monitoring	Start date	End date	Depth (mbgl)	Datum (maOD)
Oldtown	Kny 18/92 (10_013)	Kilkenny	238700	154400	Sand and gravel	Rg	18 m sand & gravel	H	E	GSI/OPW	BH	Chart recorder to Mar-08, then logger	Oct-80	Ongoing	20	118.45
Kilmeague		Kildare	278900	223700	Sand and gravel	Lm	Sand & gravel	H	H	GSI	BH	Manual dips	Jun-70	Jul-88	27.4	~107
Rahilla		Kildare	271420	271420	Till with gravel	Rg	Till with gravel	H	H	GSI	DW	Manual dips	Nov-68	Oct-87	35.4	~124
Ballincurry	Tip 55/65	Tipperary	227800	148500	Westphalian Sst	Lm	6 m clay; down-gradient of Rck	L	HL	GSI	BH	Chart recorder	Oct-77	Oct-82	60	170.35
Woodsgift/Borrismore Creek	Kny 12/8 (10_005)	Kilkenny	233000	161500	Karstified lmst	Rkd	0–3 m TLs	M	E	GSI/OPW	BH	Chart recorder to Oct-07; then logger	Apr-75	Ongoing	36	147.34
Tubbrid Lower	Kny 12/34	Kilkenny	23423	16192	Karstified lmst	Rkd	0–3 m TLs	M	E	GSI		Chart recorder	Aug-71	Dec-91	12.7	128.12
Clomantagh Lower	Kny 13/42	Kilkenny	234600	163800	Karstified lmst	Rkd	3–10 m TLs; close to KaRck	M	H	GSI		Chart recorder	Jul-74	Oct-94	57	149.39
Cullahill	Kny 35/39	Laois	237400	175700	Karstified lmst	LI	3–10 m TLs; alluvium	M	H	GSI/OPW			Sep-76	Jun-09	–	~85
Masterson		Laois	261600	193100	Karstified lmst	Rkd	3–10 m TLs; alluvium	M	H	GSI	DW	Manual dips	Nov-70	Oct-90	14	~105
Land Commission 2		Laois	259300	193100	Karstified lmst	Rkd	0–3 m TLs; close to KaRck	M	E	GSI	BH	Manual dips	Jul-71	Jan-81	–	~159
Rathduff	Kny 27/58 (10_017)	Kilkenny	250500	143300	Dolomitised lmst	Rkd	18 m TLs	M	H	GSI/OPW	BH	Chart recorder to Mar-08, then logger	Aug-81	Ongoing	62	46.75
Boston Co. Co.		Kildare	271900	220400	Dolomitised lmst	LI	Rck	–	X	GSI	DW	Manual dips	Apr-70	Aug-85	15.9	~119
Granston Manor	Ls 28/168	Laois	234100 ¹	178600	Crosspatrick Fm	LI	6.8 m clay; 1.4 m sand	M	H	GSI/Arcon	BH	Chart recorder	Sep-78	Jul-96	30	84.57
Ardscull DW		Kildare	272200	198700	Ballysteen Fm	LI	0–3 m TLs; close to Rck	–	E	GSI	DW	Manual dips	Jul-69	Oct-90	18.9	~89
Knocktopher Manor	Kny 31/72 (10_012)	Kilkenny	253140	135930	Kiltorcan Sst	Rf	5 m TLs	L	E	GSI/OPW	BH	Chart recorder to May-08; then logger	Aug-80	Ongoing	40	61.67

¹The co-ordinates of the Granston Manor fall within a lake, the actual location of the boreholes is likely to be close to this lake; ~, approximate elevations were taken from the appropriate Ordnance Survey Ireland *Discovery Series* (1:50,000) map.

²For aquifer type codes, please refer to Box 5.1.

Sst, sandstone; lmst, limestone; FM, Formation; Rck, bedrock outcrop and subcrop; TLs, tills derived chiefly from limestone; KaRck, karstified limestone bedrock outcrop or subcrop; H, High; M, Moderate; L, Low; E, Extreme; HL, High to Low (only interim data available); GSI, Geological Survey of Ireland; OPW, Office of Public Works; EPA, Environmental Protection Agency; BH, borehole; DW, drinking water; mbgl, metres below ground level; maOD, metres above Ordnance Datum.



Figure 6.1. Groundwater level monitoring systems. (a) Geological Survey of Ireland chart recorder recording groundwater levels. (b) Downloading groundwater level data from a digital logger at an Environmental Protection Agency Water Framework Directive monitoring point.

6.2 Groundwater Level Monitoring – Current

The EPA has monitored groundwater levels in the SERBD since the mid-1990s. Originally, monitoring was conducted by taking dips at approximately quarterly frequency. The current EPA groundwater level monitoring programme was established in 2006 in accordance with Article 8 of the WFD. This involved a review of all existing MPs and an assessment of their suitability. Monitoring is now conducted via data loggers recording groundwater level at 15-min intervals.

In the SERBD, four historic MPs originally established by the GSI, namely Woodsgift, Knocktopher Manor, Oldtown and Rathduff, have been assimilated into the EPA's current monitoring programme (see Fig. 2.1 for locations).

In contrast to previous legislation, the WFD encourages a holistic approach to water resources. Therefore, the groundwater monitoring network has been established to improve knowledge on the links between groundwater and associated surface water and ecological receptors. The monitoring primarily

focuses on providing information to assess the environmental status of groundwater bodies. For additional information, the reader is referred to <http://www.epa.ie> and <http://www.wfdireland.com>.

Figure 1.1 also shows the locations of the EPA's WFD groundwater level monitoring programme MPs; Table 6.2 gives details of these MPs. Figure 6.1(b) shows the downloading of groundwater level data at an MP in the EPA WFD monitoring network.

This report has concentrated on long-term historic monitoring and, therefore, the data from the majority of these MPs have not been analysed. However, hydrographs for the current groundwater level MPs are presented in Appendix C.

6.3 Information Sources

The groundwater level data for the historic MPs were provided by the GSI.

The groundwater level charts for Oldtown, Knocktopher, Rathduff, and Woodsgift Boreholes were digitised in 2009 by the EPA and the GSI. There are a large number of data gaps in these records. The digitised groundwater levels have been checked

Table 6.2. Environmental Protection Agency (EPA) Water Framework Directive monitoring programme monitoring points (MPs).

Name	EPA (GSI) MP code	County	X	Y	Start date	End date	Type of MP	Type of monitoring	Geology	Depth of borehole (mbgl)	Datum (maOD)	Operator
Oldtown	10_013 (Kny 18/92)	Kilkenny	238700	154400	Oct-80	Ongoing	BH	Chart recorder to Mar-08, then logger	Sand and gravel	20.00	118.45	GSI/OPW
Ballyragget Glanbia Factory	10_002	Kilkenny	244002	172803	Mar-08	Ongoing	BH	Logger	Sand and gravel	18.00		EPA/LA
Ballysax	09_002	Kildare	280278	210832	Jun-08	Ongoing	BH	Logger	Sand and gravel	18.00		EPA/LA
Brownstown	09_004	Kildare	278639	210092	Jun-08	Ongoing	BH	Logger	Sand and gravel	13.00		EPA/LA
Landfill Site	01_004	Carlow	270647	170052	Mar-08	Ongoing	BH	Logger	Sand and gravel	69.00		EPA/LA
PF – MB29	09_011	Kildare	275043	213065	Apr-08	Ongoing	BH	Logger	Sand and gravel	13.30		EPA/LA
PF – MB30	09_012	Kildare	275042	213190	Apr-08	Ongoing	BH	Logger	Sand and gravel	24.00		EPA/LA
PF – MB37	09_013	Kildare	277433	217126	Jun-08	Ongoing	BH	Logger	Sand and gravel	18.20		EPA/LA
PF – S10	09_017	Kildare	276426	215904	No data	No data	BH		Sand and gravel	–		EPA/LA
PF – SB31	09_018	Kildare	276423	215894	No data	No data	BH		Sand and gravel	9.00		EPA/LA
PF – MB7 (Lower)	09_016	Kildare	276810	215540	May-08	Ongoing	BH	Logger	Sand and gravel			EPA/LA
PF – MB7 (Middle)	09_015	Kildare	276810	215540	May-08	Ongoing	BH	Logger	Sand and gravel			EPA/LA
PF – MB7 (Upper)	09_014	Kildare	276810	215540	May-08	Ongoing	BH	Logger	Sand and gravel			EPA/LA
PF – Hangedman's Arch	09_010	Kildare	275916	217539	No data	No data	Spring		Sand and gravel			EPA/LA
Kyle Public Water Supply	11_008	Laois	255501	192243	Jan-77	Ongoing	Spring		Sand and gravel			EPA/LA
Tully (BH1)	09_019	Kildare	273313	210923	Jun-08	Ongoing	BH	Logger	Sand and gravel	9.00		EPA/LA
Borrismore Creek	10_005 (Kny 12/8)	Kilkenny	233000	161500	Apr-75	Ongoing	BH	Chart recorder to Oct-07, then logger	Dinantian karstified limestone	36.00	147.34	GSI/OPW
Freshford to Johnstown Rd BH	10_009	Kilkenny	231261	167072	Oct-07	Ongoing	BH	Logger	Dinantian pure bedded limestone	13.50		EPA/LA
Laffansbridge	22_005	Tipperary	219100	146620	Oct-07	Ongoing	BH	Logger	Dinantian pure bedded limestone	10.00		EPA/LA
Mayglass	26_008	Wexford	300134	112570	Mar-08	Ongoing	BH	Logger	Dinantian pure bedded limestone	60.00		EPA/LA
San Antone House (B&B)	26_011	Wexford	305307	114357	Mar-09	Ongoing	BH	Logger	Dinantian pure bedded limestone	100.00		EPA/LA
Vickerstown	11_014	Laois	261234	200342	Jan-08	Ongoing	BH	Logger	Dinantian pure bedded limestone	25.00		EPA/LA

Table 6.2 contd.

Name	EPA (GSI) MP code	County	X	Y	Start date	End date	Type of MP	Type of monitoring	Geology	Depth of borehole (mbgl)	Datum (maOD)	Operator
Paulstown	10_014	Kilkenny	266048	157294	No data	No data	Spring		Dinantian pure bedded limestone			EPA/LA
Rathduff	10_017 (Kny 27/58)	Kilkenny	250500	143300	Aug-81	Ongoing	BH	Chart recorder to Mar-08, then logger	Dinantian dolomitised limestone	62.00	46.75	GSI/OPW
Pub in Pike	10_016	Kilkenny	254859	156017	Oct-07	Ongoing	BH	Logger	Dinantian upper impure limestone	20.00		EPA/LA
Kilmaganny	10_011	Kilkenny	245805	137446	May-08	Ongoing	BH	Logger	Dinantian lower impure limestone	15.00		EPA/LA
Knocktopher	10_012 (Kny 31/72)	Kilkenny	253140	135930	Aug-80	Ongoing	BH	Chart recorder to May-08, then logger	Kiltorcan Sandstone	40.00	61.67	GSI/OPW
Adamstown (BH2 – Deer Farm)	26_001	Wexford	285900	126000	Mar-08	Ongoing	BH	Logger	Ordovician Volcanics	44.00		EPA/LA
Slieveroe (BH1)	10_018	Kilkenny	263315	113960	Mar-08	Ongoing	BH	Logger	Ordovician Volcanics	100.00		EPA/LA
Bord na Móna – Allen	09_003	Kildare	280086	220996	No data	No data	BH	Logger				EPA/LA
Duffy's Crossroads	09_007	Kildare	266614	238096	Jun-08	Ongoing	BH	Logger				EPA/LA

PF, Pollardstown Fen; BH, borehole; GSI, Geological Survey of Ireland; OPW, Office of Public Works; LA, local authority; mbgl, metres below ground level; maOD, metres above Ordnance Datum.

against the paper charts. The data gaps are believed to be actual data gaps (typically due to the clock stopping or the pen coming off the drum). It is assumed that the water levels were dipped whenever the charts were changed. However, a record of these dips could not be found to verify the accuracy of the charts.

Data for the other MPs were provided from previously digitised groundwater level charts or manual dips. The digitisation of other charts was conducted by Geoff Wright or Eugene Daly of the GSI.

Information on the Nore River Basin MPs, such as geological logs, construction details, drilling records, etc., was sourced from published reports but also from unpublished records in the GSI. For example, details on Rathduff were sourced from Daly (1994), Oldtown from Daly (1982), Ballincurry from Daly (1980), Knocktopher, Granston Manor, Tubbrid Lower, Woodsgift and Rahilla from unpublished GSI records

(Note: Daly (1994) publishes logs for nearby pumping wells to which these boreholes are observation boreholes).

A small amount of information was available from the GSI records on the Laois and Kildare MPs, usually restricted to a 1:10,560 map (6" to a mile) of the source and details such as location, catchment, well type, depth, geology and any additional observations.

Data for the current monitoring network were provided in digital format by the EPA.

The data reviewed from the various information sources over the duration of this project have been collated into a publicly available database. The database includes groundwater level data and MP information for all historic and current MPs featured in this report, as well as data collated but not used in the report.

7 Groundwater Level Trends

7.1 Hydrographs

For discussion, the MPs have been grouped based on similarity of hydrographs. The groups are outlined in Table 7.1 and are discussed in the following sections. The hydrograph grouping is subjective and a number of different groupings would be equally viable. However, the grouping allows ease of discussion, and comparison within and between groups provides an opportunity for insight into the hydrogeological setting.

Figures 7.1–7.8 present the grouped hydrographs together with the ER calculated in Section 2.3. Where possible, the grouped hydrographs have been drawn to the same vertical scale to allow ease of comparison. Where a datum is available, the hydrographs are plotted as metres above ordnance datum, otherwise they are plotted as metres below ground level. Figure 7.9 shows all hydrographs plotted together to show the relative elevation and scale of seasonal

trends. To allow comparison of groundwater levels in this figure, an approximate elevation was taken from the appropriate Ordnance Survey Ireland *Discovery Series* (1:50,000) map for MPs without a datum.

Individual hydrographs for each MP are presented in Appendix D. The hydrographs are plotted against the ER and the captions provide information on geology, subsoil, depth of well, datum and hydrogeological information such as inflow depths from geological logs. Where information on depth to rock was not available, an estimate is made using the subsoil permeability and vulnerability. The ER was calculated as discussed in Section 2.3.

Observations on physical settings have been taken from the appropriate Ordnance Survey Ireland *Discovery Series* (1:50,000) map. Observations on the aquifer classifications have been made from the *National Draft Bedrock Aquifer Map* (GSI, 2006).

Table 7.1. Hydrograph grouping.

Group	Subgroup	Monitoring point	Relevant report and appendix figure	
Bedrock hydrographs	Upper catchment	Land Commission 2	Figures 7.1, 7.2 and D.1	
		Barrow Basin	Ardscull DW	Figures 7.1, 7.2 and D.2
		Masterson	Figures 7.1, 7.2 and D.3	
		Clomantagh Lower	Figures 7.3 and D.4	
	Nore Basin	Woodsgift	Figures 7.3 and D.5	
		Tubbrid Lower	Figures 7.3 and D.6	
		Cullahill	Figures 7.4 and D.7	
	Discharge-dominated hydrographs	Granston Manor	Figures 7.4 and D.8	
		Discharge zone	Oldtown	Figures 7.5 and D.9
	River-influenced hydrographs		Rathduff	Figures 7.5 and D.10
			Knocktopher	Figures 7.5 and D.11
	Confined	Ballincurry	Figures 7.6 and D.12	
	Abstraction influenced	Boston Co. Co.	Figures 7.7 and D.13	
Gravel hydrographs		Kilmeague	Figures 7.9 and D.14	
		Rahilla	Figures 7.9 and D.15	

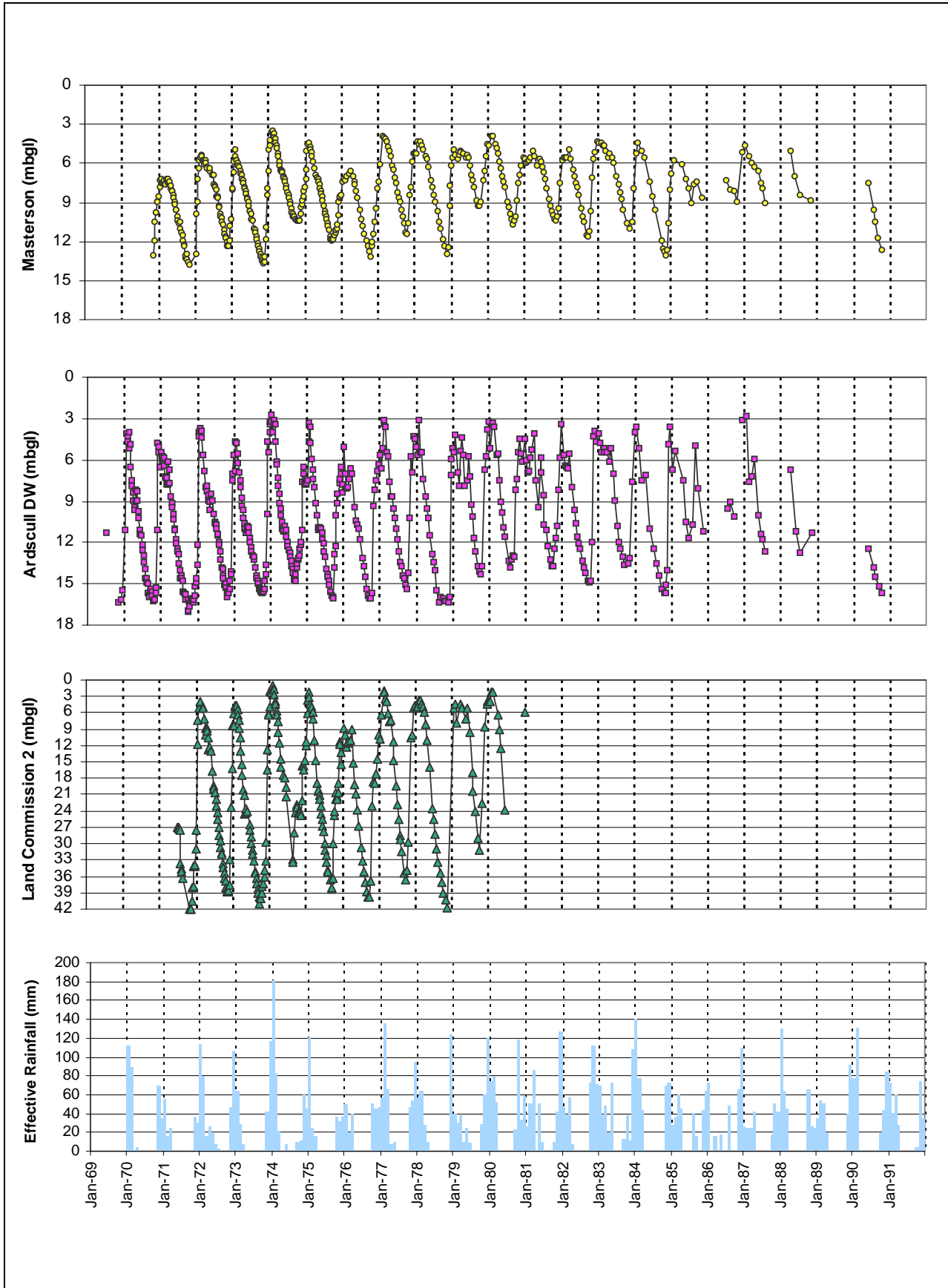


Figure 7.1. Hydrographs of the Barrow Basin group.

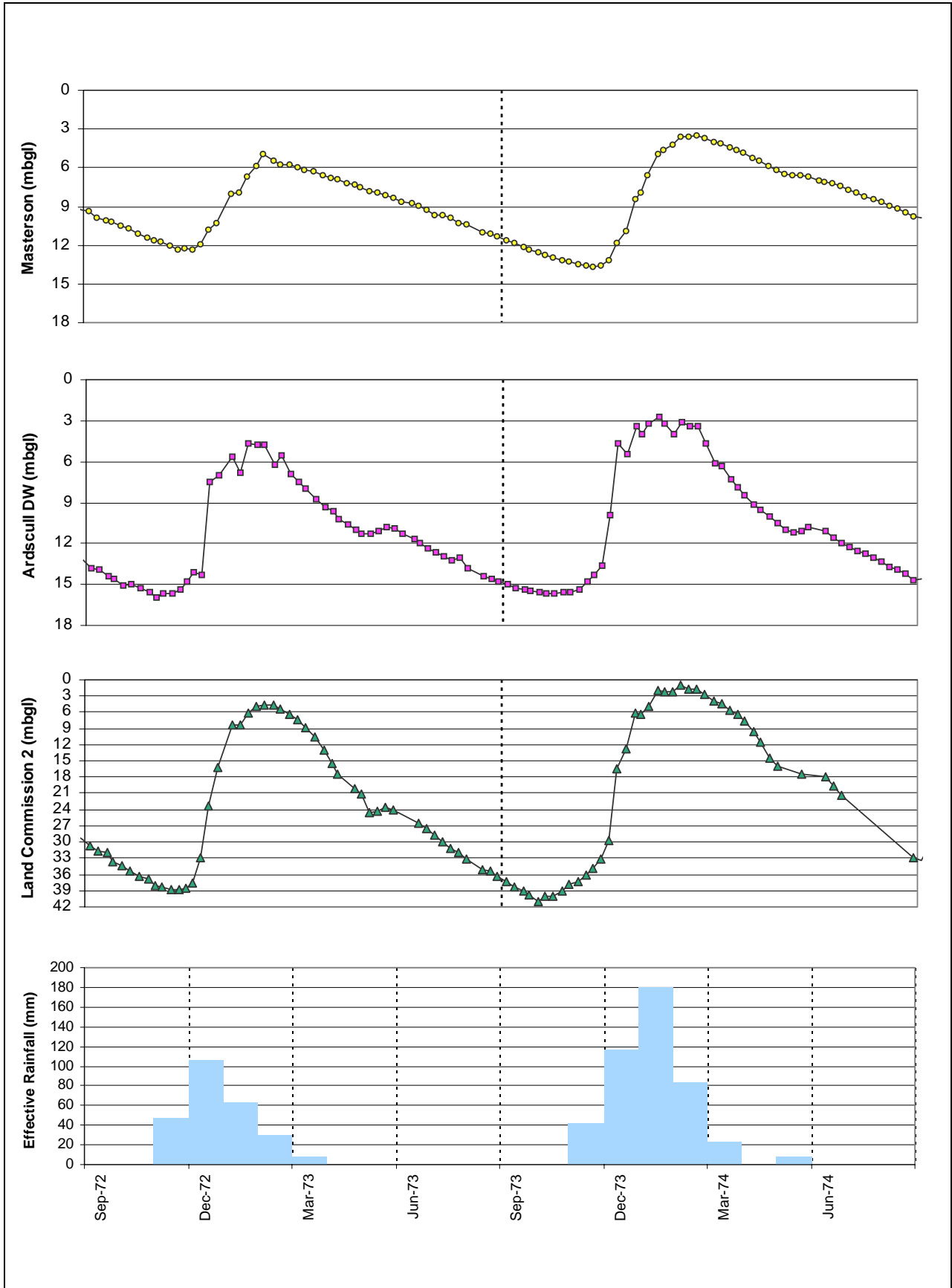


Figure 7.2. Hydrographs of the Barrow Basin group between 1972 and 1974.

Subsoil observations have been made from the *Subsoil Map of Ireland* (GSI/Teagasc/EPA, 2006) as well as the *Provisional Subsoil Permeability Map* (GSI, 2008a) and the *Provisional Subsoil Vulnerability Map* (GSI, 2008b). These sources will not be referenced individually in the discussion below.

7.1.1 Upper catchment – Barrow Basin (Fig. 7.1)

The Land Commission 2, Ardsclull DW and Masterson MPs are located in the Barrow River Basin, to the north-east of the Castlecomer Plateau. The Land Commission 2 MP is located in the Ballyadams Formation, an Rkd karstified aquifer, approximately 70 m down-gradient of where the karstified bedrock is at, or near, the surface. The Ardsclull Borehole is located in the LI Ballysteen Formation. It is located 50 m down-gradient of bedrock being at, or near, the surface. The Masterson MP is located in the Rkd karstified Clogrennan Formation. It is located within 100 m of alluvium of the River Fier, a tributary of the River Douglas.

The groundwater regime in upper catchment areas can be dominated by recharge as typically the subsoil is relatively thin or absent. A hydrograph dominated by recharge typically shows a large annual variation in groundwater level. The Land Commission 2 and Ardsclull MPs are located in areas with thin (0–3 m), moderate permeability till, and are close to areas where bedrock is at, or near, the surface. As may be expected, the annual variation of groundwater levels in these two MPs is large compared with the hydrographs of the other MPs (Fig. 7.1). However, the annual variation observed in the Land Commission 2 MP is exceptionally large (32.5 m on average). This is likely to indicate a particularly low specific yield (see further discussion in Section 7.2.2).

The Masterson MP is located in an area with thicker (3–10 m), moderately permeable till, which may influence its slightly lower annual variation in groundwater levels (Fig. 7.1).

The inter-annual groundwater level variations reflect annual variations in ER. There are a number of ‘marker’ years where similar variation may be seen across all the hydrographs (i.e. not just those in this group). For example, the groundwater maxima in 1976 are notably lower than other years, marking a

particularly dry summer and winter; the groundwater minima in 1974 are notably high and the minima in 1984 are notably low, marking a particularly wet winter and dry summer, respectively (Figs 7.1–7.5 and to a lesser extent Figs 7.7 and 7.8).

The hydrograph of the Ardsclull DW MP (LI aquifer) shows a number of short-duration, small-amplitude recharge and recession events superimposed on its annual trend (Figs 7.1 and 7.2). These occur almost exclusively when groundwater levels are elevated in the winter and spring months. By comparison, the hydrographs for the Land Commission 2 and Masterson MPs (both Rkd aquifers) are much smoother with only occasional interruption to the annual trend (Figs 7.1 and 7.2). This difference could be due to relatively low storage of the locally important aquifer compared with the regionally important aquifer. However, as outlined above for the Land Commission 2 MP, it is likely to have a particularly low storage due to its exceptionally large annual variation (see Section 7.2.2). Therefore, the difference is likely to be the ability of the different aquifers to accept potential recharge. Poor and locally important aquifers have an upper limit to the amount of recharge they can accept, after which subsequent recharge will be rejected (see Box 5.2). The short-lived recharge and recession events seen in the Ardsclull DW MP’s hydrograph are likely to represent the phenomenon of rejected recharge from this LI aquifer. In contrast, the regionally important aquifer of the Land Commission 2 and Masterson MPs can accept all potential recharge.

7.1.2 Upper catchment – Nore Basin (Fig. 7.3)

The Nuenna Catchment MPs are all in the Rkd karstified Ballyadams Formation and are located within 1.5 km of each other. Woodsgift MP is located on the catchment divide for the Nuenna River. Clomantagh Lower is located on the side of a local topographic high (elevated approximately 35 m above the Nuenna River) opposite the Slieveardagh Hills. This MP is located approximately 750 m down-gradient of where karstified bedrock is at, or near, the surface. Six springs are located along the river below the Clomantagh Lower MP. The Tubbrid Lower MP is located close to a spring which forms the head of the Nuenna River; another two springs are located within 100 m of this MP. As outlined in Section 5.2.1, the

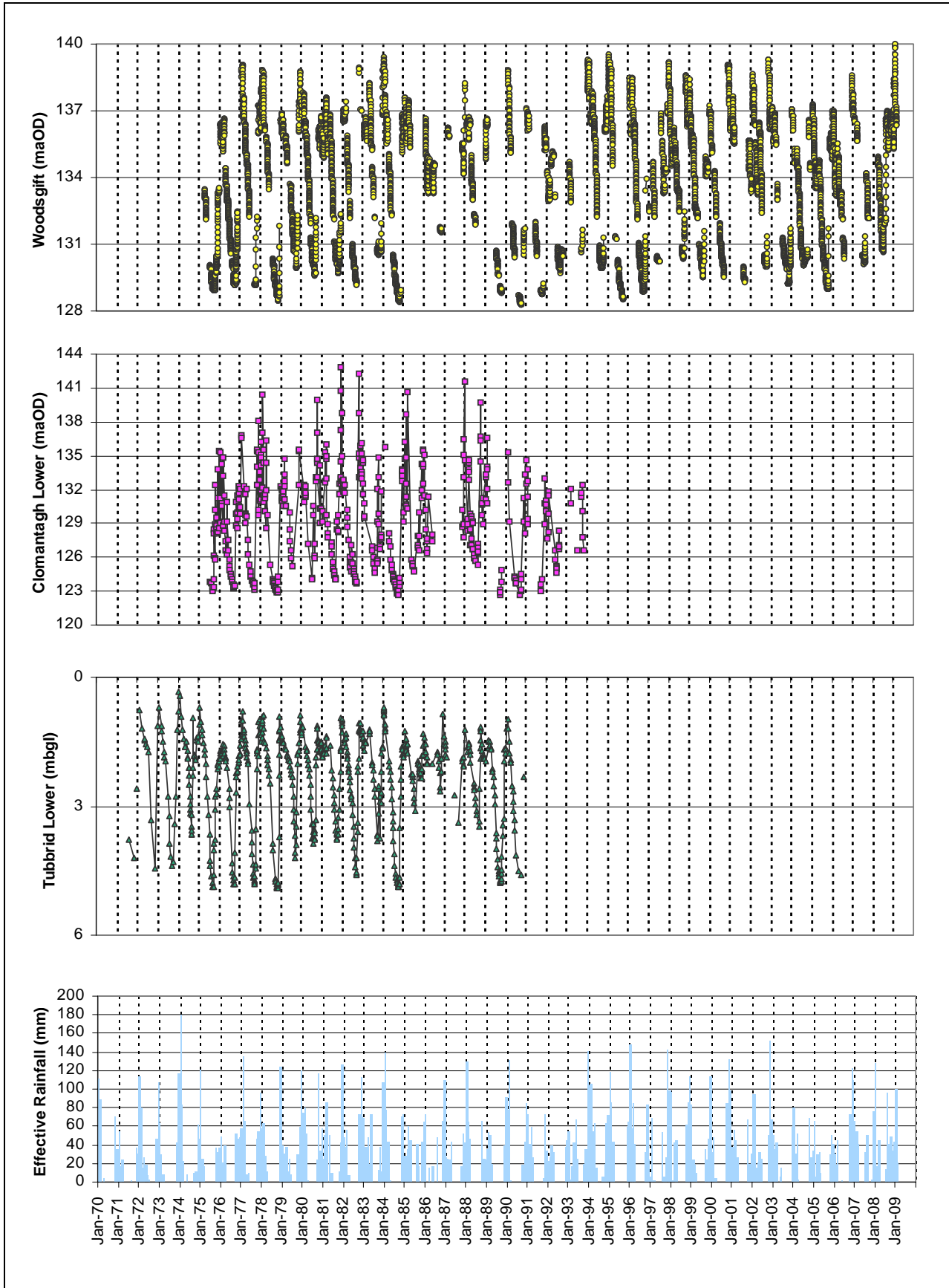


Figure 7.3. Hydrographs of the Nore Basin group.

Nuenna Catchment is a karstified area with numerous karst features and evidence of conduit flow.

The annual variations of the three MPs are very variable considering their proximity to each other. The Clomantagh Lower MP has a large annual variation (average of 14.8 m), Woodsgift has a moderate variation (average of 7.7 m) and Tubbrid Lower has a small variation (average of 3.2 m) (Fig. 7.3). The large variation observed in Clomantagh Lower may be due to the MP's proximity to the area where karstified bedrock is at, or near, the surface and thus its high potential for recharge. Tubbrid Lower's low annual variation may be due to its local discharge environment. The differences between the hydrographs of these closely clustered MPs highlight the complexity of the karstified system within which they are located.

The inter-annual groundwater level variations are similar to those in the Upper Catchment – Barrow Basin group, as noted by the trends during 'marker' years.

The Clomantagh Lower and Woodsgift hydrographs show a number of short-term water-level variations which occur throughout the annual cycle (Figs 7.3, D.4 and D.5). In contrast to the short-term water-level variations attributed to rejected recharge, these variations differ in two ways:

1. They occur throughout the year, during recharge and recession periods; and
2. Their amplitude is of a similar magnitude to the amplitude of the annual variations.

These moderately large amplitude recharge events during the summer months may be the result of either localised summer ER or point recharge, which would allow recharge to bypass the soil zone and thus the soil moisture requirements. Plotting this group of hydrographs against ER calculated for the Tullaroan rainfall station (the rainfall station nearest to the MPs, see Table 2.1), rather than for the Kilkenny synoptic station, indicates that localised summer ER is likely to be the reason for these recharge events.

7.1.3 Discharge dominated (Fig. 7.4)

Cullahill and Granston Manor MPs are located to the west of the Castlecomer Plateau, in the LI aquifers of the Durrow and Crosspatrick Formations, respectively. Both MPs are located close to rivers: Cullahill is approximately 20 m west of an unnamed tributary of the River Goul and Granston Manor is within 100 m of an unnamed tributary of the River Erkina. The 1:10,560 (6" to a mile) map for the area shows large marshy areas along the Rivers Goul and Erkina. There are no mapped karst features near the Cullahill or Granston Manor MPs.

The Crosspatrick Formation at the Granston Manor MP is overlain by 1.4 m of sand and then 5.4 m of clay. The subsoils are recorded as moderately permeable and are likely to be hydraulically connected to the underlying aquifer.

The inter-annual groundwater level variations are similar to those in the upper catchment groups, as noted by the trends during 'marker' years.

The water levels in these MPs are shallow (winter maxima are frequently less than 1 mbgl) with small annual variations (between 2.0 m and 4.5 m) (Fig. 7.4). These characteristics are likely to reflect that these MPs are located in areas where groundwater is discharging to surface water.

The slightly 'ragged' nature of these hydrographs during the winter and spring months may represent the limited ability of the LI aquifers to accept recharge.

7.1.4 River influenced (Fig. 7.5)

The regionally important Dinantian karstified, dolomitised aquifers and the Kiltorcan Sandstone Aquifer all discharge into the Callan to Bennettsbridge Lowlands (Section 5.2), where the Rathduff (Kny 27/58) and Knocktopher (Kny 31/72) MPs are located. The Rathduff Borehole is located in the Rkd Waulsortian Formation, which is overlain by 18 m of moderate permeability subsoils, dominated by limestone till. It is approximately 100 m from the King's River. The Knocktopher Borehole is located in the Rf Kiltorcan Sandstone Aquifer, which is overlain by 5 m of low permeability limestone till. It is approximately 200 m from the Little Arrigal River.

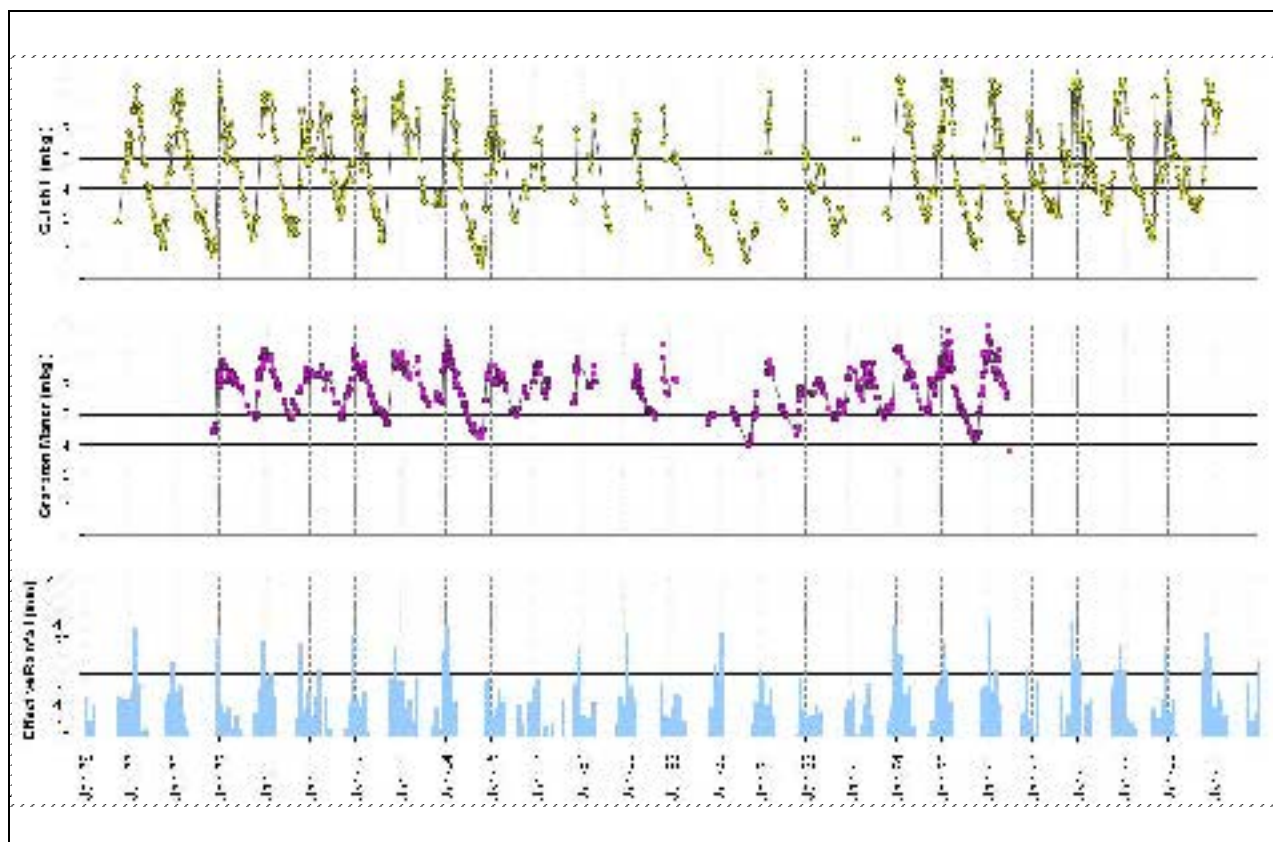


Figure 7.4. Hydrographs of the discharge-dominated group.

The Oldtown Borehole is located further up the catchment of the King's River, on the flanks of the Slieveardagh Hills. It is located in the Kilmanagh River gravels approximately 10 m from an unnamed tributary of the King's River.

These hydrographs have low annual groundwater variations compared with the hydrographs of the other MPs (averages between 1.1 m and 2.6 m). The groundwater levels are reasonably shallow throughout the year: Rathduff and Knocktopher are typically less than 7–8 m deep and Oldtown typically less than 2.5 m deep. The hydrographs are 'peaky', i.e. they show a rapid response to ER via a number of recharge and recession events within an annual time frame (Figs 7.5, D.9–D.11). The amplitude of these events is the same order of magnitude as the seasonal variations. This 'peaky' nature is likely to be due to a high level of groundwater–surface water interaction.

The hydrogeological regime at the Oldtown MP is investigated in more detail in Section 7.4. It is

demonstrated that the nearby river acts as a control on groundwater level in this MP by maintaining an 'artificially' high minimum groundwater level. On the rare occasion when this control is removed, i.e. the river runs dry, the groundwater level falls rapidly from the normal minimum level.

A similar level of evidence of surface water–groundwater interaction has not been obtained for the Rathduff or Knocktopher MPs. Therefore, their grouping with the Oldtown MP is predominantly based on the similarity of hydrographs and comparable physical settings.

The EPA maintains a permanent hydrometric station at Annamult on the King's River, the details of which are outlined in Table 7.2. The Annamult station is located 4.4 km downstream of the Rathduff MP. The hydrograph of surface water flow at Annamult hydrometric station is similar to the groundwater level hydrograph for Rathduff MP (Fig. 7.10), supporting the

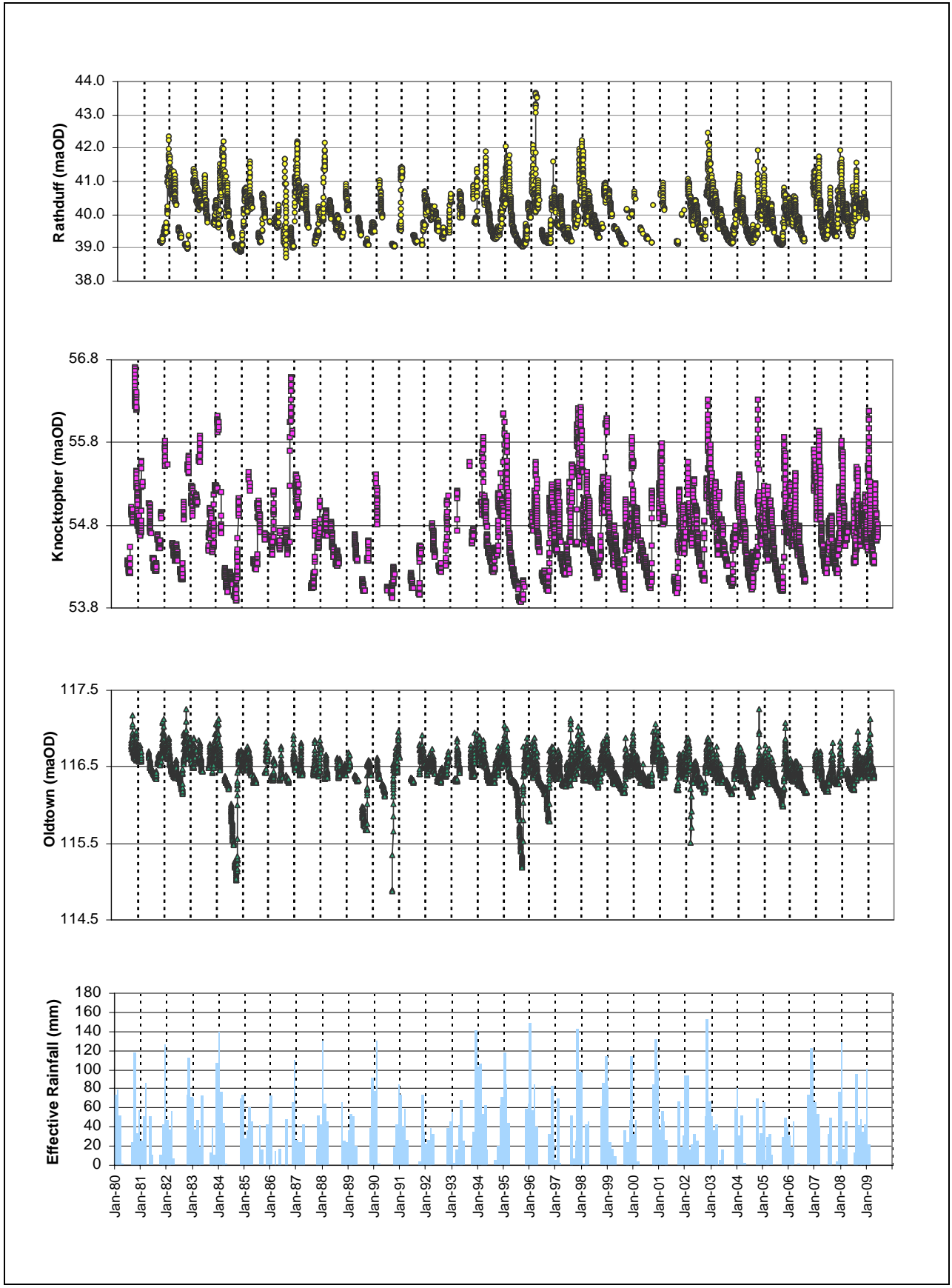


Figure 7.5. Hydrographs of the river-influenced group.

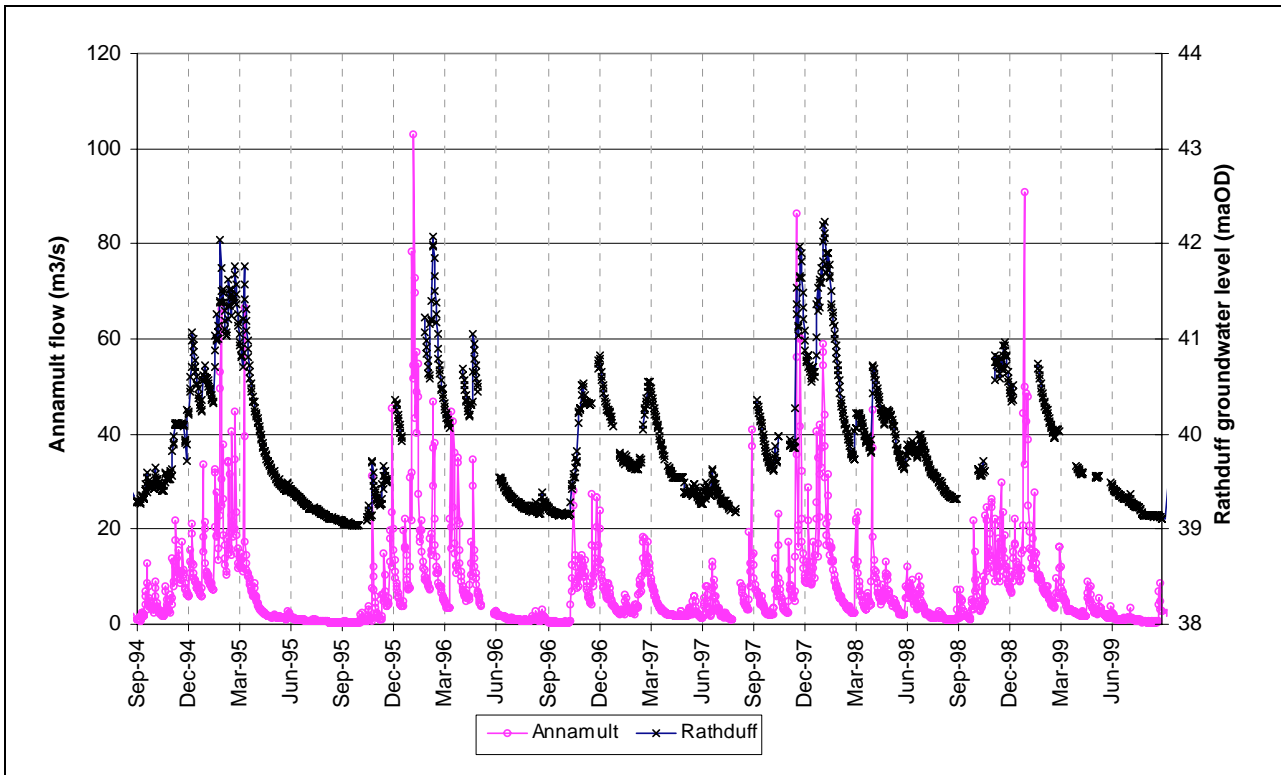


Figure 7.6. Comparison of Annamult surface water flow hydrograph with Rathduff groundwater level hydrograph.

Table 7.2. Details of Annamult hydrometric station.

Hydrometric station	Station number	X	Y	River	Distance downstream of Rathduff MP (km)	Water level record duration
Annamult	15001	254289	144376	King's	4.4	1972 to present

MP, monitoring point.

idea of surface water–groundwater interaction at this MP.

A similar surface water hydrometric station is not available for comparison with the Knocktopher hydrograph. The geology of the area around the Knocktopher MP is complicated, with a high degree of folding and faulting. The MP's location relative to the geological structure allows (but does not prove) a physical connection between the Kiltorcan Sandstone Aquifer unit and the Little Arrigal River.

Missteart and Brown (2008) show that borehole hydrographs, such as these, may be used to calibrate river base-flow separation analyses. In low-storage, rapid-flow situations, borehole hydrographs can

provide a means of assessing whether the separation method adequately represents the response to recharge in the aquifer.

7.1.5 Confined (Fig. 7.7)

The Ballincurry Borehole is located near the surface water divide for the Nore River Basin in the Westphalian Sandstones of the Slieveardagh Hills. Daly (1980) notes that the borehole was artesian when drilled and that the sandstone units are confined. The subsoil in the area of the borehole is low permeability; as a result there is a high drainage density near the borehole. Bedrock is at, or near, the surface approximately 1.4 km up-gradient from the borehole, which is likely to provide recharge into the sandstone

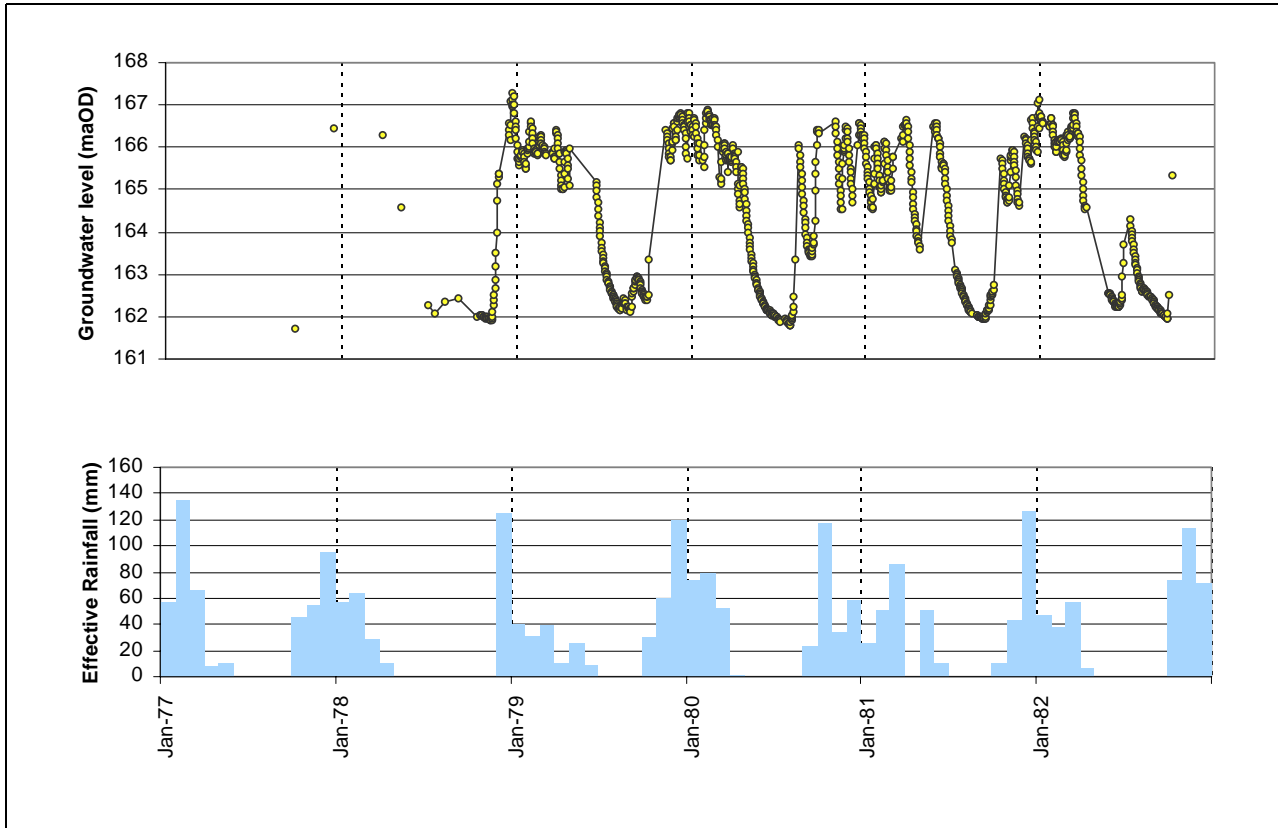


Figure 7.7. Hydrographs of the confined group.

units. The borehole is located approximately 400 m from the south-eastern extent of the Westphalian Sandstone and the contact with the underlying PI Namurian Sandstone units. An unnamed tributary to the King's River passes within 400 m of the borehole.

The annual variation of groundwater level in the Ballincurry MP is moderate at 4.71 m. The hydrograph shows rapid recharge to an elevated groundwater level, which is typically maintained for the winter and spring months, followed by a reasonably rapid groundwater level recession (Fig. 7.6). The elevated groundwater levels are maintained by a number of short-duration, small-amplitude recharge and recession events. The recessions events may represent low, confined storage and possibly subsequent discharge of the sandstone units to the nearby stream.

7.1.6 Abstraction influenced (Fig. 7.8)

The Boston Co. Co. MP is located in the upper Barrow River Basin, in a fault-bounded block (approximately

2.5 km by 3.0 km) of the LI Boston Hill Formation. The subsoil map shows the area to have bedrock at, or near, the surface. It is described as a 'perched source' and a 'poor supply' in the GSI well records. It is located approximately 75 m to the north-east and downslope of a gravel pit, which is likely to affect the recharge to the limestone in the area. It is not known if the gravel pit was operational in the 1970s–1980s, i.e. the duration of the hydrograph.

The annual groundwater level variation for the Boston Co. Co. (5.95 m) is not as large as might be expected for an aquifer unit which is at, or near, the surface (Fig. 7.7). For example, the Ardscull DW MP, which is located in the LI Ballysteen Formation (equivalent to the Boston Hill Formation) has an annual variation of 10.88 m (Fig. 7.1). Perhaps the impact of the gravel quarry, the aquifer's perched or fault-bounded nature restricts the extent of groundwater level movement.

The Boston Co. Co. MP seems to have two distinct groundwater level minima: shallow minima between 10 mbgl and 12 mbgl and deeper minima between 14

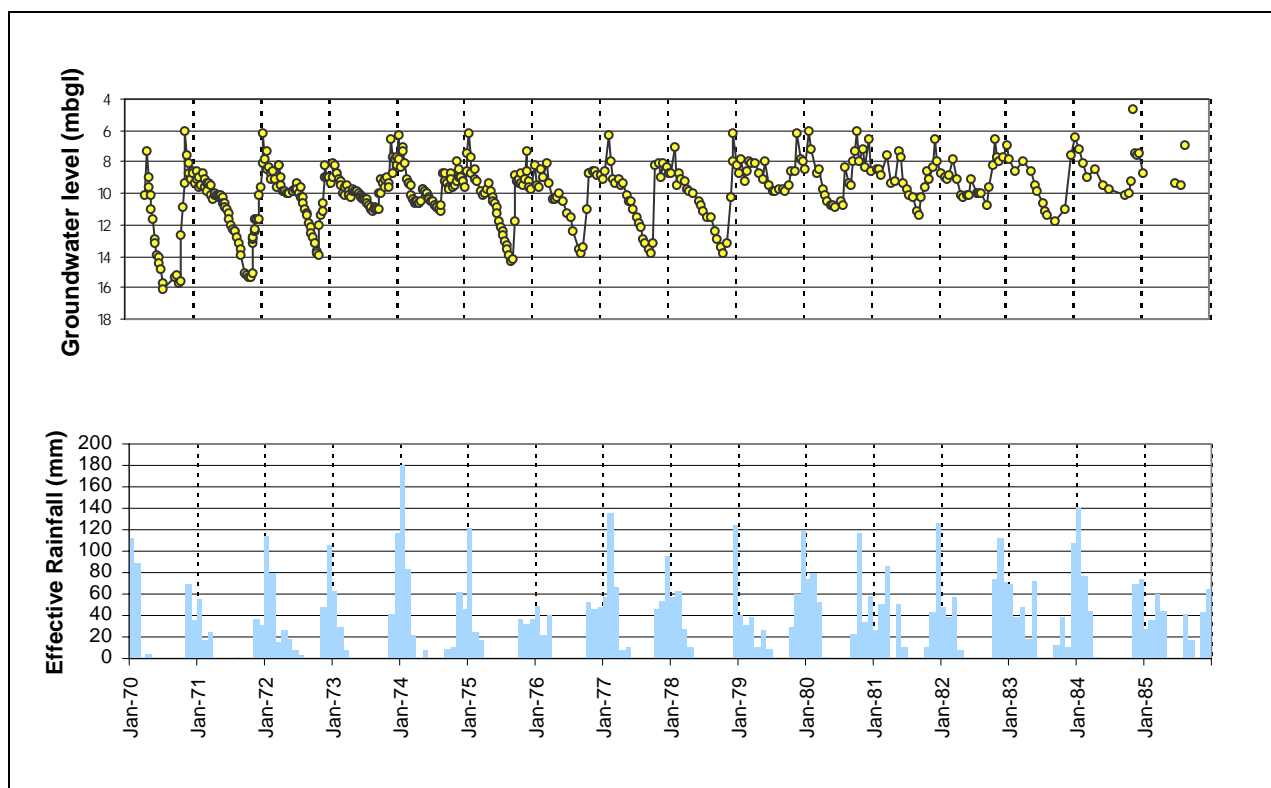


Figure 7.8. Hydrographs of the abstraction-influenced group.

mbgl and 16 mbgl (Fig. 7.7). The deeper minima occur in 'dry' years, for example the early- and mid-1970s, and may represent a drop below its perched boundary. They also become less deep with time over the duration of the hydrograph. This may be due to a decreasing impact of dewatering from the nearby quarry from the 1970s to the 1980s.

7.1.7 Gravels (Fig. 7.9)

The Rahilla Borehole is located in the regionally important Mid-Kildare Gravel Aquifer whereas the Kilmeague Borehole is located in a "high dry sandy area which rises steeply from the extensive, wet flats and bogs which dominate this part of Kildare" (GSI well records) approximately 13 km to the north-east.

Until approximately 1974, the Rahilla Borehole was used as a source of supply and the groundwater level was measured by listening for a dropping weight to hit the water; after 1974, an electronic dipper was used (Ward, 1993). These two factors account for the 'ragged' appearance of the Rahilla hydrograph prior to 1974. It is likely that the method of monitoring at Kilmeague was changed at a similar date.

The hydrographs for the Rahilla and Kilmeague MPs are similar. Where the monitoring frequency is adequate (prior to 1982 and 1985 for Kilmeague and Rahilla, respectively), the hydrographs are smooth, rounded and symmetrical. They have low annual variation and show relatively gradual recharge periods over the autumn months and equally gradual recessions over the spring months. The water levels are deep, generally between 30 m and 36 m deep at Rahilla and between 21 m and 25 m deep at Kilmeague. Relative to their low annual range, the hydrographs show a large variation in annual minima and maxima over a number of years. For example, in the Kilmeague MP the difference in groundwater level maxima is approximately 3 m, approximately twice that of the average annual variation (Fig. 7.9). These characteristics are likely to be due to large intergranular storage available in sand and gravel aquifers as well as to the thick unsaturated zones.

The range in annual minima and maxima reflects medium-term rainfall trends, with low water levels in the early- and mid-1970s and higher than normal

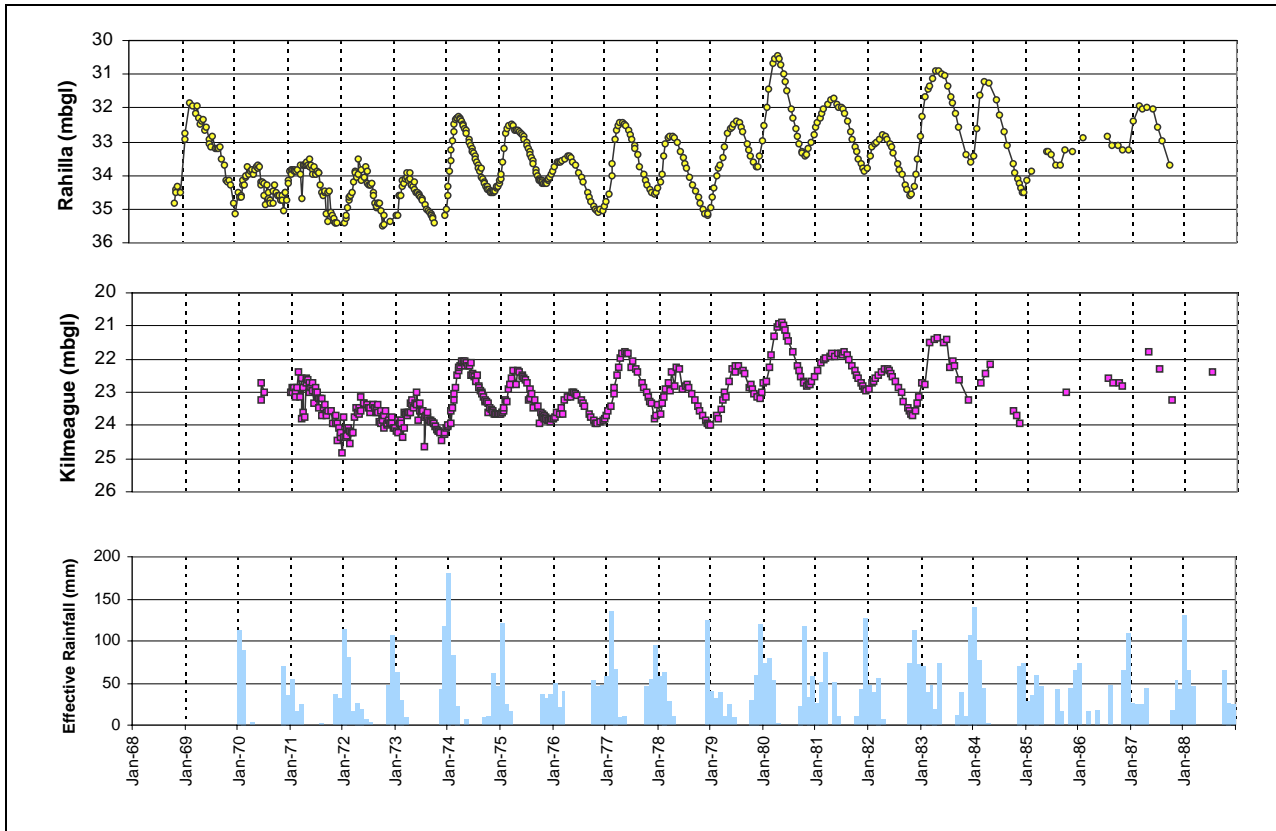


Figure 7.9. Hydrographs of the gravel group.

winter maxima in 1976, 1979 and 1982. Despite 1976 being a dry year regionally, the Naas rainfall station recorded an above-average rainfall in the winters of 1976–1977 as well as 1979–1980 and 1982–1983.

7.2 Short-Term and Seasonal Groundwater Level Trends

7.2.1 Groundwater level statistics

Each hydrograph was interrogated to obtain a list of the timing and elevation of each annual groundwater level minimum and maximum. These values were used to generate simple statistics for each MP, such as minimum, maximum and mean groundwater levels, average annual groundwater level variation and duration of recession events. For this analysis, only constrained minima and maxima were included, i.e. only turning points with supporting data points before and after the turning point, within a reasonable time frame, were included. Table 7.3 outlines the minimum, maximum and mean groundwater levels and the average annual variation for each MP.

The following observations may be made:

- Monitoring points with both shallow mean water levels (<7.0 mbgl) and low average annual variations (<4.5 m) are those associated with surface water or discharge points;
- Gravel MPs (selected for this report) have low average annual variation (<2.1 m) but deep minimum, maximum and mean water levels; and
- Monitoring points with reasonably deep mean water levels (>7.0 mbgl but <21 mbgl) and large average annual variation (>4.5 m) are those associated with recharge zones.

Table 7.4 outlines an analysis of the timing of groundwater level minima and maxima for each MP. For the analysis of the duration of recession periods, the recession period is taken to be the length of time from the maximum groundwater level in 1 year to the minimum groundwater level in the subsequent year. For most hydrographs, this method is appropriate;

Table 7.3. Minima, maxima, mean and average annual variation in groundwater levels.

Monitoring point	Maximum water level (mbgl)	Minimum water level (mbgl)	Mean dip (mbgl)	Average annual variation (m)
Oldtown	0.81	3.43	2.02	1.18
Granston Manor	0.00	4.20	2.05	2.09
Tubbrid Lower	0.62	4.91	2.37	3.18
Cullahill	0.31	6.60	3.32	4.36
Ballincurry	3.05	8.62	6.75	4.71
Rathduff	2.89	8.07	6.79	3.06
Knocktopher	5.34	7.80	7.00	1.94
Masterson	3.48	13.80	8.22	6.75
Boston Co. Co.	4.66	16.08	9.90	5.95
Ardscull DW	2.70	17.07	10.17	10.88
Woodsgift	7.30	18.86	13.85	9.08
Clomantagh Lower	6.50	26.75	20.03	13.83
Land Commission 2	1.05	42.06	20.36	32.43
Kilmeague	20.90	24.84	23.12	1.57
Rahilla	30.45	35.52	33.64	2.06

mbgl, metres below ground level.

groundwater level minima (October–November) are typically associated with Rkd aquifers with extreme vulnerability or are near to areas where the karst aquifer is at, or near, the surface. Hydrographs with slightly earlier minima (September) or maxima (November–January) tend to be associated with locally productive aquifers with high vulnerability. The later response of the Rkd aquifers may be due to the relatively increased storage of the karstified and dolomitised limestones compared with the locally important aquifers or may be due to the fact that they continue to recharge beyond the point at which locally important aquifers begin to reject recharge.

7.2.2 Specific yields

Healy and Cook (2002) describe the water-table fluctuation method to calculate recharge. The method is based on the premise that rises in groundwater levels in unconfined aquifers are due to recharge water arriving at the water table.

A water-balance equation for a groundwater system may be written as:

$$R = \left(S_y \frac{\Delta h}{\Delta t} \right) + Q_a + Q_{out} - Q_{in} \quad \text{Eqn 7.1}$$

where R is recharge, S_y is specific yield, Δh is change in water-table elevation, Q_a is groundwater abstraction, and Q_{out} and Q_{in} are any other lateral subsurface outflows and inflows, respectively. If it is assumed that the outflows are equal to the inflows, that abstractions are negligible and that water arriving at the water tables goes immediately into storage, then the water-balance equation may be simplified to:

$$R = S_y \frac{\Delta h}{\Delta t} \quad \text{Eqn 7.2}$$

This equation was inverted to calculate estimates of specific yields for a number of aquifers.

The recharge component of the equation was estimated using the methodology of Misstear et al. (2008) for making initial estimates of groundwater recharge from groundwater vulnerability mapping

Table 7.4. Typical timing of groundwater level minima and maxima.

Monitoring point	Aquifer type ¹	Typical month of maximum groundwater level	Typical month of minimum groundwater level	Range of recession duration (months)	Typical duration of recession (months)
Oldtown	Rg	Nov	Sep	4–12	8.6
Ballincurry	Lm	Dec	Sep	7–10	8.5
Cullahill	LI	Jan	Sep	6–11	7.9
Boston Co. Co.	LI	Jan	Sep	4–12	8.8
Granston Manor	LI	Jan	Sep	6–11	7.9
Rathduff	Rkd	Jan	Sep	3–11	8.3
Knocktopher	Rf	Jan	Sep/Oct	2–12	7.5
Ardscull DW	LI	Jan	Oct	6–10	8.1
Woodsgift	Rkd	Jan	Oct	7–11	8.2
Tubbrid Lower	Rkd	Jan	Oct	6–12	8.8
Clomantagh Lower	Rkd	Feb	Sep	6–10	7.9
Land Commission 2	Rkd	Feb	Oct	7–9	8.1
Masterson	Rkd	Feb	Oct/Nov	6–10	8.1
Rahilla	Rg	Apr	Oct/Nov/Dec	4–10	6.8
Kilmeague	Lm	Apr/May	Nov/Dec	5–10	6.8

¹For aquifer type codes, please refer to Box 5.1.

(Box 5.2). Recharge to an aquifer is estimated by multiplying the ER by a recharge coefficient. The recharge coefficient indicates the proportion of the ER that contributes to groundwater recharge. It is determined mainly by the permeability and thickness of overlying subsoils. The recharge coefficients are classed into three groupings:

1. High (70–90%);
2. Intermediate (30–70%); and
3. Low (5–30%).

Scanlon et al. (2002) state that the water-table method is best applied to short time periods in regions having shallow water tables that display sharp rises and declines in water levels. However, it may be applied over longer time intervals (seasonal or annual) to estimate 'net' recharge. For the majority of the historic MPs, data resolution is not sufficient to interrogate

individual recharge events. Therefore, the method was applied over an annual time period.

Healy and Cook (2002) point out that in fractured rock systems, short-term variations in groundwater levels are significantly attenuated due to the well's relatively large permeability and storage compared with the aquifer, particularly where the well radius is large (up to 0.5 m). They also state that longer-term variation in aquifer water levels (such as annual cycles) is less attenuated.

It should be noted that while the water-table fluctuation method is widely used in sedimentary (porous media) aquifers, it remains unclear if the method is valid at all in fractured rock systems due to the complexity of such systems (Healy and Cook, 2002).

Therefore, with caution, the S_y calculations were carried out using the annual groundwater level variation outlined in Section 7.2.1. The specific yield was estimated using the following equation:

$$S_y [-] = \frac{\text{Effective rainfall [m]} \times \text{Recharge coefficient [-]}}{\text{Average annual groundwater level variation [m]}}$$

Eqn 7.3

The analysis considers recharge as a result of vertical infiltration in the vicinity of the borehole. Therefore, a number of MPs were unsuitable for analysis and have been omitted. They comprise MPs where lateral throughflow from up-gradient is likely to dominate recharge (confined Ballincurry and discharge-dominated hydrographs Tubbrid Lower, Cullahill, Granston Manor, Oldtown, Rathduff and Knocktopher).

The rainfall used is the annual average rainfall for the rainfall station nearest to the MP (see Table 2.1); the AE is an average taken from the AE calculated for the Callan to Bennettsbridge Lowlands in the Misstear and Brown (2008) study. The recharge classes are chosen

based on the subsoil permeability and thickness. Where the MP is proximal to significantly different subsoil (typically down-gradient of bedrock at, or near, the surface), the S_y range over two recharge classes is calculated. The results of the analysis are presented in Table 7.5.

For these calculations the value of Δh was calculated as the difference between the annual groundwater level maximum and the antecedent minimum. In contrast, Healy and Cook (2002) state that to calculate the 'net' recharge, Δh should be calculated as the difference between "the peak of the rise and the low point of the extrapolated antecedent recession curve at the time of the peak". On an annual time frame, this would translate into the difference between the annual groundwater level maximum and the extrapolated antecedent recession curve at the time of the groundwater maximum. This latter version of Δh will be

Table 7.5. Results of specific yield analysis.

Monitoring point	Aquifer category ¹	Average groundwater level variation (m/annum)	Rainfall (mm/annum)	Actual evapotranspiration (mm/annum)	Effective rainfall (mm/annum)	Subsoil	Subsoil permeability	Vulnerability	Minimum recharge class	Maximum recharge class	Specific yield range
Land Commission 2	Rkd	32.43	974	432	542	0–3 m TLs/ KaRck	M	E	h	h	0.01–0.02
Clomantagh Lower	Rkd	13.34	1083	432	651	3–10 m TLs/ KaRck	M	H	i	h	0.01–0.04
Ardscull DW	LI	10.88	974	432	542	0–3 m TLs/ Rck	M	E	h	h	0.03–0.04
Woodsgift	Rkd	9.08	1083	432	651	0–3 m TLs	M	E	h	h	0.05–0.06
Masterson	Rkd	6.75	974	432	542	3–10 m TLs/ Alluvium	M	H	i	i	0.02–0.06
Boston Co. Co.	LI	5.95	802	432	370	Rck	–	X	h	h	0.04–0.06
Rahilla	Rg	2.06	802	432	370	Till with gravel	H	H	h	h	0.13–0.16
Kilmeague	LI	1.57	802	432	370	Sand & gravel	H	H	h	h	0.16–0.21

¹For aquifer category codes, please refer to Box 5.1.

H, High; M, Moderate; X, rock near surface or karst; E, Extreme; i, Intermediate.

greater than the version used; therefore, the calculated values of specific yield are likely to be overestimated.

The results of this simple analysis are reasonably similar to the S_y estimates from Daly (1994). The estimates for MPs with small average annual groundwater level variations are slightly higher than expected values but are within an order of magnitude.

The values calculated for the Woodsgift and Clomantagh Lower MPs are significantly different, given their proximity and the similarity of their setting in the Nuenna Catchment. This difference may indicate the complex characteristics typical of karst hydrogeology.

7.2.3 Earthquake fluctuations

A number of GSI MPs registered significant groundwater level fluctuations due to the earthquake on 26 December 2004 off Sumatra (Fig. 7.11) (Wright, 2005). Similar effects were observed in two MPs in Northern Ireland (McConvey, 2005). This discovery prompted a review by Wright (2005) of all charts from these MPs and the responses to over 100 seismic events were discovered.

The Oldtown (Kny 18/92), Rathduff (Kny 27/58) and Knocktopher Manor (Kny 31/72) MPs all registered abrupt groundwater level fluctuations in the early hours of 26 December 2004. The maximum fluctuations

observed in each borehole range from 50 mm in Oldtown, to 240 mm in Rathduff to 280 mm in Knocktopher Manor. A fluctuation of 335 mm was recorded in a Roscommon MP (Ros 14/91 at Aghaderry townland).

Water-level fluctuations in response to earthquakes are normally only detectable in confined aquifers, where the very low storage coefficient transforms the minute pressure changes into observable water-level fluctuations. Therefore, it is relatively surprising that water-level fluctuations were recorded in the shallow sand and gravel Oldtown MP (Wright, 2005).

groundwater level charts since the 1980s were reviewed for the three boreholes in Counties Kilkenny and Roscommon. This revealed responses to earthquakes in the following countries: Indonesia, Philippines, Japan, Canada, United States of America, Siberia, Mexico, Peru, Chile, Colombia, Bolivia, Iceland and other parts of the Mid-Atlantic Ridge, Macquarie Islands, Taiwan, China, Central Asia, Iran, Pakistan, India, Turkey, Greece, Cyprus and Romania. In contrast, the review of three MPs in confined aquifers in County Cork showed no response to earthquakes (Wright, 2005).

These responses were recorded because the wells were monitored using chart recorders (OTT R16 recorders), i.e. a float connected to a pen which

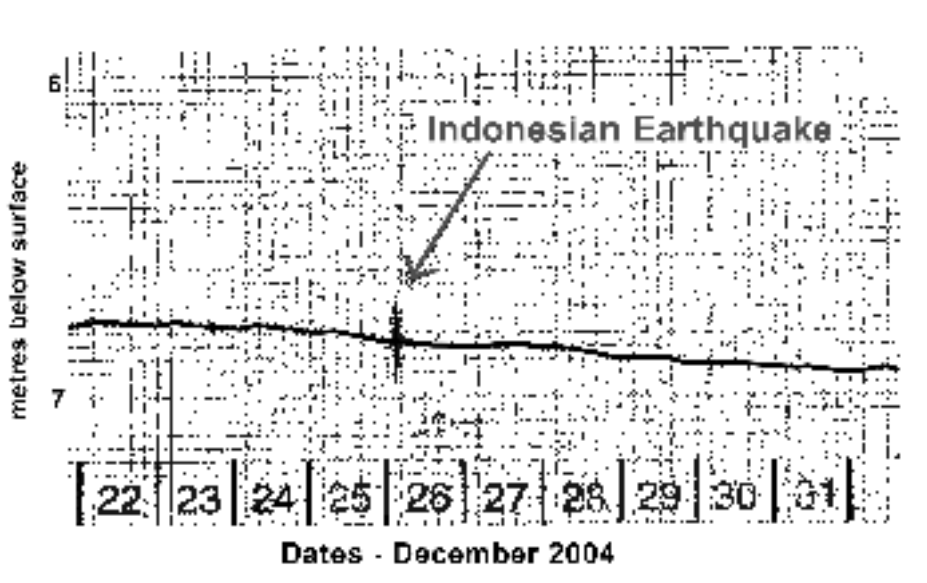


Figure 7.11. Knocktopher Manor monitoring point's groundwater level response to the 2004 tsunami.

records variations in water level onto a chart on a rotating drum. groundwater level monitoring in these boreholes is now recorded using a digital data logger. The loggers record at 15-min intervals and therefore they are very unlikely to record any similar responses in the future. In the Oldtown and Rathduff Boreholes, however, both recording systems operate simultaneously.

7.3 Trends in Long-Term Groundwater Levels

7.3.1 Climate change studies

A number of analyses have been carried out on the impact of climate change on precipitation and hydrology in Ireland (Kiely, 1999; Steele-Dunne et al., 2008; Kiely et al., 2010).

The results of the Steele-Dunne et al. study (2008) suggest an amplification of the seasonal cycle across Ireland, driven by increased winter precipitation, decreased summer precipitation and increased temperature.

Kiely (1999) used observations from eight climate stations and hydrometric stations on four rivers to analyse annual precipitation and the occurrence of extreme precipitation events in Ireland during the second half of the 20th century. He notes a change point evident in the mid-1970s for climate stations on the west coast (Valentia, Belmullet and Malin Head), after which there is increased rainfall. He also notes a change in the seasonal distribution of precipitation – most of the increase in annual precipitation was observed to come in the months of March and October, and an increased storm intensity was also observed in these months.

Kiely (1999) states that on the east side of the country there was almost no increase in the post-1975 precipitation. After the mid-1970s, however, there was a similar change in the seasonal distribution of precipitation as observed in the west, with increased precipitation in March and October, while other months experienced decreased amounts of precipitation. It should be noted that this analysis included data from the Wexford rainfall station but not from the Kilkenny station.

Kiely et al. (2010) repeated the analyses presented by Kiely (1999) with over a decade of additional data. The re-analysis showed evidence that change points in the annual total precipitation occurred for stations near the west coast: Belmullet, Claremorris, Malin Head and Valentia. Of these stations, the change points occurred between 1975 and 1978, with the exception of Belmullet, where the change point was determined to be in 1983. No significant change points were detected for stations in the remainder of the country, or for the Shannon station despite its proximity to the west coast.

An analysis of whether an equivalent change in behaviour is present in groundwater levels may not be possible due to the relatively limited duration of the groundwater level records in Ireland. In the west of the country, where a change in groundwater level behaviour is most likely to be observed, there are unlikely to be MPs with a suitable duration of record. For example, Wright (1994) documents that groundwater level monitoring in County Roscommon did not commence until 1978, County Kerry until the 1980s, County Limerick in the mid-1980s, and County Galway until the 1980s.

In the SERBD, there are a number of MPs which were established prior to the mid-1970s. The Rahilla and Kilmeague MPs were established in the late-1960s; however, up to the mid-1970s their records are 'ragged' and are likely to be influenced by pumping (see Section 7.1.7) so are not suitable. Other potentially suitable MPs (Land Commission 2, Tubbrid Lower, Boston Co. Co., Masterson and Ardsull) were established between 1969 and 1971 (see Table 6.1). On visual inspection, there is no obvious change in behaviour before and after the mid-1970s.

The timing of groundwater level minima and maxima were interrogated to investigate if the amplification of the seasonal cycle was evident in the SERBD groundwater level (Fig 7.12A and B). Increased rainfall in October and decreased rainfall in the surrounding months could refine the onset of autumn recharge observed in groundwater levels. Increased rainfall in March could prolong the recharge period and delay the onset of the recessionary period.

The month in which each groundwater level maxima and minima occurred was obtained from the five MPs

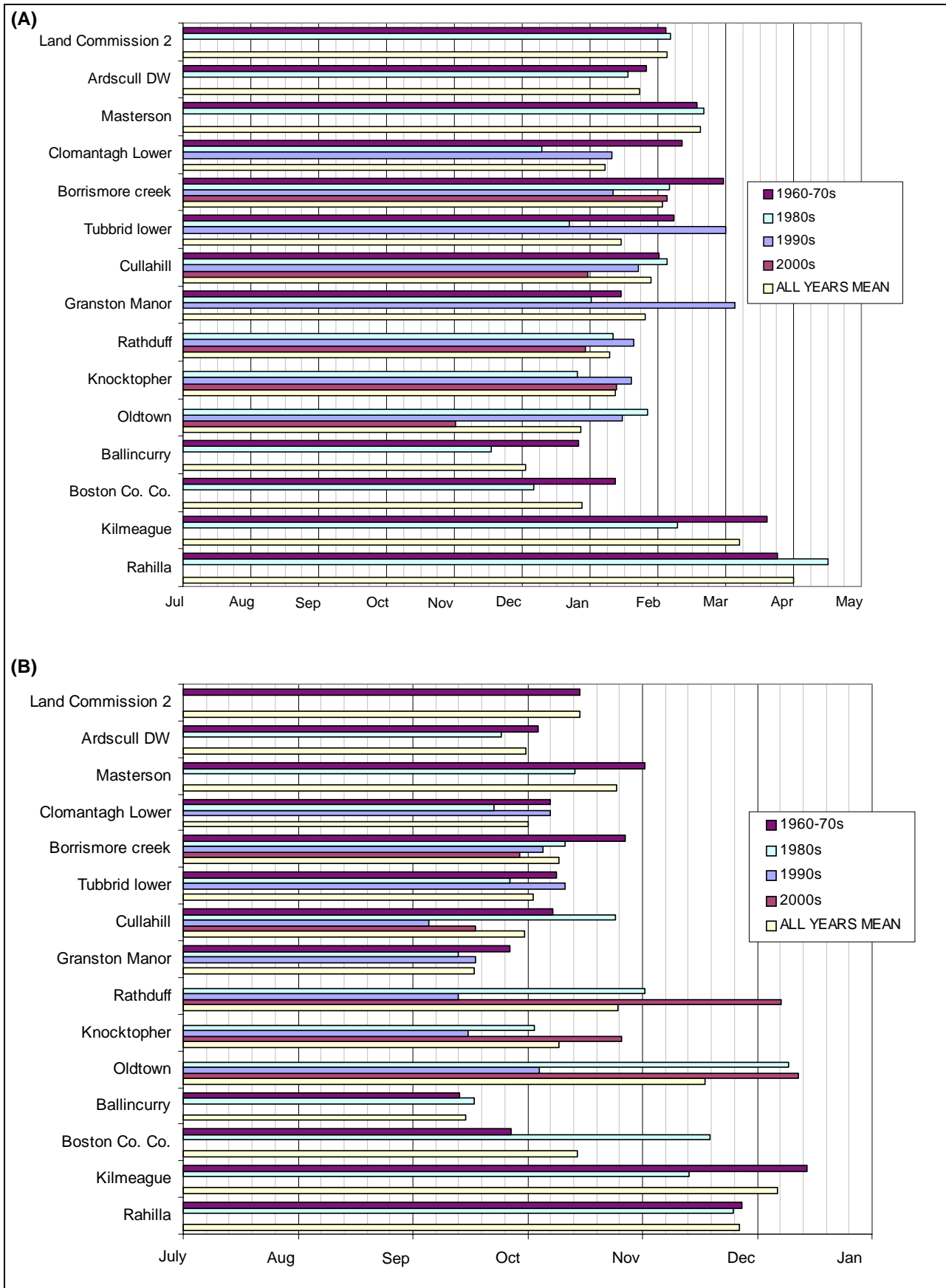


Figure 7.12. Average date of (A) groundwater level maxima and (B) groundwater level minima per decade.

with suitably long records. A comparison of the timing of maxima and minima was made for before and after the mid-1970s. The typical month was defined as the month with most turning points occurring in it; no averaging over months was conducted and only constrained turning points were included.

The results showed that there has been very little change in the timing of the groundwater level maxima for these MPs. The groundwater level minima tentatively showed a refinement in timing from a range of August to November before 1975 to a smaller range from September (one MP) to October (four of five MPs) after 1975. It should be noted that this is a basic analysis conducted with a limited data set, especially prior to 1975.

A further test was conducted to investigate any change in timing on a finer scale. The date (rather than just the month) of each constrained turning point was assessed for all 15 MPs. An average date was determined for each MP's minimum and maximum groundwater levels for the duration of the record and for each decade within the record. A consistent change in the timing of either the groundwater level maxima or minima was not observed (Fig. 7.12A and B). The results for the five MPs investigated previously did not show a refinement in the timing of the groundwater level minima. The range in the timing of turning points within one decade was generally much larger than the averaged variation in groundwater levels between decades.

7.4 Interactions between Groundwater and Surface Water

Additional analysis of the Oldtown hydrograph was conducted to investigate the groundwater–surface water interactions at this site. The MP is located in the regionally important Kilmanagh Gravel Aquifer which overlies the PI Killeshin Siltstone Formation (Namurian Shales), approximately 10 m from an unnamed tributary of the Munster River.

The geological and construction logs for the Oldtown Borehole are presented in Fig. 7.13. These logs are likely to be for the pumping well at Oldtown (Kny 18/93) as the drilling log for the observation well at Oldtown (Kny 18/92) only states “*large, medium, fine boulder*

gravel with coarse, medium sand and occasional traces of silty clay bands” and “*no samples as it is just for observation*” (GSI well records). It is expected that the geological conditions will be similar between the two boreholes.

The Oldtown hydrograph shows a number of recharge and recession periods within one hydrometric year. On a number of occasions the groundwater level annual minima plunge below the level normally reached in autumn. This is seen in 1984, 1989, 1990, 1995, 1996 and 2002 (Figs 7.5 and D.9). On closer inspection of the hydrographs, it may be seen that the point from which the water level plunges on each of these occasions is at a constant level of 116.2 maOD. This suggests that the plunging groundwater levels have a physical control. The proximity of the river and the nature of the Oldtown hydrograph suggest that this control is likely to be related to the river.

There is a weight of evidence to support the idea that the physical control is the base of the river, and that when the river runs dry the groundwater levels drop rapidly:

- 1984, 1989, 1990 and 1995 were ‘dry’ years with rainfall being much lower than average which could lead to low river flows; 1996 and 2002, however, were ‘wet’ years, where rainfall was higher than average (see Fig. 2.2).
- The EPA has two surface-water hydrometric stations near to the Oldtown MP, the details of which are outlined in Table 7.6. The stations record water level with monthly to quarterly frequency. The Ballyline station shows a number of water levels at 0 m in 1984 and 1989 (on 6 July 1984, 29 August 1984, 31 July 1989 and 28 September 1989). The Kilmanagh station does not record any zero levels but it is likely that if the water level in the larger river at Ballyline is zero then the water level at Kilmanagh is also zero. No zero levels are recorded at either station after 1989, although dry spells may not have been recorded.
- Notes on the groundwater level charts in 1984 (26 July, 19 September and 24 October), 1989 (12 August and 19 October), 1990 (11 October), 1995 (22 August and 13 October) and 1996 (24

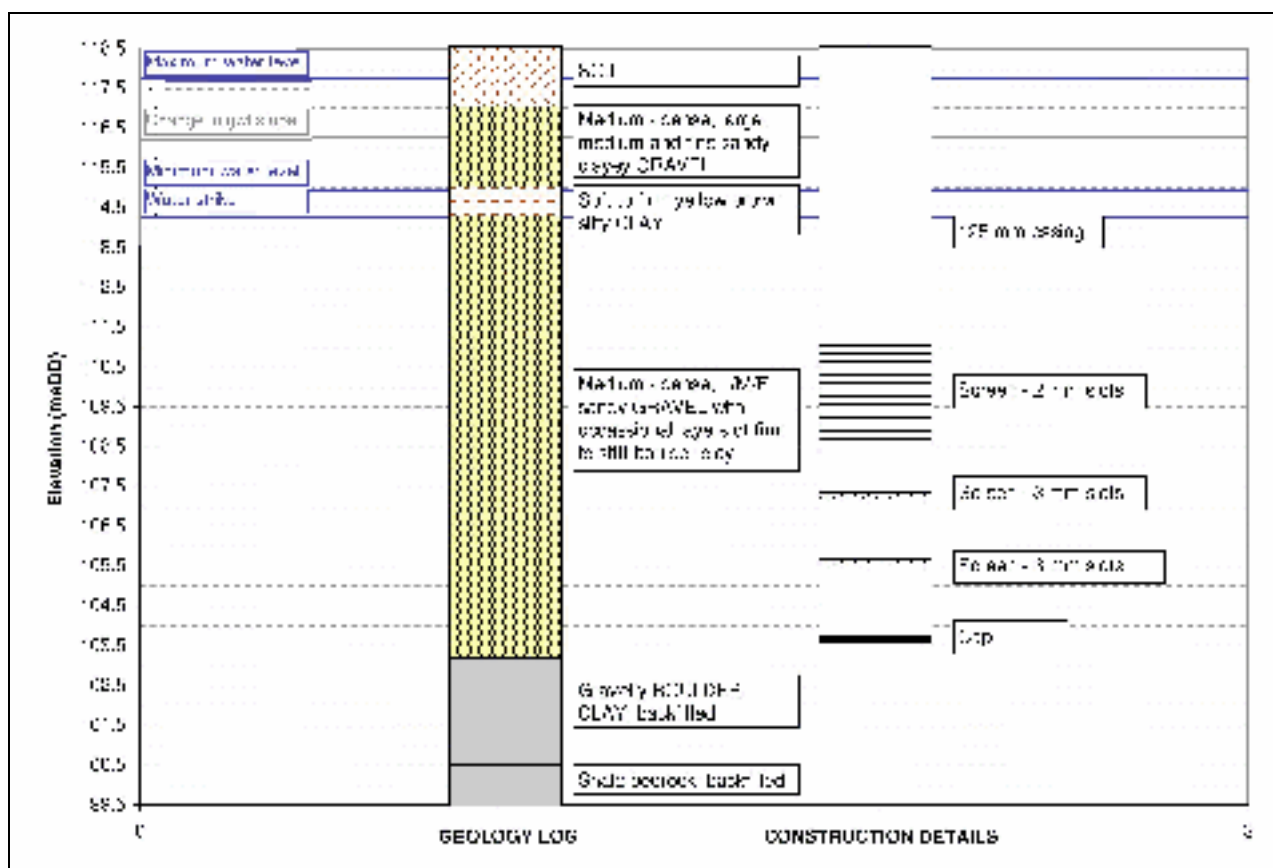


Figure 7.13. Geological and construction logs for Oldtown monitoring point.

September and 22 October) state that the river was dry. There are no similar notes in 2002. On 1 November 1984 a note states “the farmer says river dry at 10 am but there was water in it at 11.00 am”; it also notes that the river was dry “at least 200 yards downstream” of the MP. The water level is seen to increase rapidly after 1 November 1984.

- Measurements taken on 18 June 2009 are shown in Fig. 7.14. They show that the river bed is approximately 2 m below the groundwater level datum and therefore at an approximate elevation of 116.4 maOD. These measurements are very rough and therefore could be 20 cm out, thus

allowing the river bed to be at an elevation of 116.2 maOD and coincident with the level observed on the hydrograph. The most likely physical control at this level is the river bed.

7.4.1 Future data analysis

7.4.1.1 Groundwater level response to ER

A preliminary investigation into the response times of a number of hydrographs to individual storm events has been carried out. The recent data from the Woodsgift, Oldtown, Rathduff and Knocktopher Manor MPs were used, as these records are at a high resolution and are relatively continuous. The preliminary findings showed

Table 7.6. Details of hydrometric stations near to Oldtown.

Hydrometric station	Station number	X	Y	River	Distance downstream of Oldtown (km)	Water level record duration
Kilmanagh	15047	239393	152264	Tributary to Munster	2.7	1992–2000
Ballyline	15024	239200	145200	Munster	11.0	1980–2004

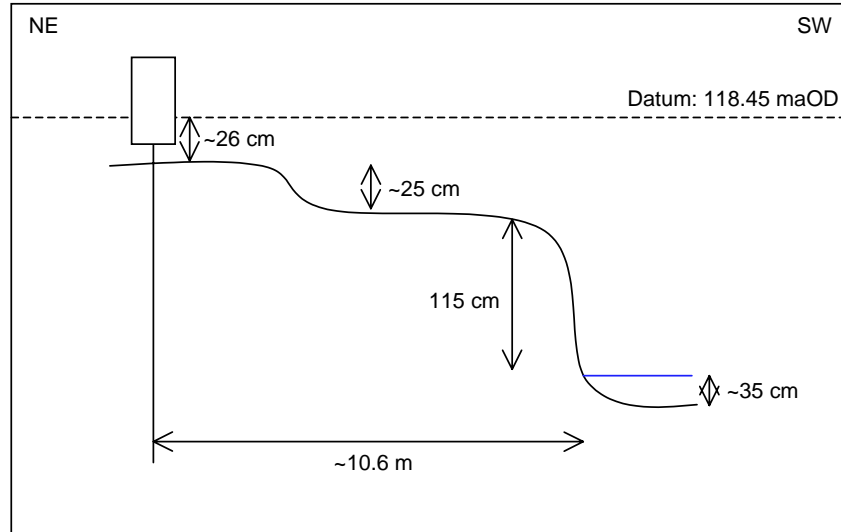


Figure 7.14. Sketched cross section of Oldtown monitoring point and adjacent river.

that the response time increased as the permeability of the subsoil decreased. Further investigations are suggested to develop the understanding of water level responses and subsoil properties.

7.4.1.2 Groundwater levels and spring discharges

The EPA is in the final stage of installing flow monitoring systems on 27 springs around the country. In the SERBD, the following springs are included in the network: Kyle, Paulstown, Pollardstown Fen and Hangedman's Arch (see Table 6.2). Once the data are available from these sites, it will be possible to analyse spring discharge with respect to groundwater levels.

7.4.1.3 Abstraction-influenced MPs

An analysis of groundwater levels influenced by abstraction is suggested. Figure 7.15 presents the

groundwater abstractions for drinking water to give an indication of which MPs are likely to be affected.

7.4.1.4 Long-term trend analysis

A visual inspection of all the SERBD historic groundwater levels for any long-term trends generally showed that there are no overall increasing, or decreasing, trends. The exception is the Oldtown hydrograph, which shows a long-term decrease in groundwater level over its duration of record from the 1980s to the present (Figs 7.5 and D.11). Time-series analysis could be conducted on hydrographs with long-term trends. This analysis may involve the use of Box-Jenkins transfer noise modelling, which allows the hydrograph to be split into a number of components related to known causes (e.g. ER, abstraction, etc.) and an unknown noise component (van Geer and Zuur, 1997).

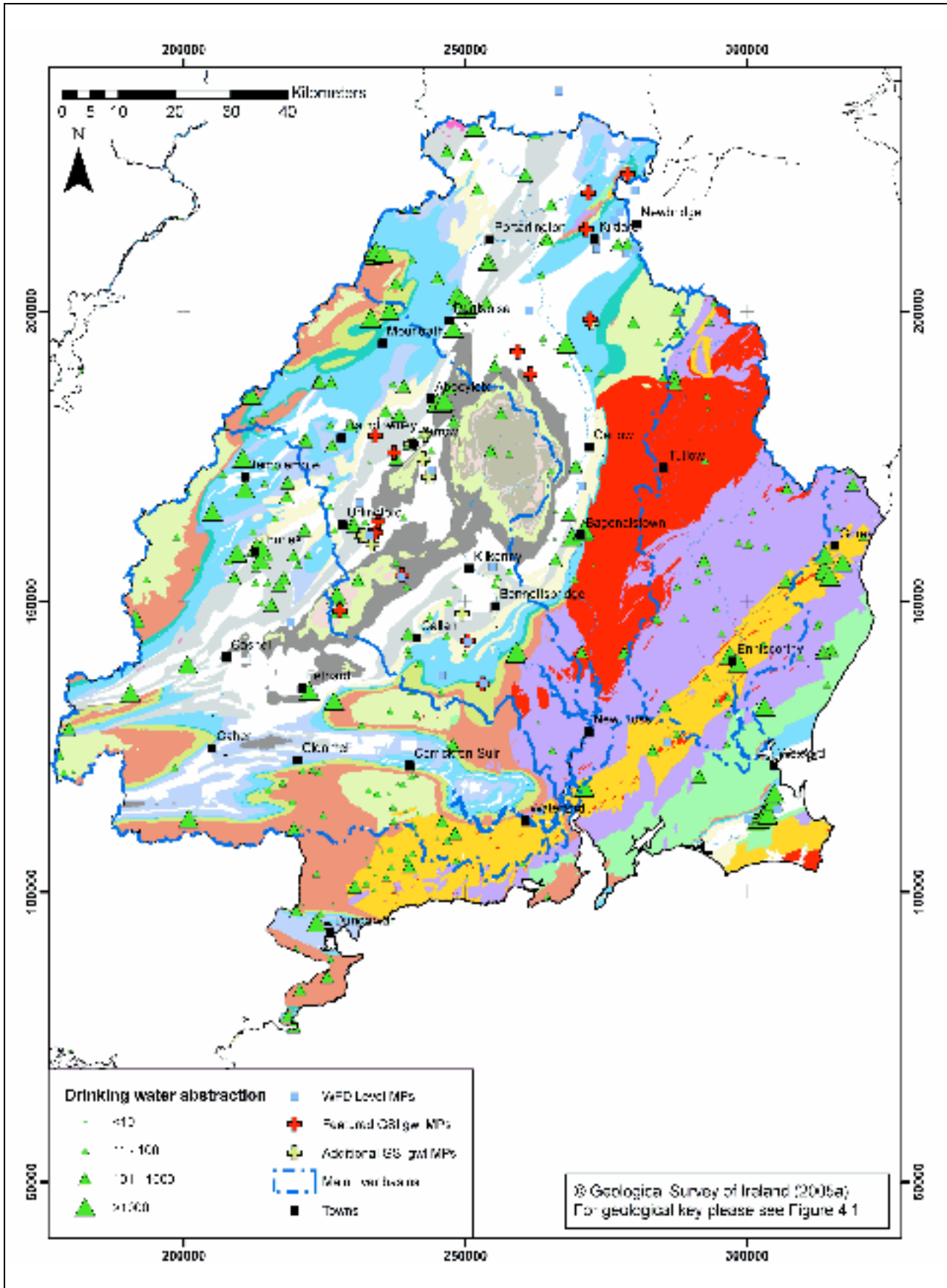


Figure 7.15. Groundwater abstractions for drinking water in the South Eastern River Basin District.

8 Summary and Recommendations

Groundwater level data have been collected in Ireland since the late-1960s. Typically, this monitoring was implemented by the GSI or local authorities, during the course of different projects. The GSI holds historical groundwater level records for over 150 MPs in 10 counties. In the 1990s, the EPA took responsibility for groundwater monitoring in Ireland. Initially, groundwater levels were dipped at approximately quarterly frequency. In 2006, the EPA set up a new national groundwater level and quality monitoring network in accordance with EU legislation, namely the WFD. This network comprises 305 MPs in all of the 26 counties of the Republic of Ireland. Groundwater level monitoring is conducted at 107 MPs in 22 counties. This report presents groundwater level monitoring data for the SERBD.

The SERBD is underlain by extremely heterogeneous strata of principally Lower Palaeozoic, Devonian and Carboniferous age, with extensive and spatially variable overlying subsoil deposits. In general, alteration, cementation and intensive structural deformation mean that groundwater flow in the bedrock is through secondary porosity and dominated by fracture flow. The groundwater flow paths are likely to be shallow, predominantly in the upper layer of the aquifer, with enhanced weathering and open fractures. However, the karstified and dolomitised limestones may have permeable zones at greater depths. In contrast to the bedrock aquifers, sand and gravel aquifers provide an opportunity for intergranular groundwater flow, which may in some cases be of regional importance. Tills are the most widespread subsoil deposit, and while they do not form aquifer units they may influence the hydraulic conditions of, and the proportion of recharge reaching, any underlying aquifers.

Groundwater level and MP information for MPs within the SERBD has been collated into a publicly available database. The hydrographs for historic MPs with suitably long records (typically greater than 10 years) have been analysed. The MPs have been divided into a number of groups based on the similarity of the

hydrographs. The grouping allows ease of discussion, and comparison within and between groups provides an opportunity for insight into hydrogeological settings. The groups are as follows:

- Upper catchment – Barrow Basin;
- Upper catchment – Nore Basin;
- Discharge dominated;
- River influenced;
- Confined;
- Abstraction influenced; and
- Gravels.

As expected, large groundwater variations are observed in MPs located in recharge zones (Land Commission 2 and Ardscull MPs), small groundwater variation in MPs influenced by surface water (Oldtown, Knocktopher Manor and Rathduff MPs) or located in discharge zones (Cullahill and Granston Manor MPs) and located in gravels (Kilmeague and Rahilla). Outside recharge and discharge zones, regionally important aquifers tend to have larger annual variations in groundwater levels than locally important aquifers.

The phenomenon of rejected recharge is observed in the hydrographs of locally important aquifers as short-term recharge and recession events are observed during winter and spring when groundwater levels are elevated. Recharge events are observed during the summer months in hydrographs from the heavily karstified Nuenna Catchment. This may be due to the influence of localised summer ER or point recharge.

The variation in medium-term groundwater level trends, i.e. over a number of annual cycles, is similar across the bedrock aquifers and is driven by temporal variations in ER. This is illustrated by particularly high or low groundwater level minima or maxima during 'marker' years.

The hydrographs for the Oldtown, Rathduff and Knocktopher MPs are grouped as being influenced by nearby rivers and may be useful MPs for further investigation of the groundwater–surface water interactions. These particular MPs are three of the four MPs which were assimilated into the EPA's current groundwater monitoring programme from the historical network. In-depth investigation into the hydrograph for Oldtown MP showed that groundwater level is controlled by the nearby river and a sharp change in behaviour is observed on the rare occasions when this control is removed, i.e. the river runs dry.

Groundwater levels in bedrock aquifers tend to reach their maximum between November and February and their minimum between September and November. The average length of the recession period for these hydrographs is just over 8 months.

The gravel aquifers show rounded hydrographs. These aquifers tend to reach their maximum and minimum groundwater levels slightly later than the bedrock aquifers: April to May and October to December, respectively. The average recession period is slightly shorter, averaging almost 7 months. The difference is likely to be due to the large intergranular storage capacity of the gravels and the effect of recharge occurring through a thick unsaturated zone.

Estimates of specific yields were made for suitable MPs using the calculated average annual groundwater level variations via the water-table fluctuation method and the methodology of Misstear et al. (2008) for estimating groundwater recharge from groundwater vulnerability mapping. The estimates were similar to estimates from literature for equivalent aquifers units.

A review of work conducted by the GSI on observed groundwater level fluctuations due to earthquakes is presented. These fluctuations were recorded because groundwater levels were recorded continuously with chart recorders. Groundwater levels recorded by digital data loggers (recording every 15 min) will not record these fluctuations.

Authors such as Steele-Dunne et al. (2008) and Kiely (1999) note an amplification of seasonal cycles in precipitation across Ireland. Kiely (1999) and Leahy et al. (in preparation) present evidence of a change point in west coast precipitation in the mid-1970s to early-1980s. There are unlikely to be suitable groundwater level records in the west of the country to allow an investigation of whether these change points are evident in groundwater. An analysis to investigate if the amplification of the seasonal cycle was evident in groundwater levels in the SERBD showed no change in the timing of groundwater level minima or maxima.

A number of potential future research areas have been recommended. An investigation into the influence of subsoil properties on hydrograph response time to individual short-term storm events is suggested. Data from the EPA's new network of spring flow monitoring systems may be used in the future to investigate the relationship between spring discharge and groundwater level. An analysis of the impact of groundwater abstractions on groundwater levels is suggested. Finally, time-series analysis could be conducted on hydrographs which show long-term trends to investigate the reasons for the trends.

References

- Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., 1998. *Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper 56. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Archer, J.B., Sleeman, A.G. and Smith, D.C., 1996. *A Geological Description of Tipperary and Adjoining Parts of Laois, Kilkenny, Offaly, Clare and Limerick – to accompany the Bedrock Geology 1:100,000 Scale Map Series; Sheet 18, Tipperary*, with contributions by K. Claringbold, G. Staley (Mineral Resources) and G. Wright (Groundwater Resources). Geological Survey of Ireland, Dublin, Ireland. 76 pp.
- Cawley, A., 1990. *The Hydrological Analysis of a Karst Aquifer System*. Unpublished M.Eng. Thesis. Department of Engineering Hydrology, University College Galway, Galway, Ireland.
- Collins, J.F., and Cummins, T., 1996. *Agroclimatic Atlas of Ireland*. AGMET. Joint Working Group on Applied Agricultural Meteorology, AGMET, Dublin, Ireland.
- Daly, D., Lloyd, J.W., Misstear, B.D.R. and Daly, E.D., 1980. Fault control of groundwater flow and hydrochemistry in the aquifer system of the Castlecomer Plateau, Ireland. *Quarterly Journal of Engineering Geology* **13**: 167–175.
- Daly, E.P., 1978. *Groundwater Investigations in County Laois in 1976*. Groundwater Division, Geological Survey of Ireland. Internal Report Number 4. Geological Survey of Ireland, Dublin, Ireland.
- Daly, E.P., 1980. *The Drilling and Testing of Two Boreholes and Groundwater Development in the Westphalian Sandstones of the Slieveardagh Hills, Co Tipperary*. Groundwater Division, Geological Survey of Ireland. Internal Report Number 7. Geological Survey of Ireland, Dublin, Ireland.
- Daly, E.P., 1981. *Case Study: The Kilmanagh River Gravels*. Groundwater Division, Geological Survey of Ireland. Geological Survey of Ireland, Dublin, Ireland.
- Daly, E.P., 1982. *The Groundwater Resources of the Southeast Industrial Development Region*. Unpublished draft report of the Geological Survey of Ireland, Dublin, Ireland.
- Daly, E.P., 1987. *Artesian Wells in South Kilkenny*. GSI Groundwater Newsletter, No. 6. Geological Survey of Ireland, Dublin, Ireland.
- Daly E.P., 1988. *The Kiltorcan Sandstone Aquifer*. Proceedings of the 8th Annual Seminar, International Association of Hydrogeologists (Irish Group), Portlaoise, Ireland.
- Daly, E.P., 1990. *The Likely Effects of Significant Climatic Changes on the Flow Regime in the Principal Irish Aquifers*. Proceedings of 10th Annual Seminar, International Association of Hydrogeologists (Irish Group), Portlaoise, Ireland.
- Daly, E.P., 1993. *Hydrogeology of the Dolomite Aquifer in the Southeast of Ireland*. Proceedings of 13th Annual Seminar, International Association of Hydrogeologists (Irish Group), Portlaoise, Ireland.
- Daly, E.P., 1994. *Groundwater Resources of the Nore River Basin*. Geological Survey of Ireland Report Series RS 94/1 (Groundwater). Geological Survey of Ireland, Dublin, Ireland.
- DELG/EPA/GSI, 1999. *Groundwater Protection Schemes*. Department of the Environment and Local Government, Environmental Protection Agency and Geological Survey of Ireland, Ireland.
- European Commission, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action the field of water resources. *Official Journal of the European Union*. L327.
- Freeze, A.R. and Cherry, J.A., 1979. *Groundwater*. Prentice-Hall, NJ, USA.
- Fitzsimons, V.P. and Misstear, B.D.R., 2006. Estimating groundwater recharge through tills: a sensitivity analysis of soil moisture budgets and till properties in Ireland. *Hydrogeology Journal* **14**: 548–561.
- GSI (Geological Survey of Ireland), 1995. *Geology of Carlow – Wexford*. Sheet 19. Scale 1:100,000. Geological Survey of Ireland, Dublin, Ireland.
- GSI (Geological Survey of Ireland), 1996. *Geology of Tipperary*. Sheet 19. Scale 1:100,000. Geological Survey of Ireland, Dublin, Ireland.
- GSI (Geological Survey of Ireland), 2002. *County Kilkenny Groundwater Protection Scheme. Volume II: Source Protection Zones*. Geological Survey of Ireland, Dublin, Ireland.
- GSI (Geological Survey of Ireland), 2004. *County Kildare Groundwater Protection Scheme. Volume II: Source Protection Zones*. Geological Survey of Ireland, Dublin, Ireland.
- GSI (Geological Survey of Ireland), 2005a. *Grouped Rock Units. Scale 1:100,000*. Geological Survey of Ireland, Dublin, Ireland.
- GSI (Geological Survey of Ireland), 2005b. *National Draft Gravel Aquifer Map. Scale 1:100,000*. Geological Survey of Ireland, Dublin, Ireland.

- GSI (Geological Survey of Ireland), 2006. *National Draft Bedrock Aquifer Map. Scale 1:100,000*. Geological Survey of Ireland, Dublin, Ireland.
- GSI (Geological Survey of Ireland), 2008a. *Provisional Subsoil Permeability Map. Scale 1:100,000*. Geological Survey of Ireland, Dublin, Ireland.
- GSI (Geological Survey of Ireland), 2008b. *Provisional Subsoil Vulnerability Map. Scale 1:100,000*. Geological Survey of Ireland, Dublin, Ireland.
- GSI/Teagasc/EPA (Geological Survey of Ireland/Teagasc/Environmental Protection Agency), 2006. *Subsoil Map of Ireland. Scale 1:150,000*.
- Hayes, T., Sutton, S., Cullen, K. and Faherty, J., 2001. *The Curragh Aquifer: Current Conceptual Understanding and Numerical Modelling*. Proceedings of the 21st Annual Seminar, International Association of Hydrogeologists (Irish Group), Tullamore, Ireland.
- Healy, R.W. and Cook, P.G., 2002. Using groundwater levels to estimate recharge. *Hydrogeology Journal* **10**: 91–109.
- Keane, T. and Collins, J.F., 2004. *Climate, Weather and Irish Agriculture*. Joint working group on Applied Agricultural Meteorology, Dublin, Ireland.
- Kiely, G., 1999. Climate change in Ireland from precipitation and streamflow observations. *Advances in Water Resources* **23**: 141–151.
- Kiely, G., Leahy, P., Ludlow, F., Stefanini, B., Reilly, E., Monk, M. and Harris, J., 2010. *Extreme Weather, Climate and Natural Disasters in Ireland*. Climate Change Research Programme (CCRP) 2007–2013. Report Series No. 5. Environmental Protection Agency, Johnstown Castle Estate, Wexford, Ireland.
- Leahy, P., Ludlow, F., Stefanini, B., Reilly, E., Monk, M. and Harris, J. (in preparation). *Extreme Weather, Climate and Natural Disasters in Ireland*. Environmental Protection Agency, Johnstown Castle estate, Wexford, Ireland.
- McConnell, B., Philcox, M.E., Sleeman, A.G., Stanley, A.M., Flegg, E.P. and Warren, W.P., 1994. *A Geological Description to ACCOMPANY the Bedrock Geology 1:100,000 Map Series, Sheet 16, Kildare – Wicklow*. Geological Survey of Ireland, Dublin, Ireland.
- McConvey, P., 2005. *Northern Ireland Groundwater Monitoring Detects Tsunami Earthquake*. GSI Groundwater Newsletter, No. 45. Geological Survey of Ireland, Dublin, Ireland.
- Misstear, B.D.R. and Fitzsimons, V., 2007. Estimating groundwater recharge in fractured bedrock aquifers in Ireland. In: Krasny, J. and Sharp, J. (Eds) *Groundwater in Fractured Rocks* (Chapter 16). Special Publication 9 of the International Association of Hydrogeologists, Taylor & Francis, London, UK. pp. 243–257.
- Misstear, B.D.R. and Brown, L., 2008. *Recharge and Groundwater Vulnerability*. ERTDI Programme 2000–2006 Phase 3: Water Framework Directive. Environmental Protection Agency, Johnstown Castle estate, Wexford, Ireland.
- Misstear, B.D.R., Brown, L. and Daly, D., 2008. A methodology for making initial estimates of groundwater recharge from groundwater vulnerability mapping. *Hydrogeology Journal* **17(2)**: 275–285.
- Misstear, B.D.R., Brown, L. and Johnston, P.M., 2009. Estimation of groundwater recharge in a major sand and gravel aquifer in Ireland using multiple approaches. *Hydrogeology Journal* **17**: 693–706.
- Misstear, B.D.R., Daly, E.P., Daly, D. and Llyod, J.W., 1980. *The Groundwater Resources of the Castletomer Plateau*. Geological Survey of Ireland Report Series RS 80/3 (Groundwater). Geological Survey of Ireland, Dublin, Ireland.
- O'Sullivan, B.E., 1992. *The Status and Potential of Large Groundwater Abstractions*. Proceedings of 12th Annual Seminar, International Association of Hydrogeologists (Irish Group), Portlaoise, Ireland.
- Robins, N.S. and Misstear, B.D.R., 2000. *Groundwater in the Celtic Regions: Studies in Hard Rock and Quaternary Hydrogeology*. Geological Society, Special Publication No. 182. pp. 5–17. The Geological Society, London, UK.
- Scanlon, B.R., Healy, R.W. and Cook, P.G., 2002. Choosing appropriate techniques for quantifying groundwater recharge. *Hydrogeology Journal* **10**: 18–39.
- Schulte, R.P.O., Diamond, J., Finkle, K., Holden, N.M. and Berereton, A.J., 2005. Predicting the soil moisture conditions of Irish grasslands. *Irish Journal of Agricultural and Food Research* **44**: 95–110.
- SNIFFER (Scotland and Northern Ireland Forum for Environmental Research), 2003. *Derivation of a Methodology for Groundwater Recharge Assessment in Scotland and Northern Ireland*. Final Report. Scotland and Northern Ireland Forum for Environmental Research. Entec UK Ltd, UK.
- Steele-Dunne, S., Lynch, P., McGrath, R., Semmler, T., Wang, S., Hanafin, J., and Nolan, P., 2008. The impacts of climate change on hydrology in Ireland. *Journal of Hydrology* **356**: 28–45.
- Tietzsch-Tyler, D., Sleeman, A.G., McConnell, B.J., Daly, E.P., Flegg, A.M., O'Connor, P.J. and Warren, W.P., 1994. *Geology of Carlow–Wexford*. A geological description to accompany the Bedrock Geology 1:100,000 Scale Map Series; Sheet 19, Carlow – Wexford. Geological Survey of Ireland, Dublin, Ireland, 58 pp.
- van Geer, F.C. and Zuur, A.F., 1997. An extension of

- Box–Jenkins transfer/noise models for spatial interpolation of groundwater head series. *Journal of Hydrology* **192**: 65–80.
- Ward, F., 1993. *Groundwater levels in the Rahilla Observation Well from 1969–1979*. Groundwater Division, Geological Survey of Ireland, Dublin, Ireland. Internal Report.
- Working Group on Groundwater, 2005. *Water Framework Directive (WFD) Pressures and Impacts Assessment Methodology: Guidance on the Assessment of the Impact of Groundwater Abstractions*. Geological Survey of Ireland, Environmental Protection Agency and River Basin Districts Coordinating Authorities, Dublin, Ireland.
- Wright, G.R., 1988. *The Mid-Kildare Gravel Aquifer*. Proceedings of 8th Annual Seminar, International Association of Hydrogeologists (Irish Group), Portlaoise, Ireland.
- Wright, G.R., 1994. *The Development of a National Groundwater Level Monitoring Programme in the Republic of Ireland*. Groundwater section, Geological Survey of Ireland, Dublin, Ireland. Internal Report.
- Wright, G., 2005 *Earthquakes and Groundwater Level Records in Ireland*. GSI Groundwater Newsletter, No. 45. Geological Survey of Ireland, Dublin, Ireland.

Websites

- www.epa.ie – Environmental Protection Agency
- www.wfdireland.ie – Water Framework Directive in Ireland
- www.met.ie – Met Éireann
- <http://www.met.ie/climate/agri-meteo-data.asp>; consulted on 20 July 2009
- www.gsi.ie – Geological Survey of Ireland
- <http://www.gsi.ie/NR/rdonlyres/3997D698-F11E-4506-BF6E-1C61C0BA8B4E/0/BarrowValley.pdf>; Barrow Valley Sands and Gravels Groundwater Body description; consulted on 22 January 2010.

Acronyms

AE	Actual evapotranspiration
EPA	Environmental Protection Agency
ER	Effective rainfall
EU	European Union
FAO	Food and Agriculture Organization
GSI	Geological Survey of Ireland
Ks	Water stress factor
LTA	Long-term average
maOD	Metres above Ordnance Datum
MPs	Monitoring points
OSi	Ordnance Survey Ireland
PE	Potential evapotranspiration
RAW	Readily available water
SERBD	South Eastern River Basin District
SMD	Soil moisture deficit
TAW	Total available water
TCD	Trinity College Dublin
WFD	Water Framework Directive

Appendix A Index of Geological Formations and Rock Units

Table A.1. Index of geological formations and rock units.

Rock unit	Formation name, aquifer category
Permo-Triassic Sandstones	Killag Formation, LI
Westphalian Sandstones	Clay Gall Sandstone Formation, Lm Lickfinn Coal Formation, Lm Swan Sandstone Member, Lm
Westphalian Shales	Coolbaun Formation, Pu Moyadd Coal Formation, Pu
Namurian Shales	Giants Grave Formation, PI Killeshin Siltstone Formation, PI Lackantedane Formation, LI Luggacurren Shale Formation, Pu Moanour Formation, LI
Namurian Sandstones	Bregaun Flagstone Formation, PI
Namurian Undifferentiated	Farranacliff Formation, LI Namurian (undifferentiated), LI Shrough Formation, LI
Dinantian Sandstones	Cloghan Sandstone Formation, Lm
Dinantian Pure Bedded Limestones	Allenwood Formation, Lk Allenwood Formation, Rkd Ballyadams Formation, Lk Ballyadams Formation, Rkd Ballyglasheen Oolite Formation, Lm Bullockpark Bay Member, Lm Clogrenan Formation, Lk Clogrenan Formation, Rkd Crosspatrick Formation, Lm Edenderry Oolite Member, Lm Fortwilliam Oolite Member, Lm Hore Abbey Limestone Formation, Rkd Johnstown Red Marble Formation, Rkd Kilsheelan Formation, Rkd Knockordan Limestone Formation, Lk Knockordan Limestone Formation, Rkd Lisduff Oolite Member, Lm Milford Formation, Rkd Rickardstown Formation, Rkd Silverspring Formation, Rkd Suir Limestone Formation, Lk Suir Limestone Formation, Rkd Wexford Formation, Rkd Wexford Formation, Unclassified

Table A.1 *contd.*

Rock unit	Formation name, aquifer category
Dinantian Upper Impure Limestones	Aghmacart Formation, LI
	Athassel Limestone Formation, LI
	Butlersgrove Formation, LI
	Calp, LI
	Calp, Lm
	Croane Formation, LI
	Durrow Formation, LI
	Lagganstown Formation, LI
	Lucan Formation, LI
	Lucan Formation, Lm
	Visean Limestones (undifferentiated), LI
	Visean limestones, undifferentiated, LI
	Dinantian Dolomitised Limestones
Ballysteen Formation and dolomitisation, Lk	
Ballysteen Formation and dolomitisation, Rkd	
Bullockpark Bay Member and dolomitisation, Lk	
Butlersgrove Formation and dolomitisation, Lk	
Butlersgrove Formation and dolomitisation, Rkd	
Crosspatrick Formation, Rkd	
Milford Formation and Dolomitisation, Rkd	
Waulsortian Limestones, Lk	
Waulsortian Limestones, Rkd	
Dinantian Pure Unbedded Limestones	Clogrenan Formation and Mudbank limestone, Rkd
	Mudbank limestone, Lk
	Rathronan Formation, Rkd
	Waulsortian Limestones, Lk
	Waulsortian Limestones, LI
	Waulsortian Limestones, Rkd
	Waulsortian Limestones, Unclassified
Dinantian Lower Impure Limestones	Ballymartin Formation, LI
	Ballymartin Formation, Lm
	Ballymartin Formation, Rf
	Ballynash Member, LI
	Ballysteen Formation, LI
	Ballysteen Formation, Lm
	Ballysteen Formation, Rf
	Boston Hill Formation, LI
Dinantian (early) Sandstones, Shales and Limestones	Crows Point Formation, LI
	Feighcullen Formation, LI
	Ferbane Mudstone Formation, PI
	Lower Limestone Shale, PI
	Porters Gate Formation, LI
	Porters Gate Formation, Rf
	Quinagh Formation, PI
	Ringmoylan Formation, PI

Table A.1 contd.

Rock unit	Formation name, aquifer category	
Devonian Kiltorcan-type Sandstones	Clonaslee Member, Rf	
	Kiltorcan Formation, Rf	
Devonian Old Red Sandstones	Ardane Formation, LI	
	Ardmore Member, LI	
	Ballyquinn Member, LI	
	Ballytrasna Formation, LI	
	Beenlea Head Member, LI	
	Brownstown Head Member, LI	
	Cadamstown Formation, LI	
	Cappagh White Sandstone Formation, LI	
	Carrigmaclea Formation, LI	
	Comeragh Conglomerate Sandstone Group, Rf	
	Coumaraglin Formation, LI	
	Coumshingaun Conglomerate Formation, LI	
	Croughaun Formation, LI	
	Devilsbit Formation, LI	
	Duncormick Formation, LI	
	Galtymore Formation, LI	
	Gyleen Formation, LI	
	Harrylock Formation, LI	
	Helvick Formation, LI	
	Kilnafrehan Conglomerate Formation, LI	
	Knockavellish Member, LI	
	Devonian Old Red Sandstones contd	Knockmealdown Sandstone Formation, LI
		Lough Muskry Formation, LI
Mine Head Member, LI		
Old Red Sandstone (undifferentiated), LI		
Oldtown Bay Formation, LI		
Pigeon Rock Formation, LI		
Poulgrania Sandstone Formation, LI		
Sheskin Formation, LI		
Slievenamuck Conglomerate Formation, LI		
Templetown Formation, LI		
Treanearla Formation, LI		
Silurian Metasediments and Volcanics	Ahenny Formation, PI	
	Assaroola Member, LI	
	Ballindysert Formation, LI	
	Ballyhest Member, PI	
	Brownstown Member, PI	
	Capard Formation, PI	
	Carrighill Formation, Pu	
	Garryduff Formation, PI	
	Glen Ding Formation, Pu	
	Hollyford Formation, PI	
	Inchacoomb Formation, LI	

Table A.1 *contd.*

Rock unit	Formation name, aquifer category
Silurian Metasediments and Volcanics <i>contd</i>	Kilclooney Member, PI
	Pollaphuca Formation, PI
	Rathclarish Formation, PI
	Slate Quarries Formation, Pu
	South Lodge Formation, PI
	Tipperkevin Formation, PI
Ordovician Metasediments	Arthurstown Member, PI
	Askingarran Formation, PI
	Ballinatray Formation, PI
	Ballybeg Member and Intermediate volcanics, PI
	Ballybeg Member, LI
	Ballybro Formation, PI
	Ballyhack Member and Intermediate volcanics, PI
	Ballyhack Member and Intermediate volcanics, Rf
	Ballyhack Member, PI
	Ballyhack Member, Rf
	Ballyhoge Formation, PI
	Ballylane Formation and Intermediate volcanics, PI
	Ballylane Formation, PI
	Ballyneale Member and Intermediate volcanics, PI
	Ballyneale Member, LI
	Brownsford Member, LI
	Butter Mountain Formation, LI
	Carrighalia Formation, Rf
	Courtown Formation, PI
	Dunmurry Formation, PI
	Garraun Member, PI
	Garraun Member, Rf
	Grahormack Formation, PI
	Grange Hill Formation, PI
	Guidenstown Formation, PI
	Kilcarry Member, LI
	Kildare Limestone Formation, PI
	Kilmacrea Formation and Felsic volcanics, PI
	Kilmacrea Formation, LI
	Loftusacre Member, PI
	Maulin Formation and Intermediate volcanics, LI
	Maulin Formation, LI
	Milltown Formation, PI
Monaughrim Member and Intermediate volcanics, PI	
Monaughrim Member, LI	
Moneyteige Member, PI	
Muggorts Bay Formation, PI	
Newtown Head Member and Felsic volcanics, PI	
Oaklands Formation, LI	
Oaklands Formation, Rf	
Oldcourt Member, LI	

Table A.1 *contd.*

Rock unit	Formation name, aquifer category
Ordovician Metasediments <i>contd</i>	Palace Member, PI
	Rahilla Formation, PI
	Riverchapel Formation, PI
	Ross Member and Intermediate volcanics, Rf
	Seamount Formation, PI
	Shale units, Rf
	Tramore Limestone Formation and Felsic volcanics, Rf
	Tramore Limestone Formation, PI
	Tramore Limestone Formation, Rf
	Tramore Shale Formation, PI
	Tramore Shale Formation, Rf
	Tuskar Group, PI
Ordovician Volcanics	Allen Andesite Formation, PI
	Ballynaclogh Formation and Intermediate volcanics, Rf
	Ballynaclogh Formation, Rf
	Bunmahon Formation, Rf
	Campile Formation and Intermediate volcanics, Rf
	Campile Formation and Felsic volcanics, Rf
	Campile Formation, Rf
	Clashabeema Formation, Rf
	Courtown Formation and Felsic volcanics, PI
	Donard Andesite Member, LI
	Donard Andesite Member, PI
	Dunabrattin Formation, Rf
	Kilmacthomas Formation and Intermediate volcanics, Rf
	Kilmacthomas Formation, Lm
	Kilmacthomas Formation, Rf
	Newtown Head Member, PI
	Rhyolite, Rf
	Ross Member, Rf
Cambrian Metasediments	Ardenagh Formation, PI
	Ballycogly Group, PI
	Ballynacarrig Member, PI
	Booley Bay Formation, PI
	Cahore House Formation, PI
	Cahore Point Formation, PI
	Carricktriss Formation, PI
	Conlanstown Formation, PI
	Cross Lake Formation, PI
	Cullenstown Formation, PI
	Cullentra Formation, PI
	Glascarrig Formation, PI
	Kiln Bay Formation, PI
	Newtown Formation, PI
	Poll-darrig Formation, PI
	Roney Formation, PI
	Shelmaliere Formation, PI

Table A.1 *contd.*

Rock unit	Formation name, aquifer category
Precambrian Quartzites, Gneisses and Schists	Greenore Point Group, PI
	Kilmore Quay Group, PI
Granites and Other Igneous Intrusive rocks	Andesite, Rf
	Aplite, PI
	Appinite, PI
	Ballynamuddagh Granite, PI
	Carnsore Granite, PI
	Carrawaystick Aplite, PI
	Croghan Kinshelagh Granite, PI
	Diorite, PI
	Diorite, Rf
	Dolerite, PI
	Dolerite, Rf
	Feldspar porphyry, Rf
	Gabbro, Rf
	Glen of Imaal Quartz-diorite, PI
	Graiguenamanagh Granite Gneiss, PI
	Granite (undifferentiated), PI
	Granite (undifferentiated), Rf
	Percys Table Granodiorite, PI
	Saltees Granite, PI
	Serpentine, PI
	Type 1 Granite, PI
	Type 1 granodiorite, PI
	Type 2 Equigranular Granite, LI
	Type 2 Equigranular Granite, PI
	Type 2 Equigranular Granite, Rf
	Type 2 Microcline Porphyritic Granite, PI
Type 2 Sparsely Porphyritic Granite, PI	
Type 2p microcline porphyritic, PI	
Basalts and Other Volcanic Rocks	Agglomerate, Lm
	Basalt, Lm
	Carrigduff Volcanic Member, LI
	Coolnahorna Volcanic Member, LI
	Porphyritic rhyolite, LI
	Volcanics (undifferentiated), LI
	Volcanics (undifferentiated), Lm
Key to aquifer types:	
R, Regionally Important Aquifers; Rk, Karstified bedrock; Rf, Fissured bedrock; Rg, Extensive sand & gravel.	
L, Locally Important Aquifers; Lm, Bedrock which is Generally Moderately Productive; LI, Bedrock which is Moderately Productive only in Local Zones; Lg, Sand & gravel.	
P, Poor Aquifers; PI, Bedrock which is Generally Unproductive except for Local Zones; Pu, Bedrock which is Generally Unproductive.	

Appendix B

Table B.1. Summary of the Geological Survey of Ireland historic groundwater level monitoring.

County	Site	Type	6" sheet	Geodata Td	GSI well name	Recorder no.	NGR	Easting	Northin g	Date started	Date ended	Operator	Remarks	Easting 6 fig	Northing 6 fig	Accuracy
Kildare	Ardscull BH	B	31	Rathgrumly	2619SWW424					1 9-Jul-69	1 7-Apr-76	GSI				
Kildare	Ardscull DW	D	31	Rathgrumly	2619SWW436					2 9-Jul-69	2 13-Oct-90	GSI				
Kildare	Nicholastown	D	28	Nicholastown	2619NEW397					3 31-Oct-68	3 13-Oct-90	GSI				
Kildare	Eyrefield	D	28	Kineagh	2621SEW415					4 28-Nov-73	4 14-Jul-88	GSI				
Kildare	Rahilla	D	22	Loughandys	2621SWW288					5 11-Nov-68	5 1-Oct-87	GSI				
Kildare	Kilmeague	B	13	Mylerstown	2621NEW126					6 10-Jun-70	6 14-Jul-88	GSI				
Kildare	Boston (Sullivan)		17	Bostoncommon						7 10-Jun-70	7 17-Nov-71	GSI				
Kildare	Boston (Murphy)		17	Bostoncommon						8 24-Jun-70	8 12-Aug-71	GSI				
Kildare	Boston (Co. Council)	D	17	Bostoncommon	2621NWW281					9 22-Apr-70	9 28-Aug-85	GSI				
Kildare	Eadestown (1) (DW)	D	24	Newtown Baltracey	2921SWW248					10 25-Nov-68	10 1-Oct-87	GSI				
Kildare	Eadestown (2) (BH)	B	24	Newtown Baltracey	2921SWW247					11 2-Jun-70	11 1-Jun-79	GSI				
Kildare	Eadestown (3) Murren (BH)	B	24							12 12-Sep-69	12 7-Oct-71	GSI				
Kildare	Gormanstown									13 6-Jan-71	13 20-Feb-80	GSI				
Kildare	Grangebeg									14 11-Mar-71	14 6-Oct-76	GSI				
Kilkenny	Kny 3/8		3							May-72	Sep-76	GSI				
Kilkenny	Kny 4/3	B	4	Ballynaslee	2317SWW416		S 426 746			Sep-72	Sep-76	GSI				
Kilkenny	Kny 4/6	B	4	Ballyconra	2317SWW421		S 435 715			Oct-72	Jan-74	GSI				
Kilkenny	Kny 7/5	D	7	Baunmore	2015NEW105					Dec-71	Mar-74	GSI				
Kilkenny	Kny 8/17	D	8	Rathlogan	2315NWW085					Dec-71	Sep-76	GSI				
Kilkenny	Kny 8/18	D	8	Donaghmore Upper	2315NWW012					Dec-71	Apr-79	GSI				
Kilkenny	Kny 8/22	D	8	Baunballinlough	2017SEW317					Dec-71	Apr-79	GSI				
Kilkenny	Kny 9/13	D	9	Rathbeagh	2315NWW098	45540				Dec-71	Apr-79	GSI	Recorder only from October 1976			
Kilkenny	Kny 12/8, Woodsgift	B	12	Woodsgift	2315NWW046	37781	S 331 614	23322	16145	Jul-74	Still operating	GSI/OPW	Recorder only from August 1975			
Kilkenny	Kny 12/27	D	12	Glenreagh	2315NWW139			23151	16138	Aug-71	Sep-76	GSI				
Kilkenny	Kny 12/28	B	12	Forekill	2315NWW044	37796	S 320 614			Jul-74	Aug-80	GSI	Recorder only from August 1975			
Kilkenny	Kny 12/32	D	12	Kildrinagh	2315SWW019			23355	15988	Aug-71	Sep-76	GSI				
Kilkenny	Kny 12/34	B	12	Tubbrid Lower	2315NWW056	37797	S 342 620	23423	16192	Aug-71	Dec-91	GSI	Recorder only from August 1975			
Kilkenny	Kny 13/10	D	13	Garrigeen	2315NWW166					Aug-71	Sep-76	GSI				
Kilkenny	Kny 13/26	B	13	Rathealy	2315NWW071					Aug-71	Sep-76	GSI				

Table B.1 contd.

County	Site	Type	6" sheet	Geodata Td	GSI well name	Recorder no.	NGR	Easting	Northin g	Date started	Date ended	Operator	Remarks	Easting 6 fig	Northing 6 fig	Accuracy
Kilkenny	Kny 13/42, Clomantagh L.	B	13	Clomantagh Lower	2315NWW057	37795	S 346 638	234600	163800	Jul-74	Oct-94	GSI	Recorder only from August 1975			
Kilkenny	Kny 14/18	B	14	Mohill						24-Sep-71	25-Apr-74	GSI				
Kilkenny	Kny 14/22	D	14	Jenkinstown						10-May-72	28-Sep-76	GSI				
Kilkenny	Kny 14/23	B	14	Jenkinstown						24-Jan-72	11-Sep-80	GSI				
Kilkenny	Kny 18/27	D	18	Kilmanagh	2315SEW137					Oct-71	Sep-76	GSI				
Kilkenny	Kny 18/28	D	18	Tullaroan	2315SWW091					Oct-71	Sep-76	GSI				
Kilkenny	Kny 18/87	B	18	Michael's Church	2315SWW162					Jul-77	Apr-79	GSI				
Kilkenny	Kny 18/92, Oldtown	B	18	Oldtown	2315SWW234	56310	S 388 546	238800	154600	Aug-80	Still operating	GSI/OPW	Recorder from beginning			
Kilkenny	Kny 20/1	D	20	Flagmount/Ballyquirk	2615SWW021					Aug-71	Oct-73	GSI				
Kilkenny	Kny 20/18	B	20	Dunbell Big	2315SEW264					Aug-71	Sep-76	GSI				
Kilkenny	Kny 20/33	D	20	Sraghgaddy	2615SWW025					Jul-71	Dec-73	GSI				
Kilkenny	Kny 22/71	D	22	Knockeenbaun	2315SWW048					Jul-71	Sep-74	GSI				
Kilkenny	Kny 22/122	D	22	Lakyle	2313NWW220					Jul-77	Apr-79	GSI				
Kilkenny	Kny 23/47	D	23	Rathclogh	2313NEW038					Jan-72	Sep-76	GSI				
Kilkenny	Kny 23/55	B	23	Dundaryark	2313NEW026					Mar-72	Oct-73	GSI				
Kilkenny	Kny 23/57	B	23	Graigue Upper	2313NEW023		S 495 480			Apr-72	Nov-80	GSI	Recorder from July 1976			
Kilkenny	Kny 24/25	D	24	Kilmanaheen (Dungarvan)	2613NWW008					Jan-72	Sep-76	GSI				
Kilkenny	Kny 27/48	B	24	Garrynamann Upper	2313NEW094					Jul-71	Sep-76	GSI				
Kilkenny	Kny 27/58, Rathduff, Kells	B	27	Rathduff (Bayley)	2313NEW118	45537	S 505 433	250500	143300	Aug-81	Still operating	GSI/OPW	Recorder from beginning			
Kilkenny	Kny 30/16	D	30	Garryricken	2313SWW117					Mar-72	Sep-76	GSI				
Kilkenny	Kny 30/17	D	30	Coolaghmore	2313SWW133					Mar-72	Oct-74	GSI				
Kilkenny	Kny 31/47	D	31	Rossenarra	2313SEW149					Mar-72	Sep-76	GSI				
Kilkenny	Kny 31/48	D	31	Dunnamaggan West	2313SEW003					Mar-72	Sep-76	GSI				
Kilkenny	Kny 31/72	B	31	Knocktopher Manor	2313SEW061	56304	S 531 358	253100	135800	Aug-80	Still operating	GSI/OPW	Recorder from beginning			
Kilkenny	Kny 42/35	B	42	Filbuckstown						27-Jul-71	10-Oct-73					
Kilkenny	Kny 42/36		42	Fiddown						30-Dec-71	10-Oct-73	GSI				
Kilkenny	Kny 45/5	D	45							16-May-72	10-Oct-73	GSI				
Kilkenny	Kny 46/2	B	46	Mountneill	2311SEW177					Jul-71	Oct-73	GSI				
Kilkenny	Urlingford Watershed (40#)			(various)						Jul-74	Sep-76	GSI				
Kilkenny	Killahy Sheepdip Weir	Weir				37798				Oct-75	Jun-81	GSI	Stream flow – recorder from beginning			
Kilkenny	Borrismore Creek Weir	Weir				25502				Jan-78	Oct-81	GSI	Stream flow – recorder from beginning			

Table B.1 contd.

County	Site	Type	6" sheet	Geodata Td	GSI well name	Recorder no.	NGR	Easting	Northin g	Date started	Date ended	Operator	Remarks	Easting 6 fig	Northing 6 fig	Accuracy
Laois	Masterson	D	25	Corbally						17-Nov-70	13-Oct-90	GSI				
Laois	Land Commission #2	B	19	Ballintlea						6-Jul-71	9-Jan-81	GSI				
Laois	Byrne									5-Jul-73	4-Oct-73	GSI				
Laois	Moore									25-Nov-70	5-Apr-78	GSI				
Laois	Ls 16/1		16	Aghafin						Oct-73	Sep-76	GSI				
Laois	Ls 21/1		21							Oct-73	Sep-76	GSI				
Laois	Ls 22/2		22							Oct-73	Sep-76	GSI				
Laois	Ls 23/1	D	23	Derrykearn	2317NWW151					Oct-73	Sep-76	GSI				
Laois	Ls 27/1		27							Oct-73	Sep-76	GSI				
Laois	Ls 28/1		28							Oct-73	Sep-76	GSI				
Laois	Ls 28/2		28							Oct-73	Sep-76	GSI				
Laois	Ls 28/165	B	28	Kilpurcell	2017SEW229					Nov-76	Jan-79	GSI				
Laois	Ls 28/168, Granston Manor		28			37750	S 341 786	234100	178600	Sep-78	Mar-84	GSI/Arcon	Recorder from beginning			
Laois	Ls 29/1	D	29	Durrow	2317SWW057					Jul-73	Sep-76	GSI				
Laois	Ls 29/2	D	29	Abbeyleix Demesne	2317SWW223					Nov-73	Sep-76	GSI				
Laois	Ls 29/3 & 29/6	B	29	Castledurrow Demesne	2317SWW058/061		S 404 772			Jul-76	Sep-78	GSI	Recorder from dec-76			
Laois	Ls 29/7		29	Tintore						Sep-76	Jan-79	GSI	Recorder from beginning			
Laois	Ls 29/115	B	29	Fermoyle	2317SWW104		S 430 788			Sep-77	Jan-79	GSI				
Laois	Ls 31/1		31							Apr-73	Sep-76	GSI				
Laois	Ls 35/11	D	35	Galesquarter	2317SWW177					Oct-73	Sep-76	GSI				
Laois	Ls 35/23	D	35	Grenan	2317SWW190					Oct-73	Sep-76	GSI				
Laois	Ls 35/39, Newtown, Cullahill	B	35	Newtown	2317SWW205	45536	S 374 757	237400	175700	Sep-76	1999	GSI/OPW	Discontinued			
Cork	Mallow Hospital	B	33		1409NWW001	56303				2-Jun-87	24-Jun-88	GSI	Recorder from beginning			
Cork	Mallow Academy	B	33			56308				24-Apr-87	24-Jun-88	GSI	Recorder from beginning			
Cork	Mallow Mart	B	33			56303				7-May-87	11-Jun-87	GSI	Recorder from beginning			
Cork	Caherdrinny	B			1709NWW019	45538		17972	10839	20-May-87	1-Dec-87	GSI	Recorder from beginning			
Cork	Kiltrislane	B			1711SWW046	45539		18107	11006	20-May-87	24-Jun-88	GSI	Recorder from beginning			
Cork	Ballynageragh	B														
Cork	Ballyderown BH 1	B	28	Ballyderown	1709NNWW033			184885	101078	12-Jan-90	27-Mar-97	Teagasc/TCD	Karl Richards PhD			
Cork	Ballyderown BH 2	B	28	Ballyderown	1709NNWW034			184540	101060	12-Jan-90	27-Mar-97		Karl Richards PhD			

Table B.1 contd.

County	Site	Type	6" sheet	Geodata Td	GSI well name	Recorder no.	NGR	Easting	Northin g	Date started	Date ended	Operator	Remarks	Easting 6 fig	Northing 6 fig	Accuracy
Cork	Ballyderown BH 3	B	28	Ballyderown	1709NNWW035			184764	100819	12-Jan-90	27-Mar-97		Karl Richards PhD			
Cork	Ballyderown BH 4	B	28	Ballyderown	1709NNWW036			184585	100873	13-Dec-93	27-Mar-97		Karl Richards PhD			
Cork	Ballyderown BH 5	B	28	Ballyderown	1709NNWW037			184309	101180	13-Dec-93	27-Mar-97		Karl Richards PhD			
Cork	Ballyoneen	D	54	Ballyoneen			W 829 852			11-Aug-76	06-Mar-79	GSI				
Cork	Peafield	D	54	Peafield				18630	8450	11-Aug-76	02-Apr-79	GSI				
Cork	Lisgoold Cross	B	65							27-May-76	02-Apr-79	GSI				
Cork	Ballygibbon	D	66	Ballygibbon						11-Aug-76	02-May-79	GSI				
Cork	Kilcounty (Dangan X)	D	66	Kilcounty						11-Aug-76	12-Dec-78	GSI				
Cork	Corbally (Mount Uniacke)	D	66	Corbally						11-Aug-76	12-Dec-78	GSI				
Cork	Ballyquirk	D	66	Ballyquirk		45521	W 991 757	199100	75700	29-May-05		GSI/CCC	Now manual only			
Cork	Creighmore	D	67	Creighmore			X 046 750			27-Jul-76	11-Dec-79	GSI				
Cork	Monearmore	D	67	Monearmore			X 072 749			27-Jul-76	11-Dec-79	GSI				
Cork	Redbarn	D	67	Redbarn			X 080 746			27-Jul-76	26-Jun-79	GSI				
Cork	Summerfield Cross	D	67				X 092 761			03-Aug-76	13-Feb-80	GSI				
Cork	Ballycurreen	D	75	Ballycurreen						27-May-76	26-Jun-79	GSI				
Cork	Gearagh	D	76	Gearagh			W 905 716			22-Jul-76	13-Feb-80	GSI				
Cork	Whiterock	D	76	Whiterock			W 915 734			22-Jul-76	10-Aug-79	GSI				
Cork	Baneshane	D	76	Baneshane			W 868 724			22-Jul-76	10-Aug-79	GSI				
Cork	Ballynabointra	B	76	Ballynabointra		45519	W 851 734	185100	73400	30-May-05		GSI/CCC	Now manual only			
Cork	Attiquin	D	77	Attiquin		45523	W 939 722	193900	72200	29-May-05		GSI/CCC				
Cork	Ballintotis	D	77	Ballintotis			W 932 728			27/05/76	13-Feb-80	GSI				
Cork	Castlerichard	D	77	Castlerichard			X 000741			22/07/76	13-Feb-80	GSI				
Cork	Kilbeg	D	77	Kilbeg			W 978 719			27-Jul-76	13-Feb-80	GSI				
Cork	Dromsarane	D	77	Dromsarane			W935 702			11-Aug-76	10-Aug-79	GSI				
Cork	Garryvoe Lower	D	77	Garryvoe Lower			W 990 687			11-Aug-76	21-Nov-78	GSI				
Cork	Dower Spring	D	77	Dower		44198	W 979 728	197900	72800	29-May-05		GSI/CCC				
Cork	Gortavella	D	78	Gortavella			X 021 727			27-Jul-76	10-Aug-79	GSI				
Cork	Aghavine	B	78	Aghavine		45525	X 041 725	204100	72500	29-May-05		GSI/CCC	Now manual only			
Cork	Town Parks	B	88	Town Parks			W 913 675	191300	67500	30-May-05		CCC	Now manual only			
Cork	Commons East	B	88	Commons East			W 919 672	191900	67200	30-May-05		CCC	Now manual only			
Cork	Castlemary	B	88	Castlemary			W 908 674	190800	67400	02-Jun-05		CCC				
Cork	Lissanly	B	88	Lissanly			W 910 669	191000	66900	02-Jun-05		CCC	Close to pumping well			

Table B.1 contd.

County	Site	Type	6" sheet	Geodata Td	GSI well name	Recorder no.	NGR	Easting	Northin g	Date started	Date ended	Operator	Remarks	Easting 6 fig	Northing 6 fig	Accuracy
Cork	Lurrig	D	88	Lurrig			W 898 664			27-Jul-76	06-Mar-79	GSI				
Cork	Ballyfin	D	88	Ballyfin			W 918 651			27-May-76	10-Aug-79	GSI				
Cork	Ballymacandrick	D	88	Ballymacandrick						11-Aug-76	10-Aug-79	GSI				
Cork	Farranamannagh	D	88	Farranamannagh			W 906 652	190600	65200	30-May-05		CCC	Close to pumping well			
Cork	Carrigacrump	D	88	Carrigacrump			W 901 650	190100	65000	30-May-05		CCC	Now manual only			
Cork	Ballybane	D/B	89	Ballybane			W 965 676			27-Jul-76	10-Aug-79	GSI				
Cork	Ballingarrane	D	89	Ballingarrane			W 961 658			27-Jul-76	10-Aug-79	GSI				
Cork	Ballybranagh	D	89	Ballybranagh			W 932 674			27-Jul-76	10-Aug-79	GSI				
Cork	Ballyduff	D	89	Ballyduff		45524	W 945 670	194500	67000	29-May-05		GSI/CCC				
Cork	Ballylongane	D	89	Ballylongane			W 996 674			11-Aug-76	03-Aug-78	GSI				
Cork	Ballycatoo	D	89	Ballycatoo						11-Aug-76	10-Aug-79	GSI				
Cork	Ballygeany	D	89	Ballygeany						11-Aug-76	02-May-79	GSI				
Kerry	39/41, Joe O'Connor		39	Scart	0811SWW	45526		9370	11150	28-Jun-81	03-May-88	GSI/KCC	Recorder from beginning			
Kerry	39/83, James Pigott		39	Kilfallinga	0809NWW196	56309		9475	10765	20-Jun-81	14-Feb-85	GSI/KCC	Recorder from beginning			
Kerry	39/96, Loughlin		39	Parknamulloge	0809NEW	45520		9840	10650	03-Jul-81	03-May-88	GSI/KCC	Recorder from beginning			
Kerry	39/154, Roger Rahilly		39	Knockeen	0811SEW088			9967	11120	13-Jul-81	15-Jun-82	GSI/KCC	Recorder from beginning			
Kerry	40/21, Gene Connor		40	Caheragh	0809NEW104			10100	10720	01-Jul-81	15-Jun-82	GSI/KCC	Recorder from beginning			
Kerry	40/42, Co. Council		40	Breahig	0809NEW	45539		10330	10720	19-Jun-81	05-Aug-86	GSI/KCC	Recorder from beginning			
Kerry	Tullig Beg			Tullig Beg	0509SEW005	45522		7322	9535	10-May-83	10-Oct-85	GSI	Intermittent readings			
Kerry	Tooreennasliggaun		56	Tooreennasliggaun	0509SEW005	56306		7255	9418	17-Sep-84	10-Apr-88	GSI	Intermittent readings			
Roscommon	R 8/30, Cloonmagunnaun		8	Cloonmagunnaun	1429SEW095	44197	M 676 953	167600	295300	01-Nov-84	Still operating	GSI/OPW	Stopped in 1990; reactivated in 1994; recorder from beginning	167560	295320	2
Roscommon	R 14/84, Lung Bridge		14	Lissian	1429SEW087	37782	M 653 926	165300	292600	01-Dec-81	Still operating	GSI/OPW	Stopped in 1990; reactivated in 1994; recorder from beginning	165190	292860	2
Roscommon	R 14/91, Aghadrestan		14	Aghaderry	1427NEW062	44199	M 621 886	162100	288600	01-Nov-84	still operating	GSI/OPW	Stopped in 1990; reactivated in 1994; recorder from beginning	162090	288450	2
Roscommon	R 13/24, Lisacul		13	Creevy	1429SEW044	56307	M 583 902	158300	290200	01-Nov-81	Oct-86	GSI/OPW	Stopped in 1986; reactivated in 2001; recorder from beginning	158390	290020	2

Table B.1 contd.

County	Site	Type	6" sheet	Geodata Td	GSI well name	Recorder no.	NGR	Easting	Northin g	Date started	Date ended	Operator	Remarks	Easting 6 fig	Northing 6 fig	Accuracy
Roscommon	R 6/56		6	Ardcarn	1729NEW017	56305	G 873 027	187300	302700	01-Jul-85	1990	GSI/OPW	Stopped in 1990; recorder from beginning	187300	302800	2
Tipperary (N)	Ballincurry, Tip 55/65	B	55	Springfield			S 278 485	227800	148500	01-Oct-77	Oct-82	GSI	Stopped in 1982; recorder from beginning			
Louth	L8/12a	B	8	Ardtully Beg	2929NEW040			319600	306280	31-Aug-78	06-Jul-80	AFF	Recorder from beginning			
Louth	Drybridge, Drogheda	B			2927SEW059			306100	276020	25-Oct-79	20-Sep-95	AFF	Recorder from beginning			
Monaghan	M9/15a, Cortolvin Bridge	B	9	Killyconigan	2633SWW109			265640	332900	24-Nov-78	11-Jan-84	AFF	Recorder from beginning			
Monaghan	M3/7e, Derrykinnard BH, Emyvale	B	3	Derrykinnard	2633NWW013			266850	348160	23-Mar-79	19-Apr-94	AFF	Recorder from beginning			
Monaghan	M12/8m (Monaghan Co. Co.)	B	12	Magherarney	2331NEW058			258210	329710	21-Feb-80	06-Mar-86	AFF	Recorder from beginning			
Cavan	C19/7b, Croaghan Bridge	B	19					23038	30761	07-May-79	06-Feb-88	AFF	Recorder from beginning			

Appendix C Groundwater Hydrographs for Environmental Protection Agency Current Monitoring Points

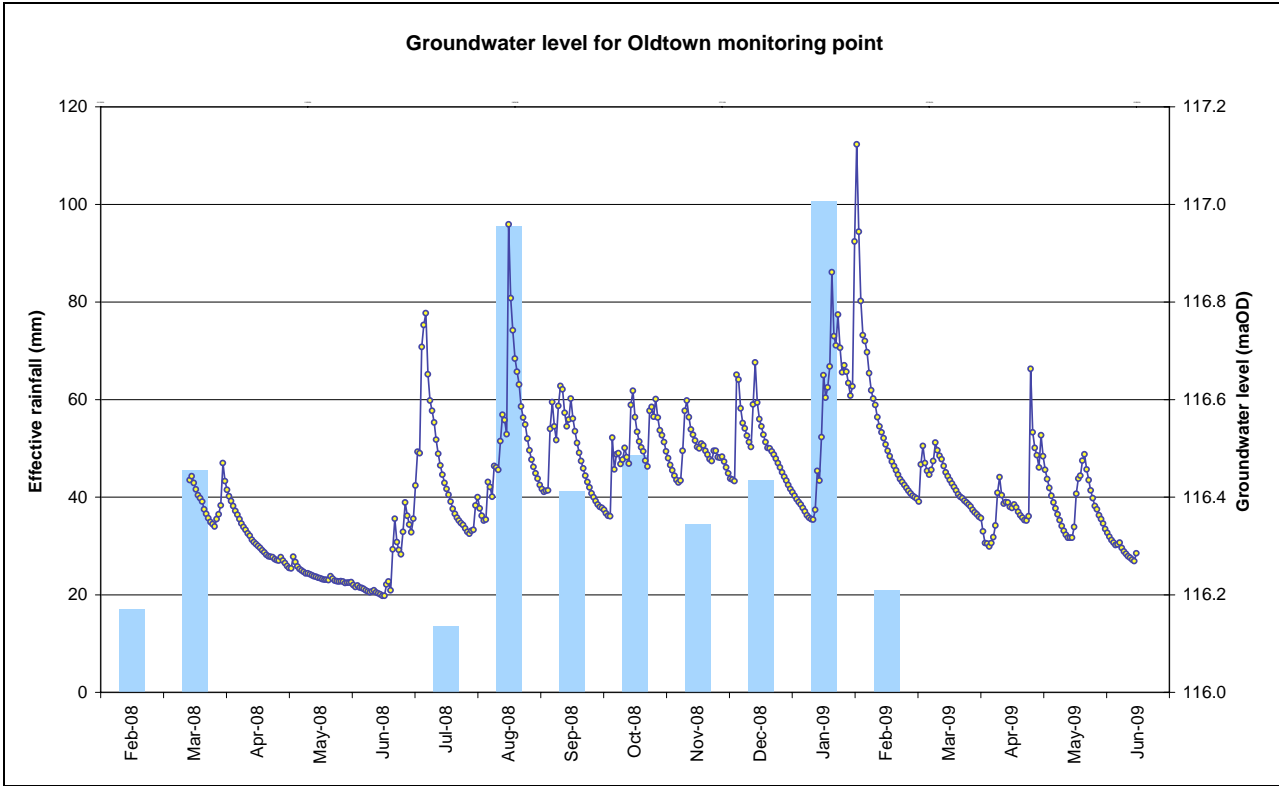


Figure C.1. Groundwater hydrograph for Oldtown monitoring point.

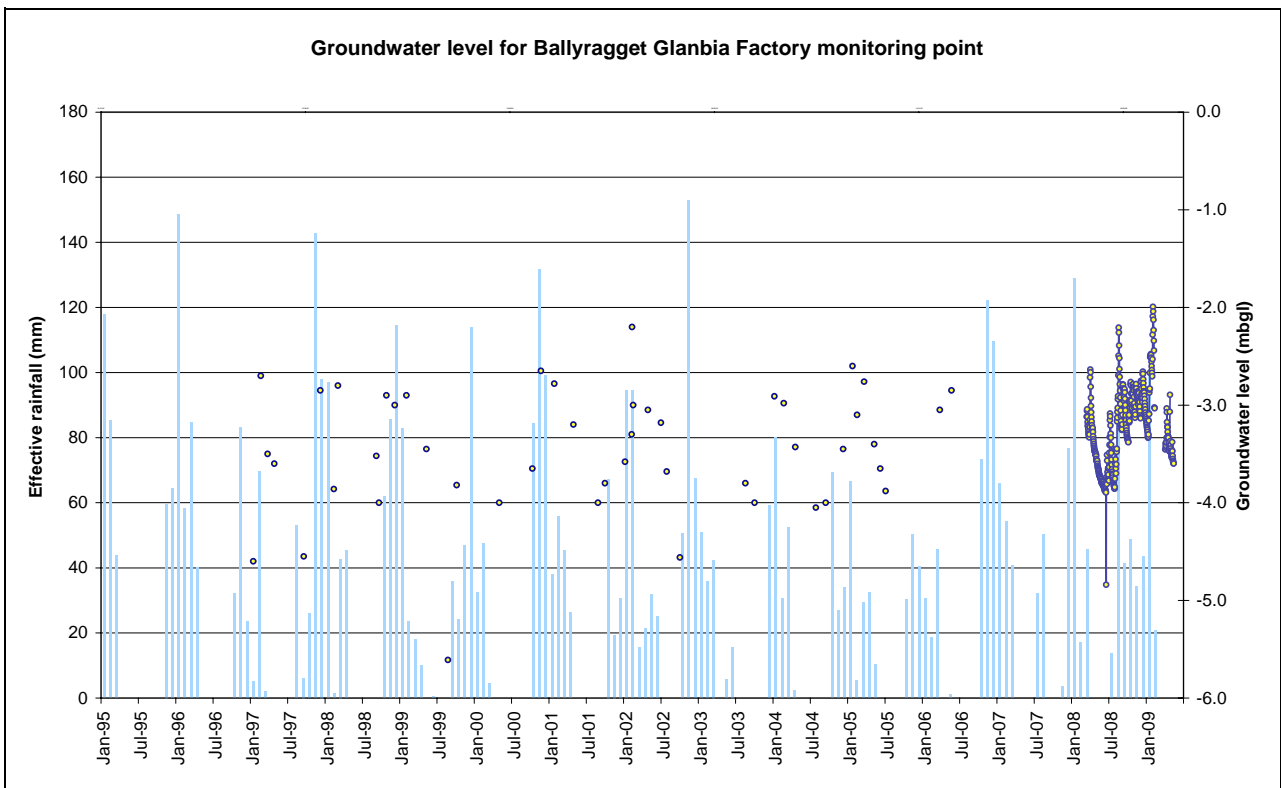


Figure C.2. Groundwater hydrograph for Ballyragget Glanbia factory monitoring point.

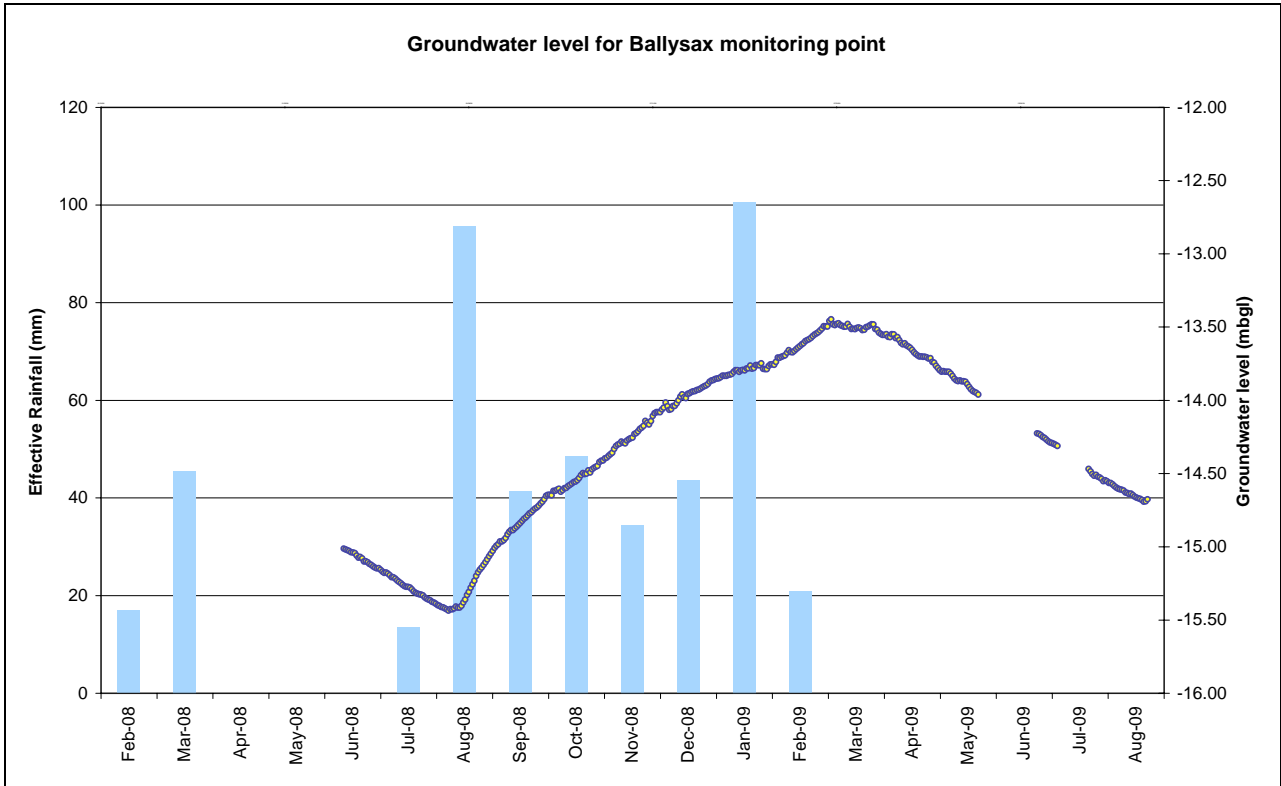


Figure C.3. Groundwater hydrograph for Ballysax monitoring point.

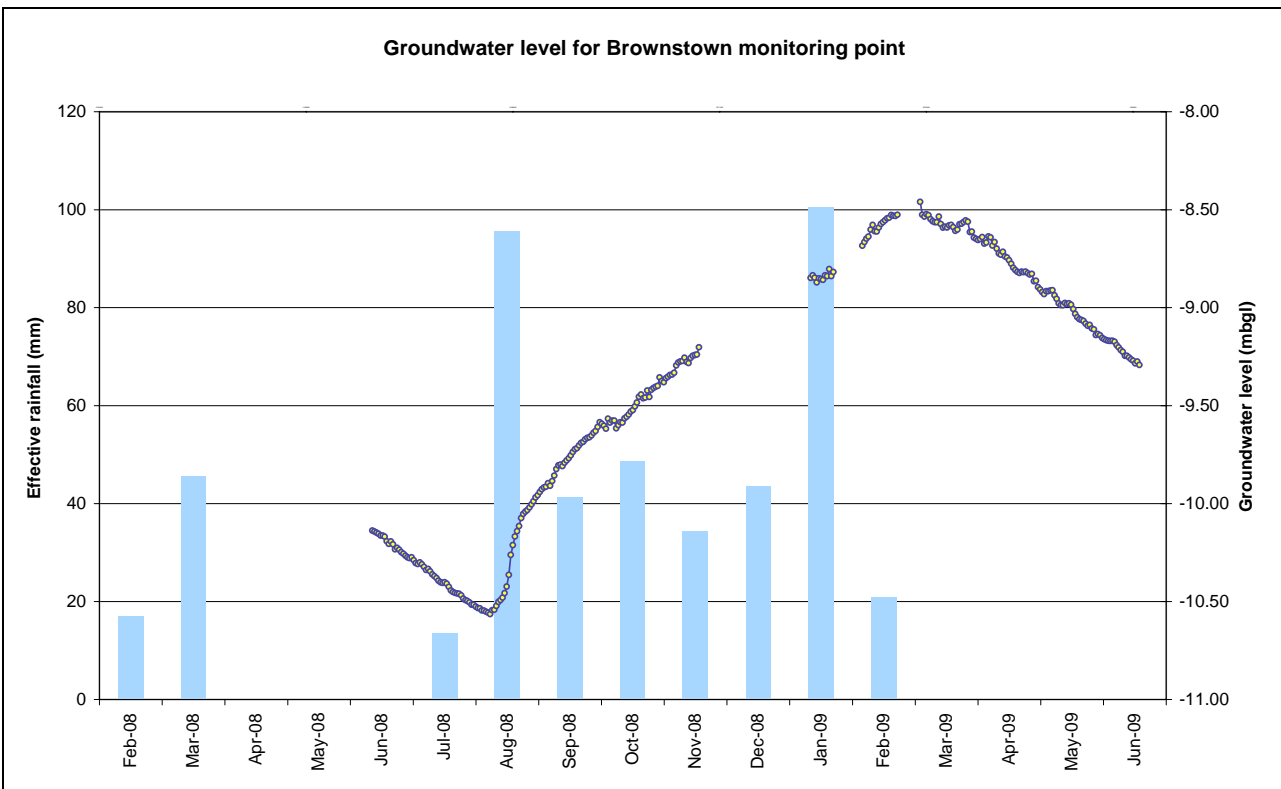


Figure C.4. Groundwater hydrograph for Brownstown monitoring point.

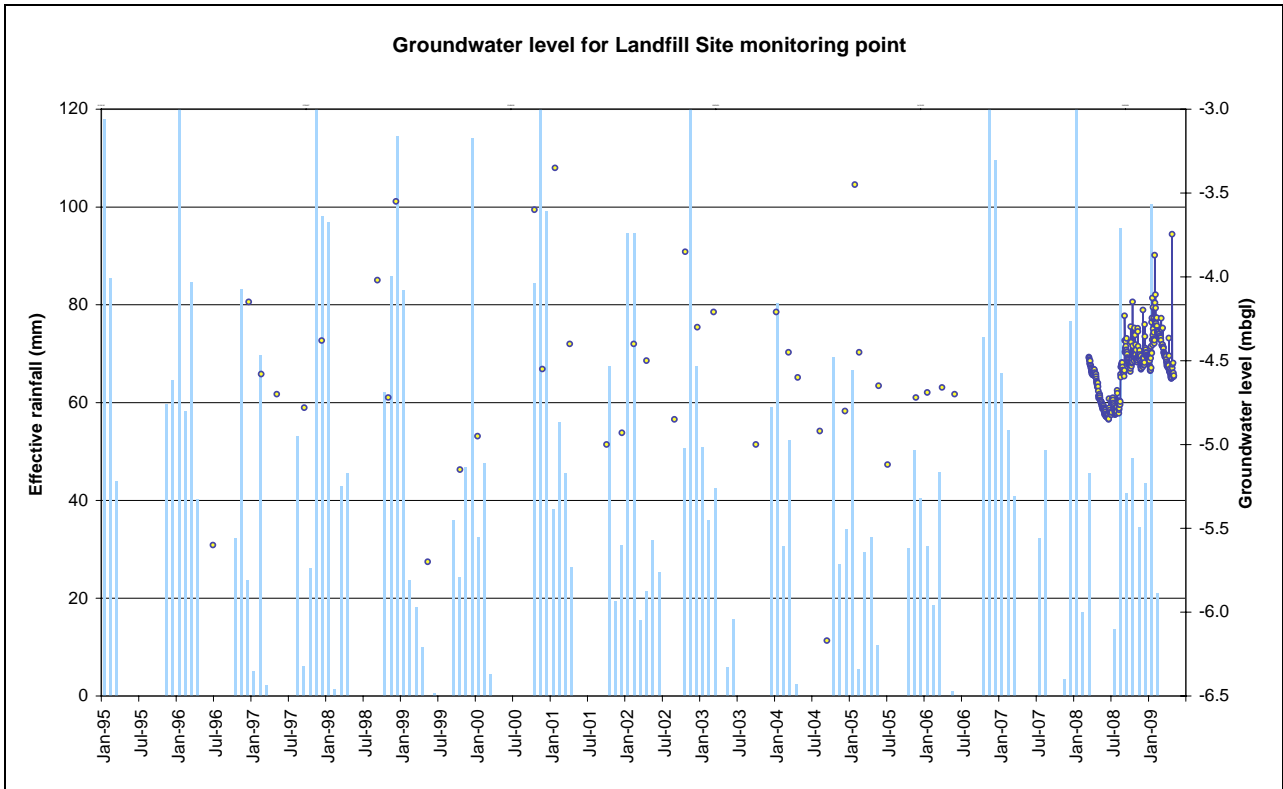


Figure C.5. Groundwater hydrograph for Landfill Site monitoring point.

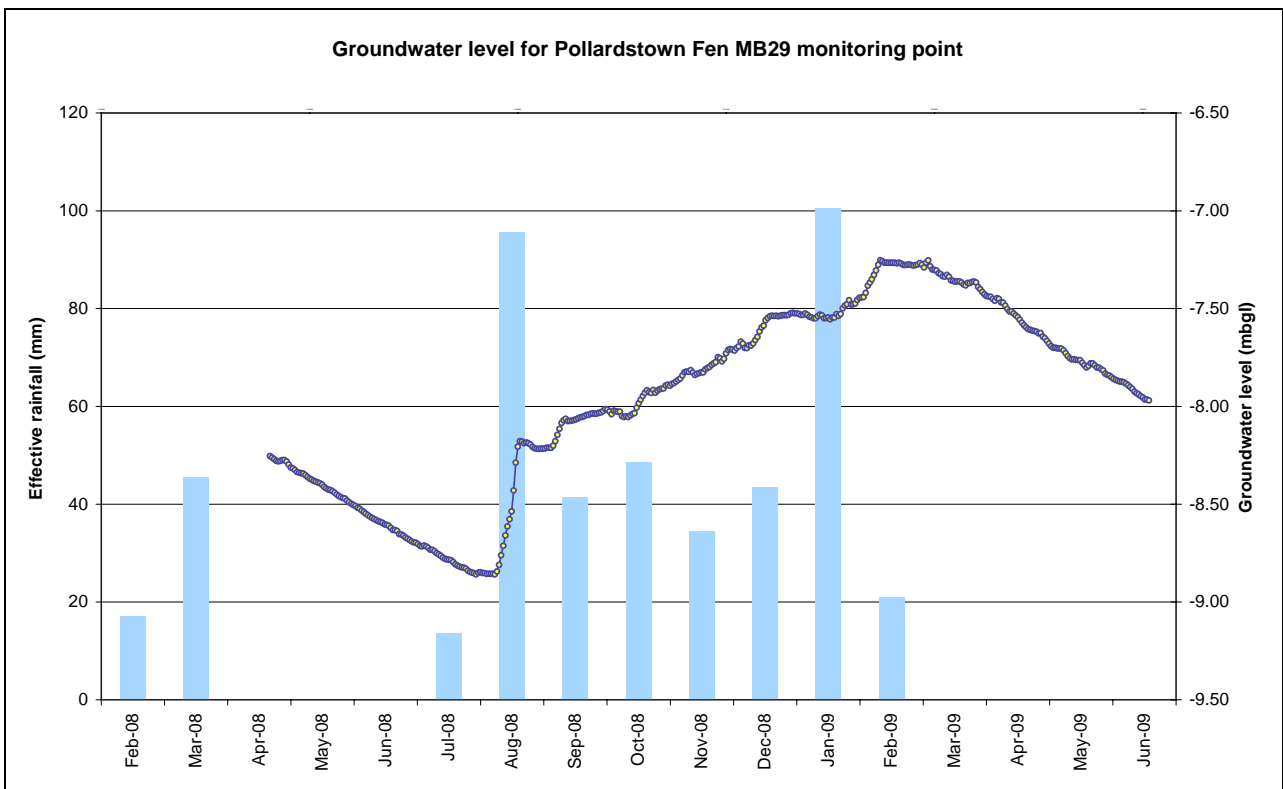


Figure C.6. Groundwater hydrograph for Pollardstown Fen MB29 monitoring point.

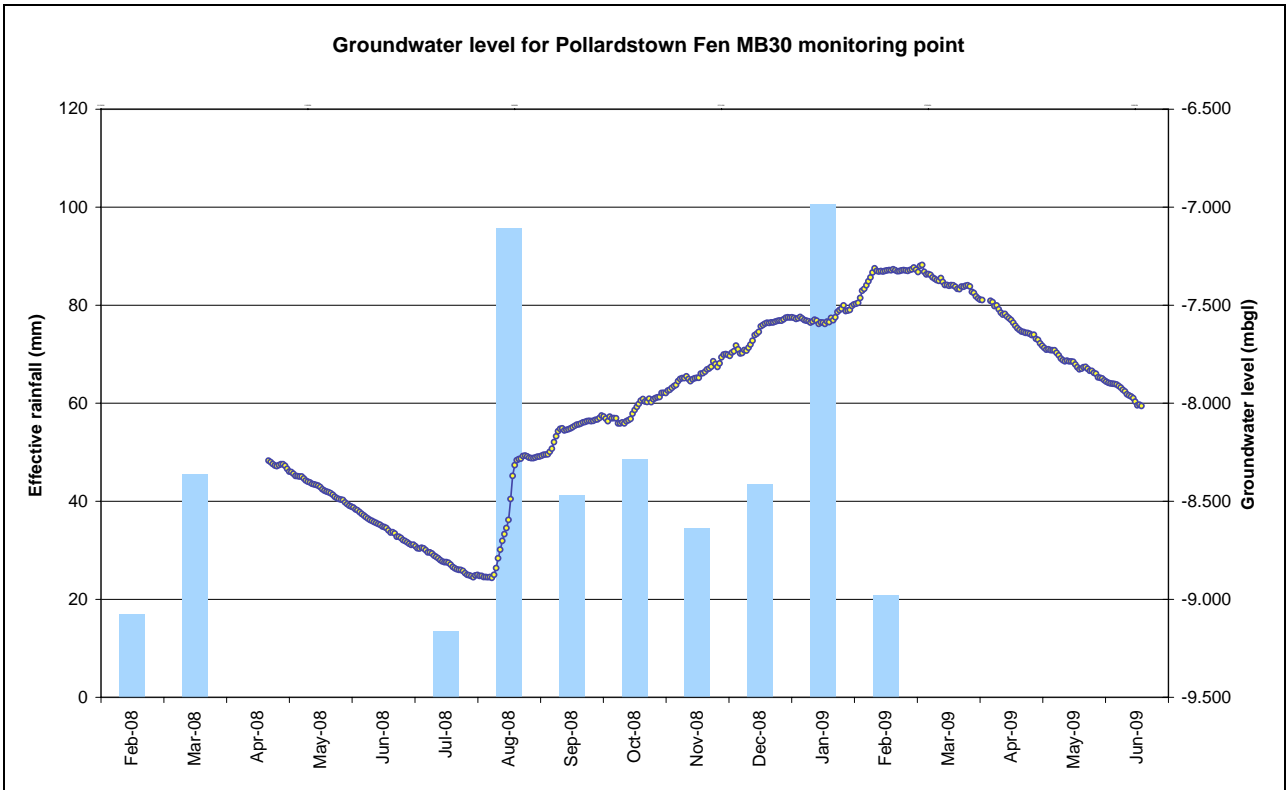


Figure C.7. Groundwater hydrograph for Pollardstow Fen MB30 monitoring point

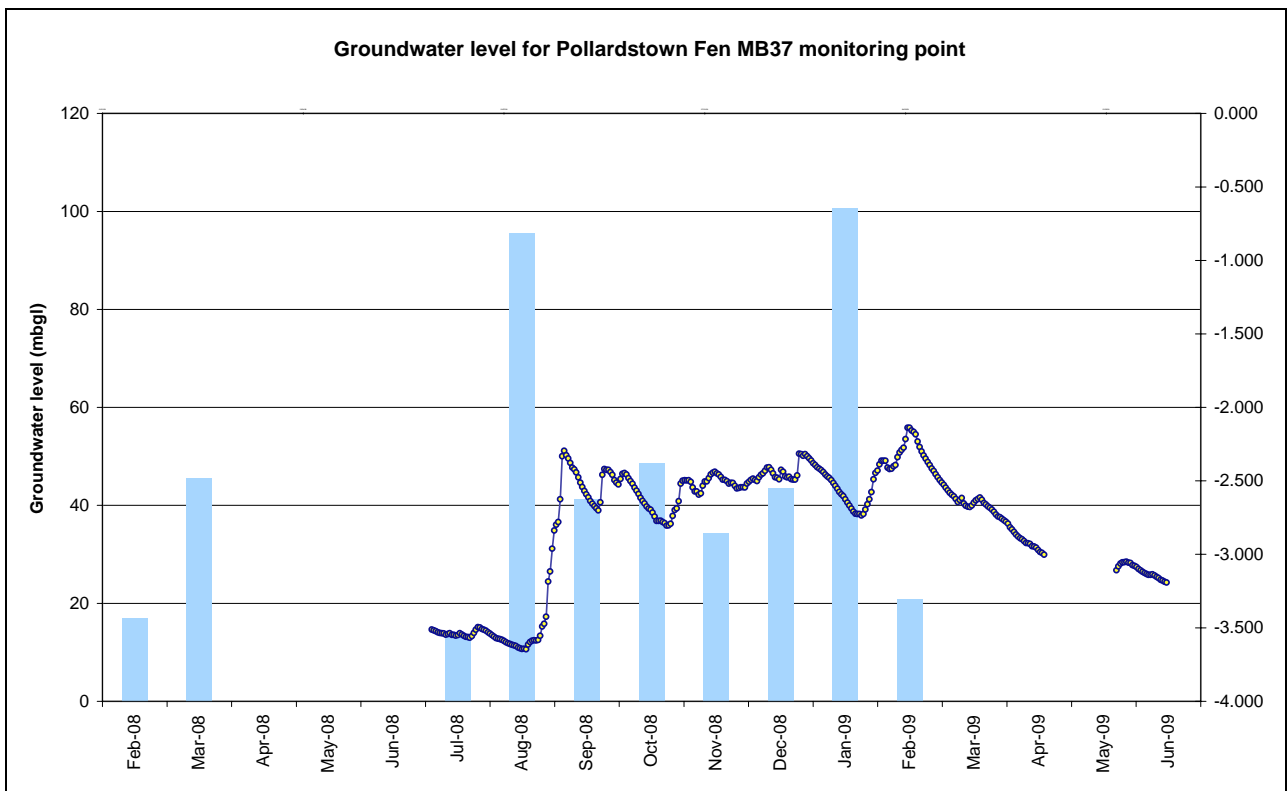


Figure C.8. Groundwater hydrograph for Pollardstow Fen MB37 monitoring point.

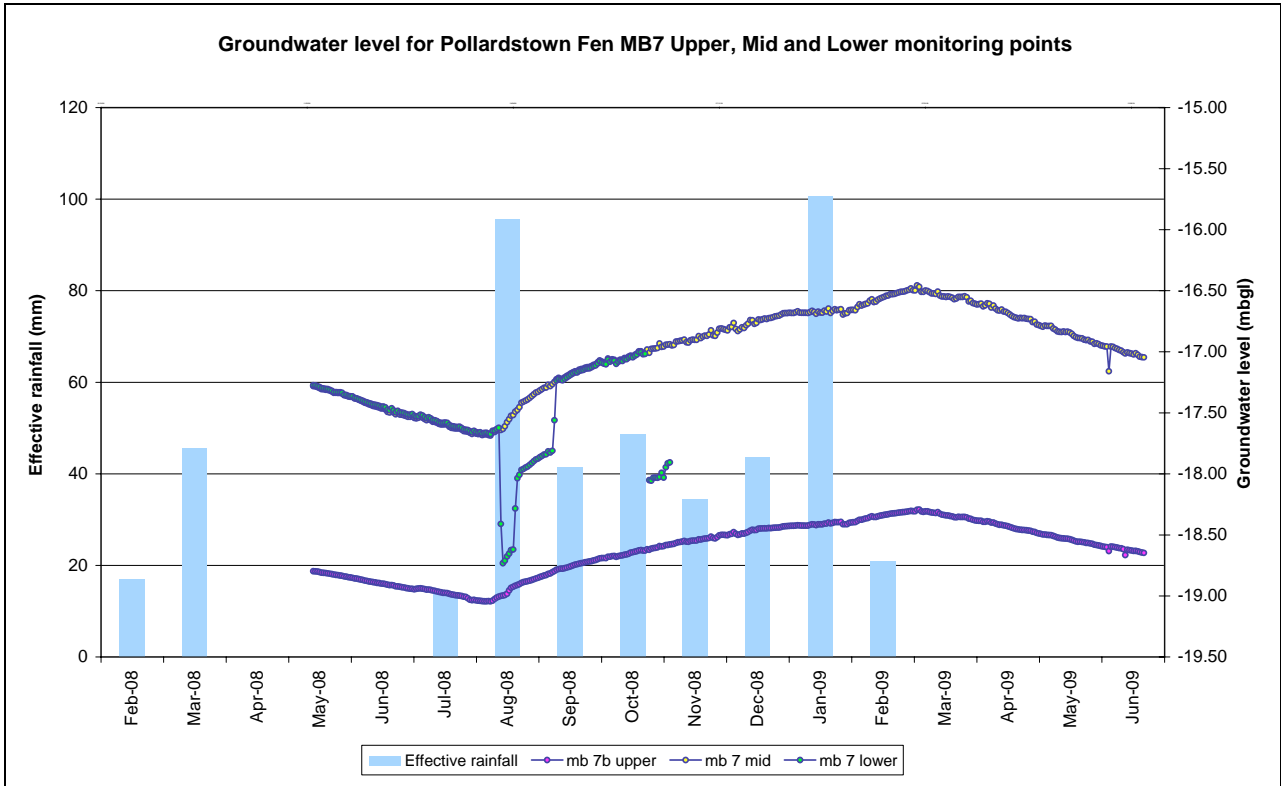


Figure C.9. Groundwater hydrograph for Pollardstown Fen MB7 monitoring point.

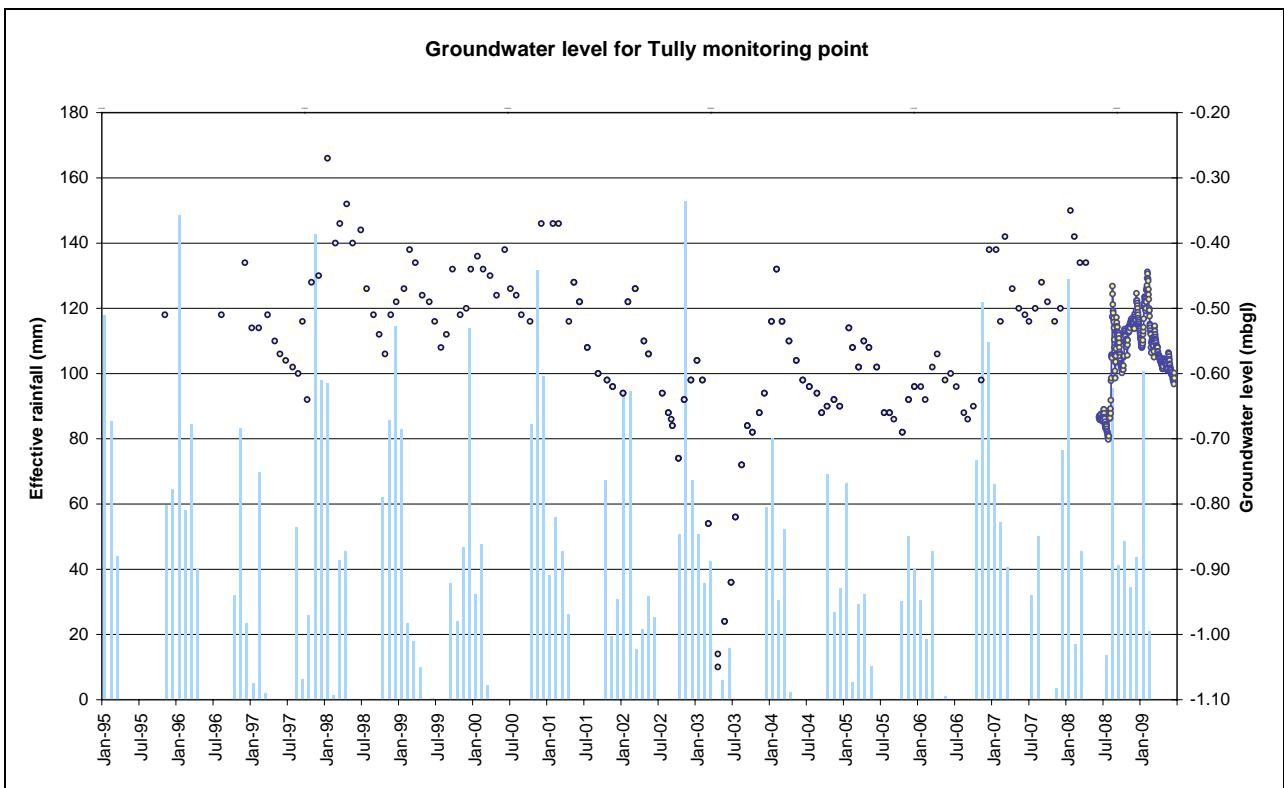


Figure C.10. Groundwater hydrograph for Tully monitoring point.

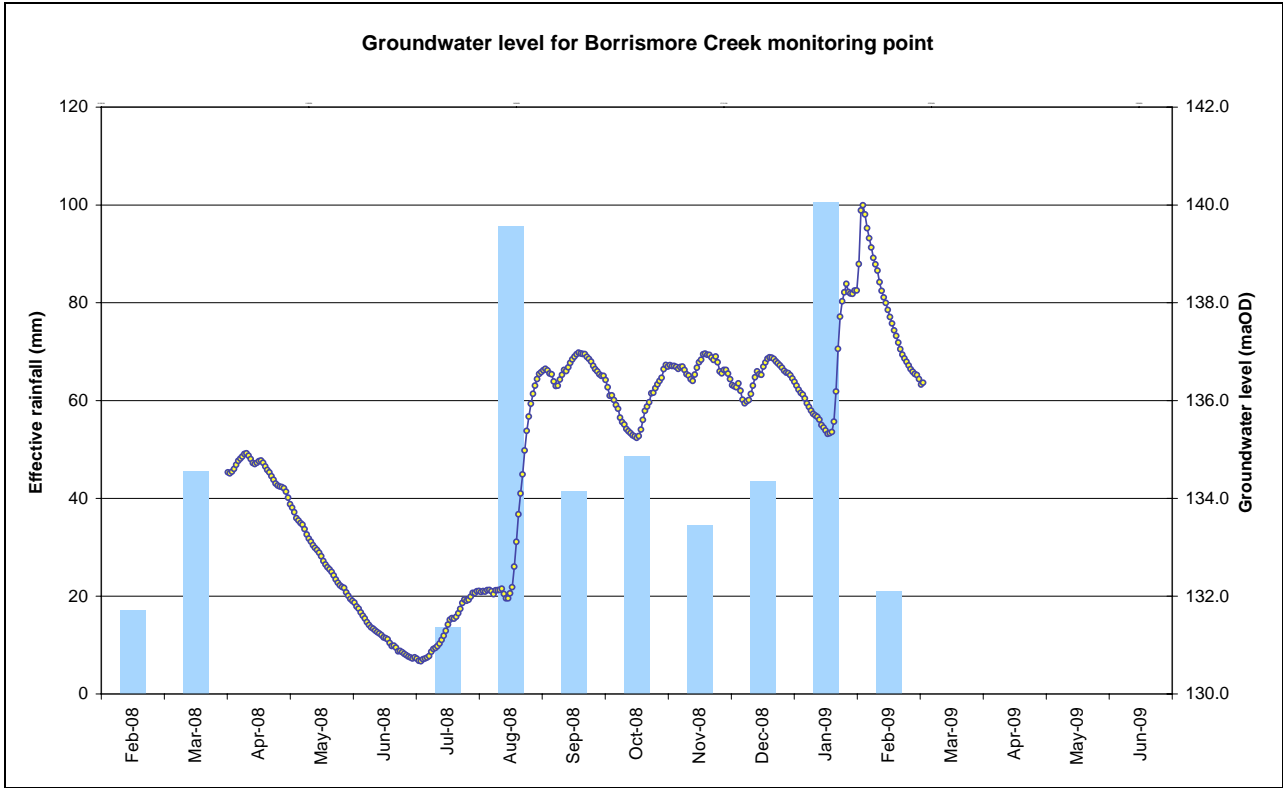


Figure C.11. Groundwater hydrograph for Borrismore Creek monitoring point.

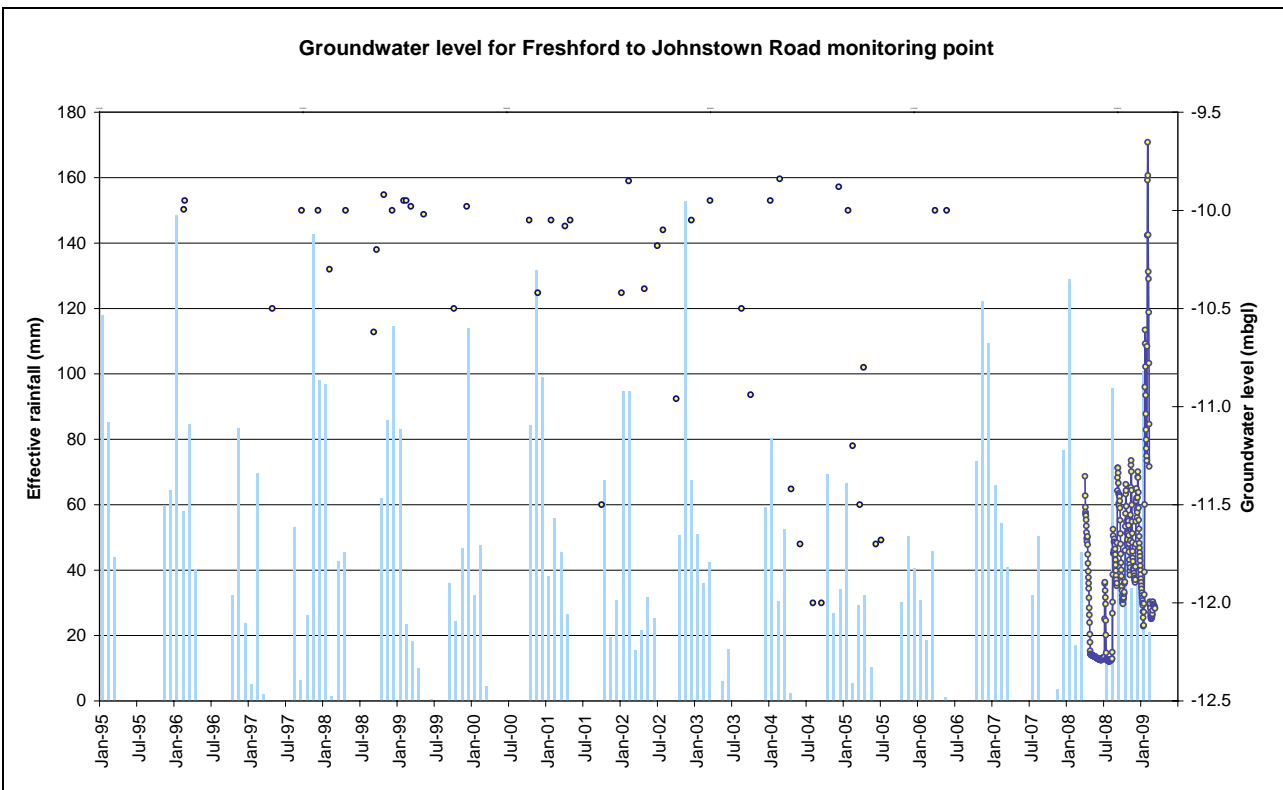


Figure C.12. Groundwater hydrograph for Freshford to Johnstown Road monitoring point.

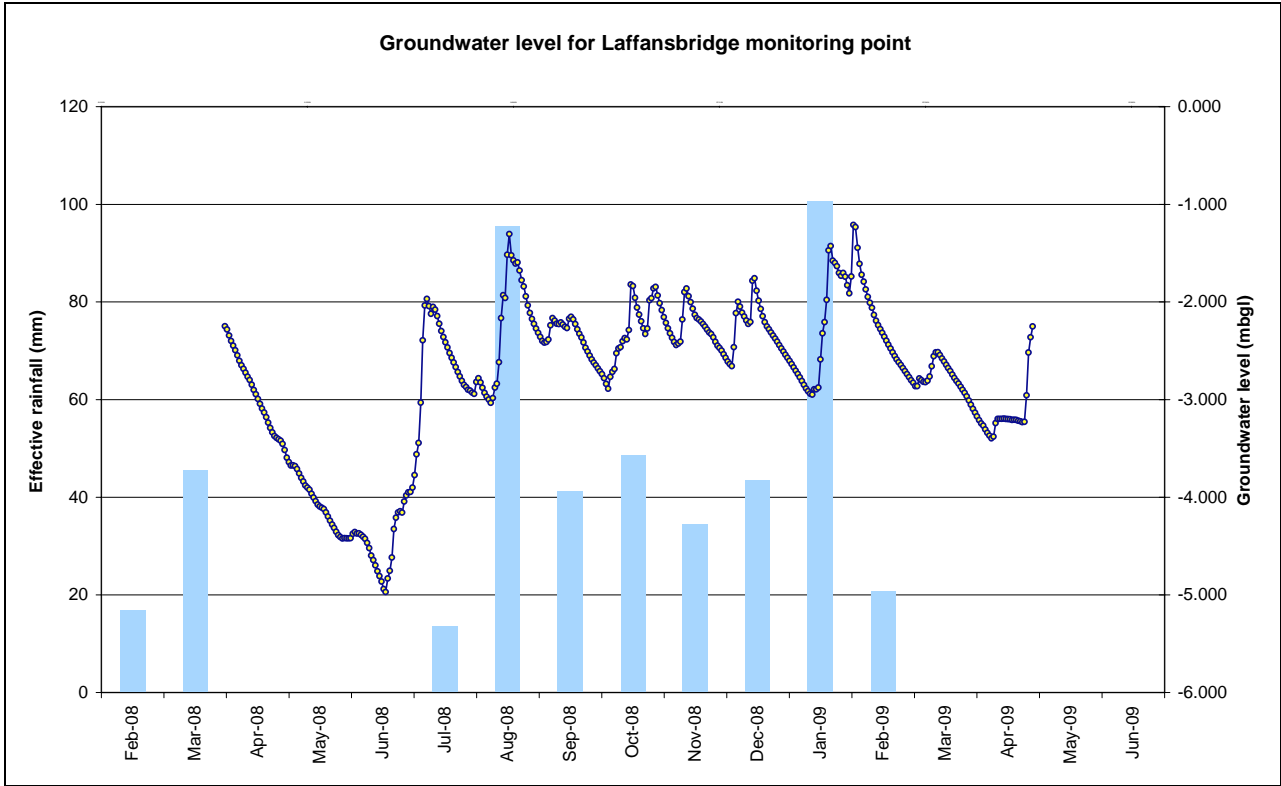


Figure C.13. Groundwater hydrograph for Laffansbridge monitoring point.

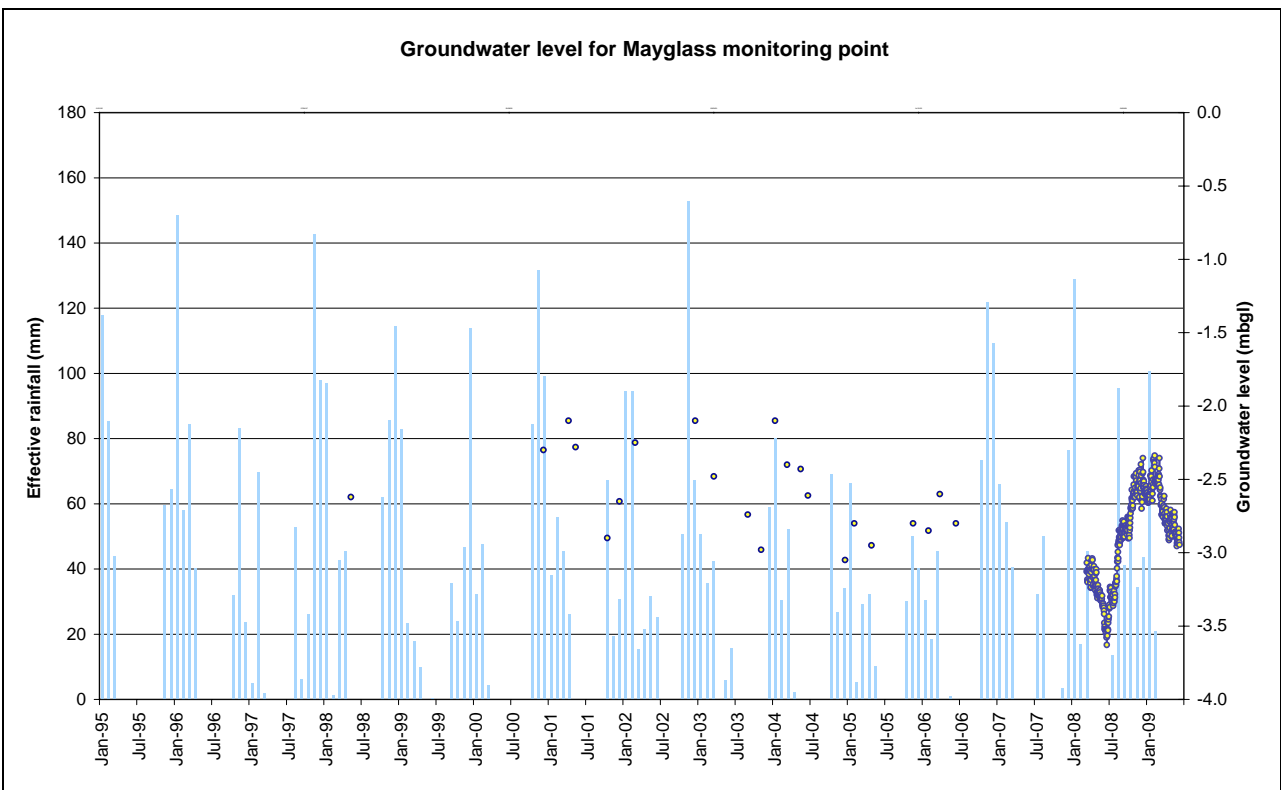


Figure C.14. Groundwater hydrograph for Mayglass monitoring point.

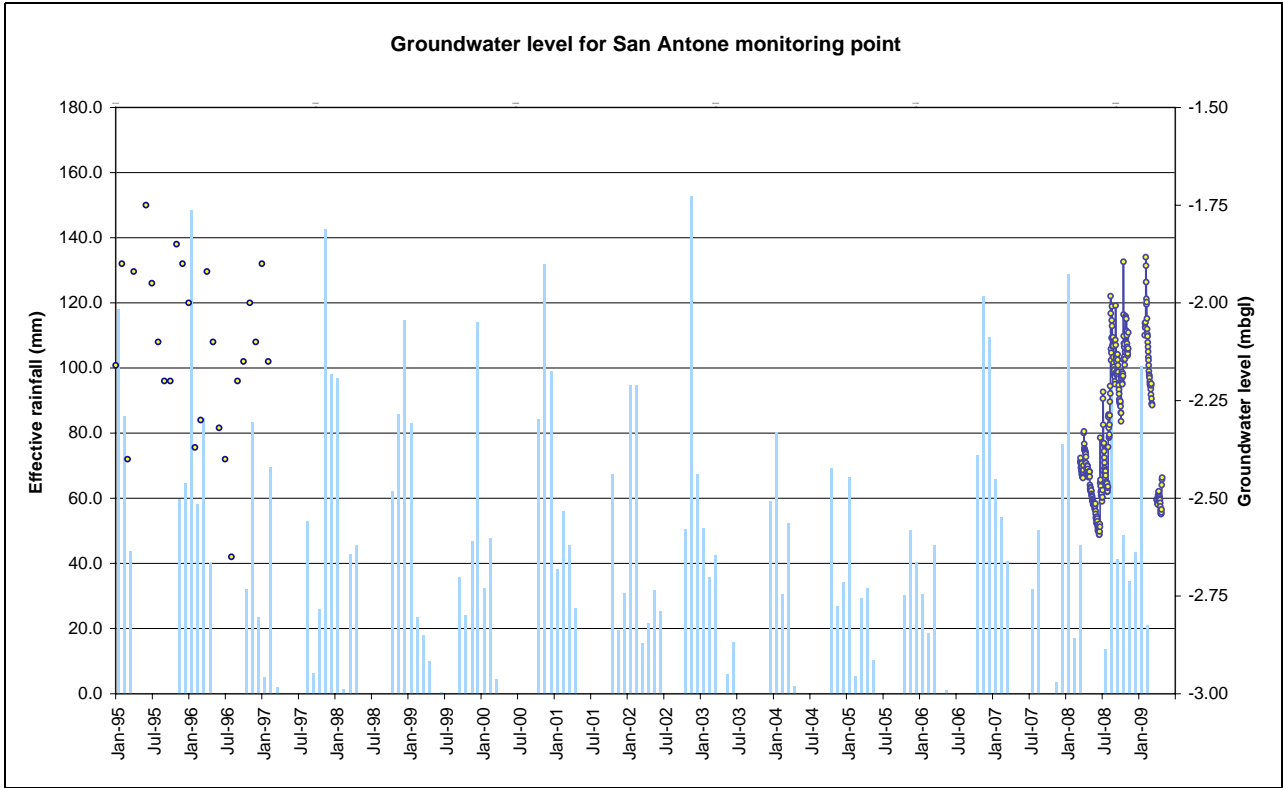


Figure C.15. Groundwater hydrograph for San Antone House monitoring point.

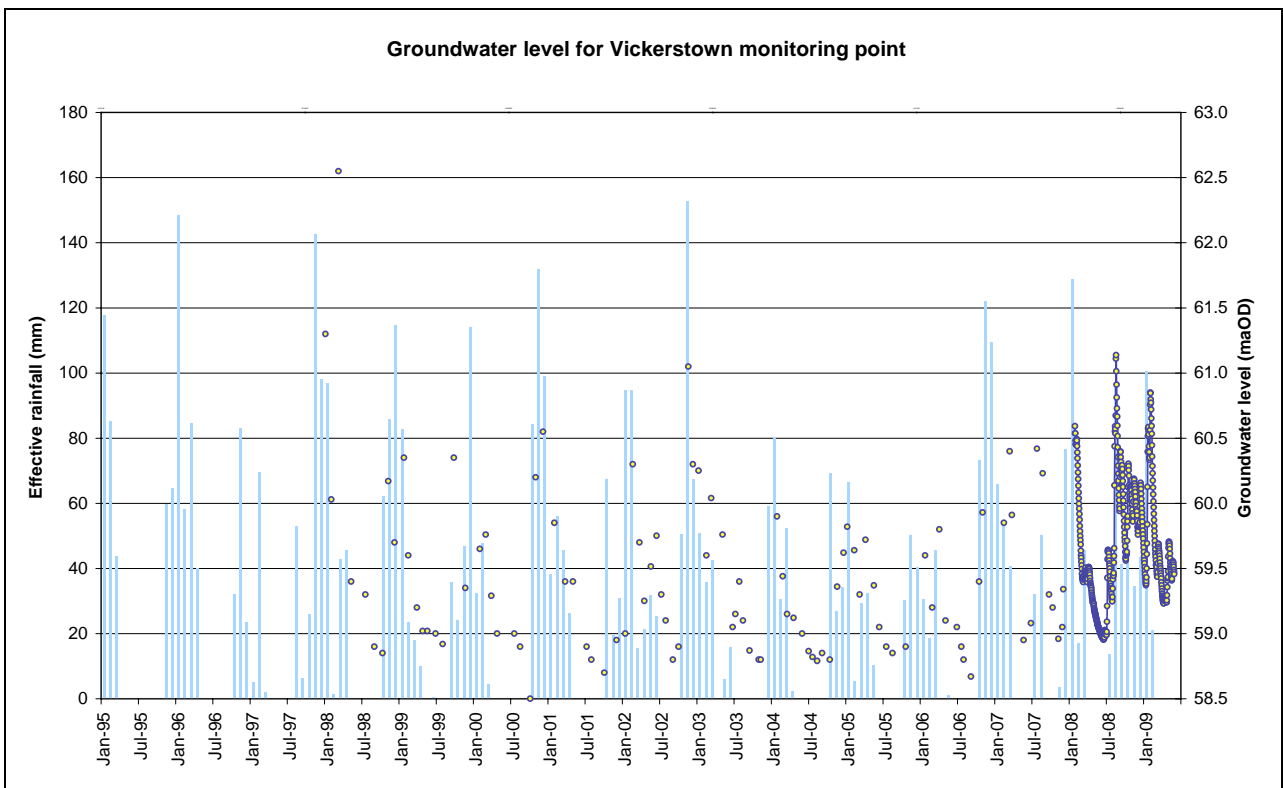


Figure C.16. Groundwater hydrograph for Vickerstown monitoring point.

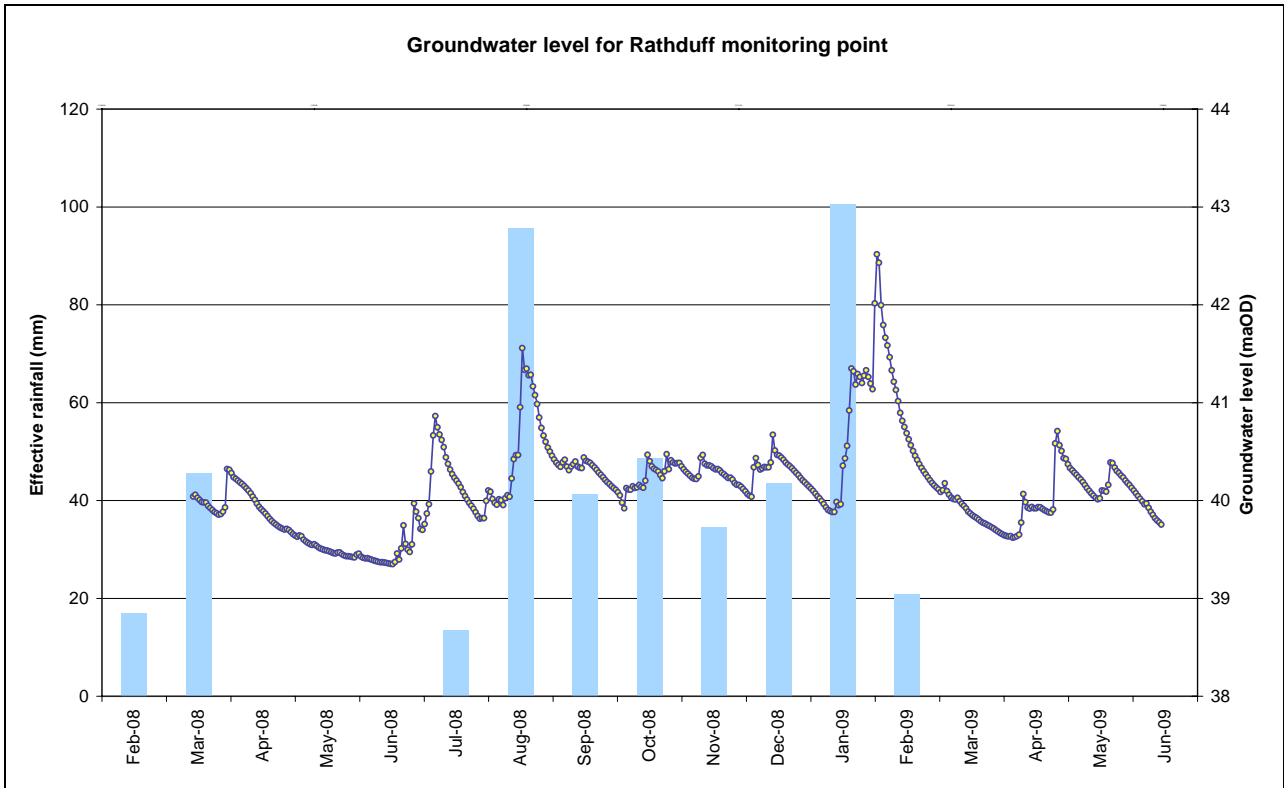


Figure C.17. Groundwater hydrograph for Rathduff monitoring point.

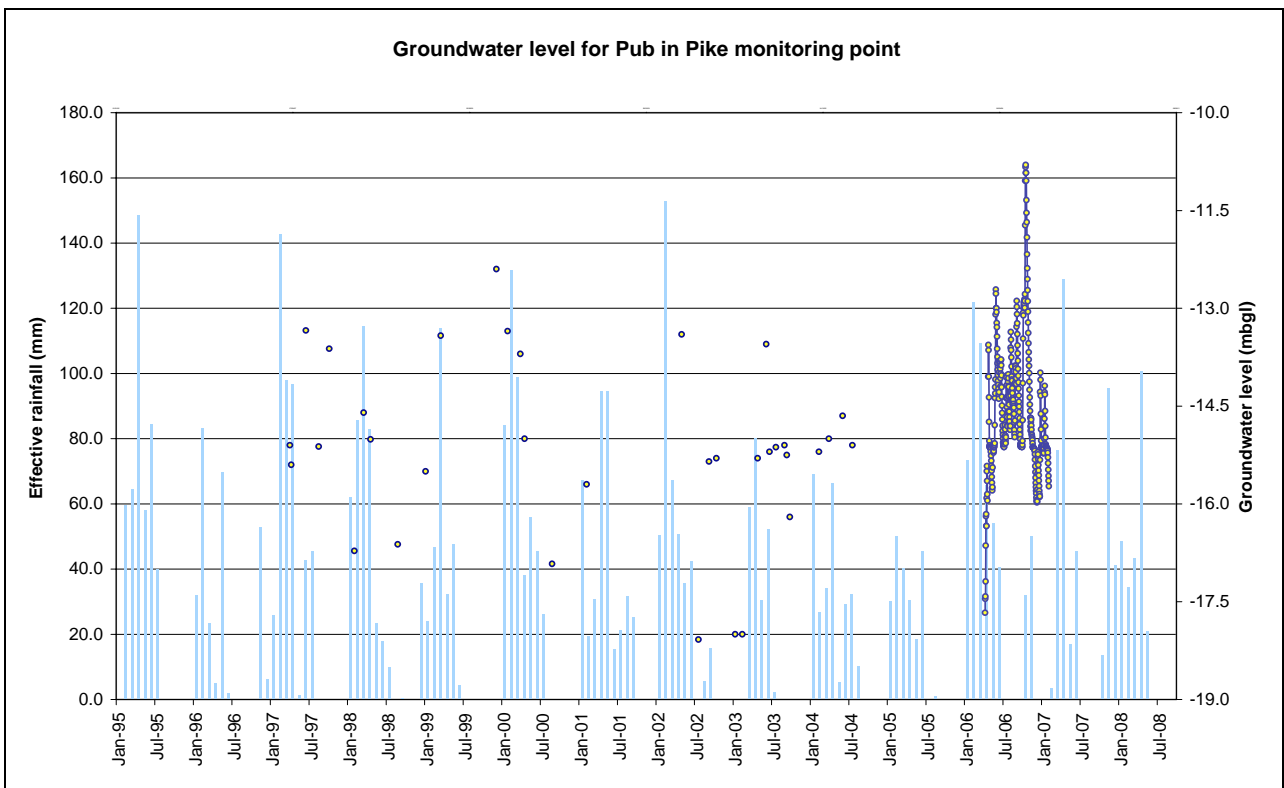


Figure C.18. Groundwater hydrograph for Pub in Pike monitoring point.

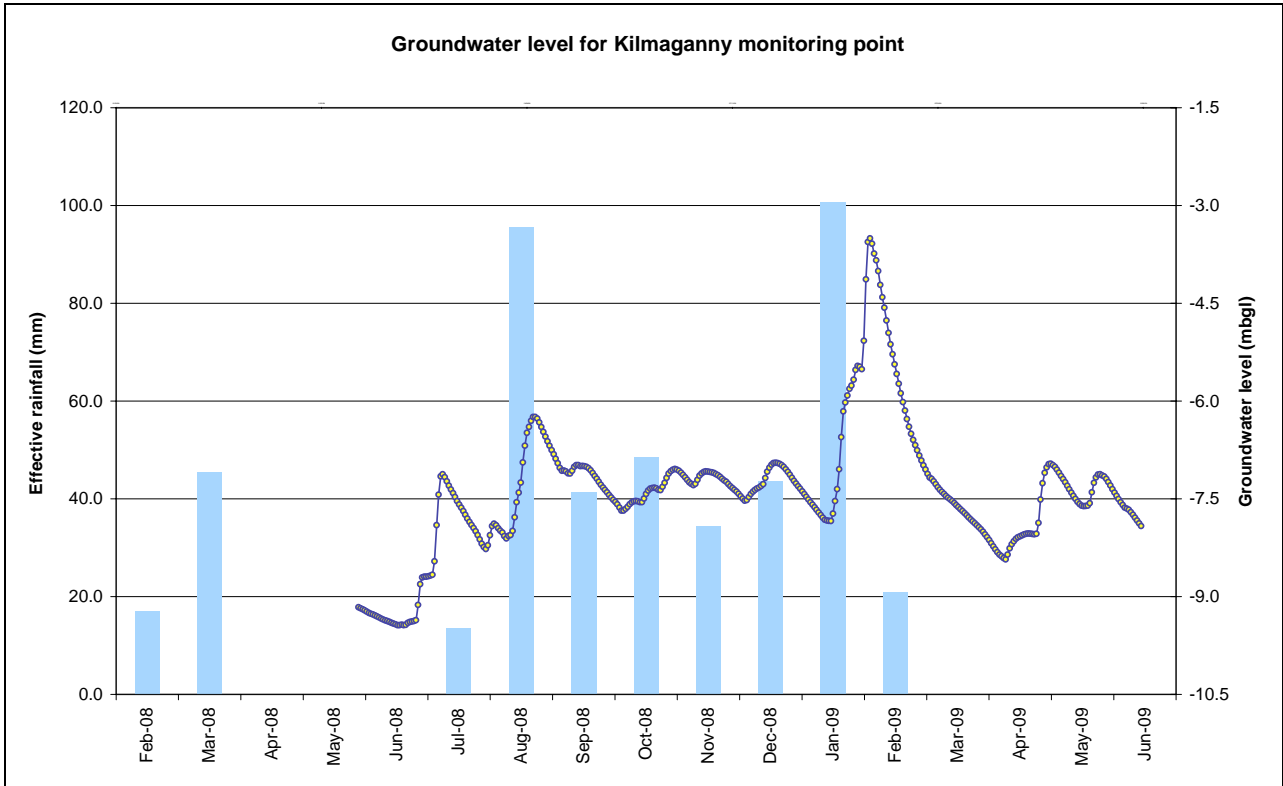


Figure C.19. Groundwater hydrograph for Kilmaganny monitoring point.

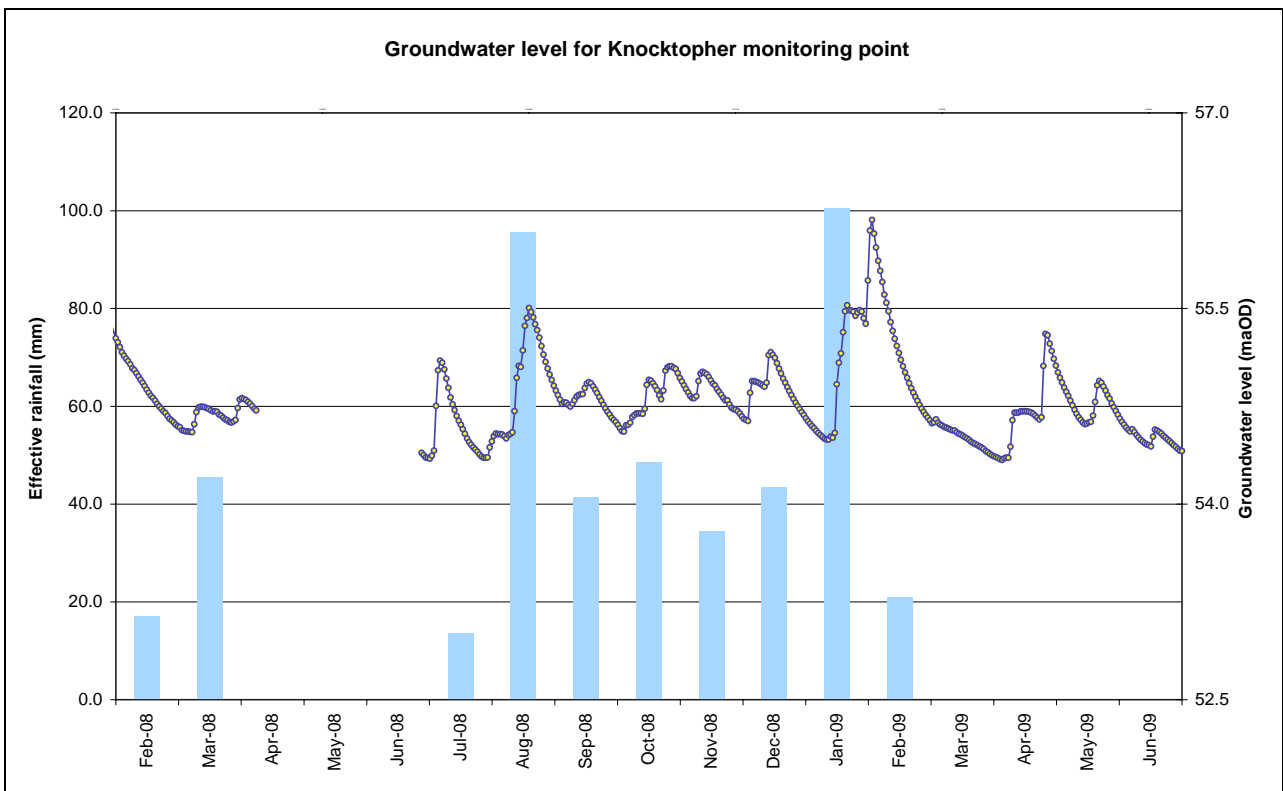


Figure C.20. Groundwater hydrograph for Knocktopher monitoring point.

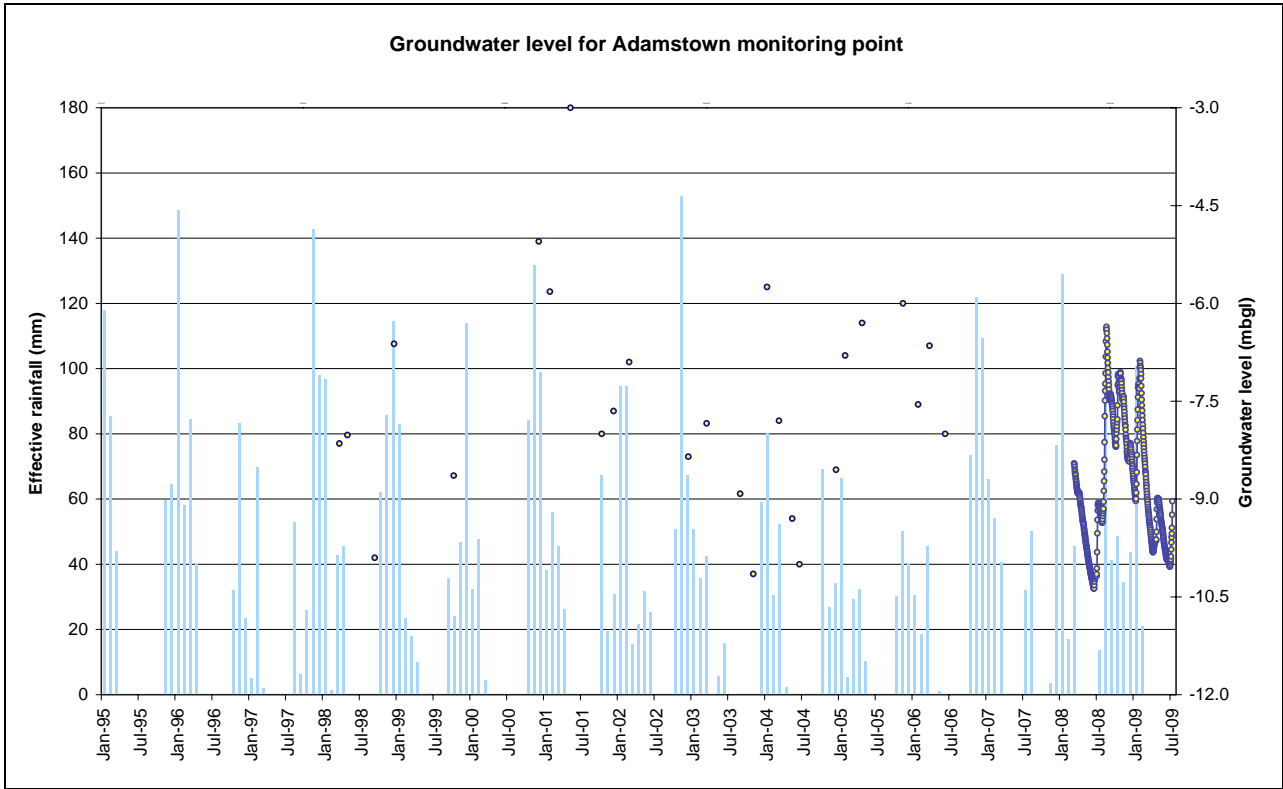


Figure C.21. Groundwater hydrograph for Adamstown monitoring point.

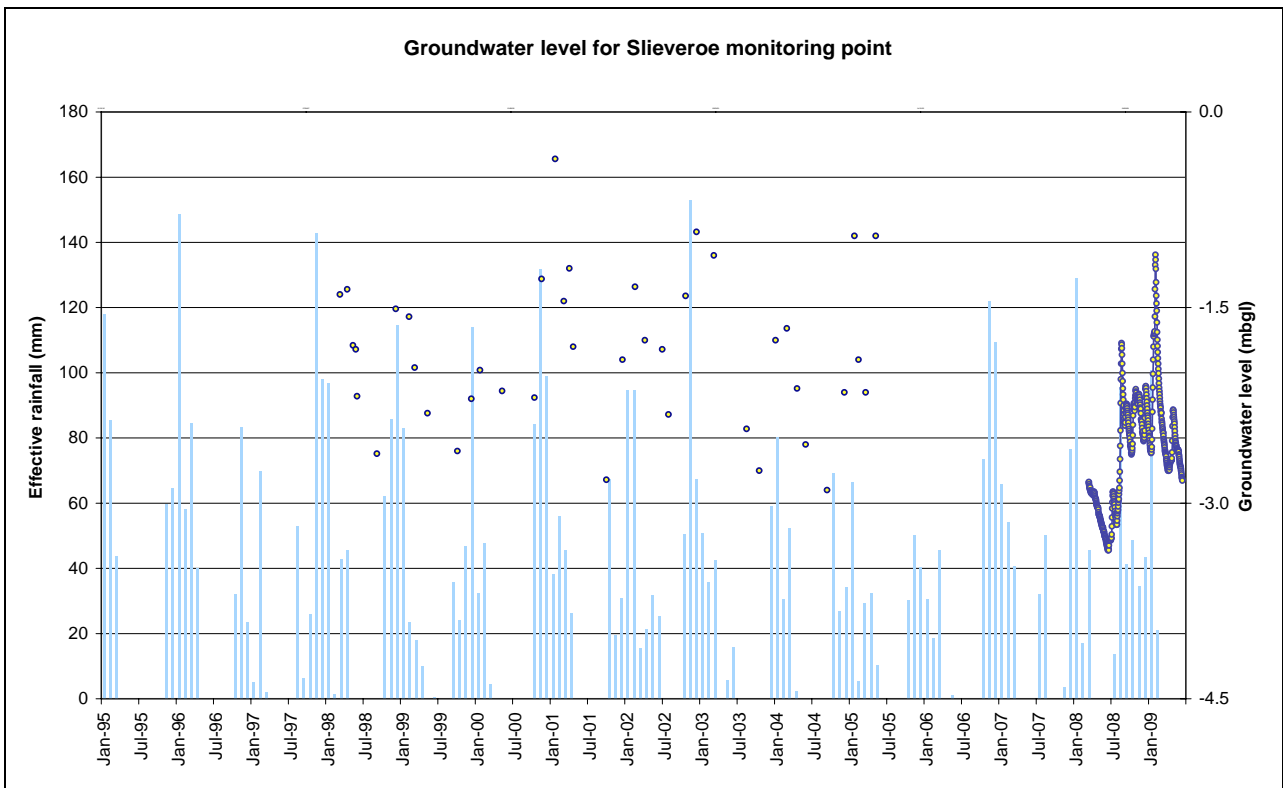


Figure C.22. Groundwater hydrograph for Slieveroe monitoring point.

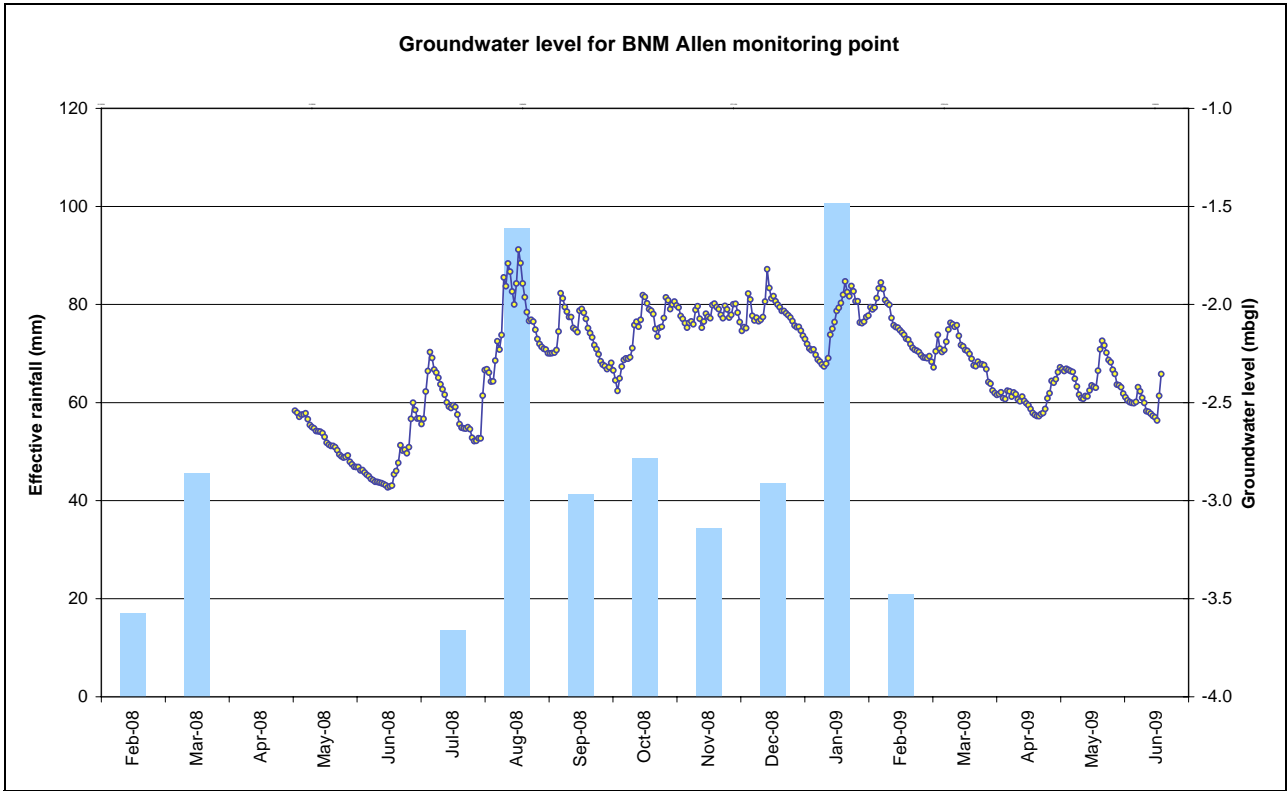


Figure C.23. Groundwater hydrograph for Bord na Móna Allen monitoring point.

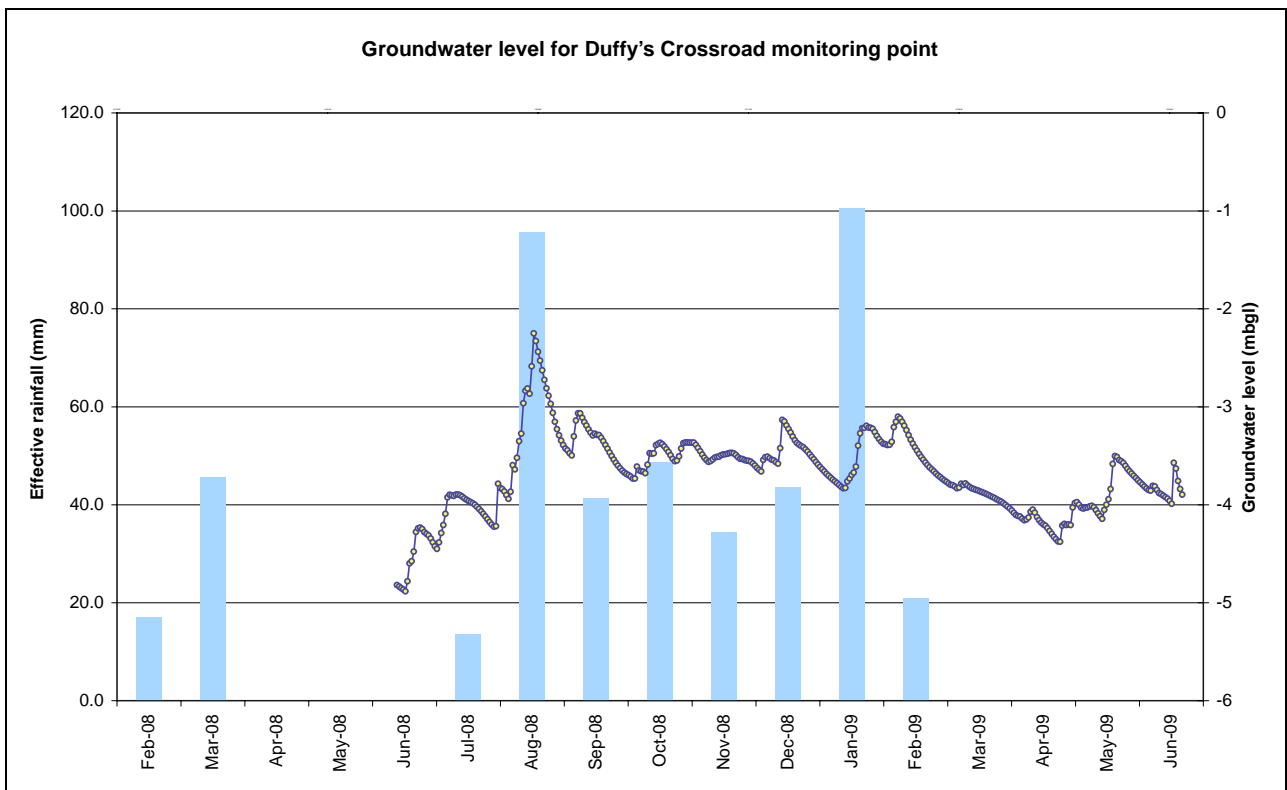


Figure C.24. Groundwater hydrograph for Duffy's Crossroad monitoring point.

Appendix D Groundwater Hydrographs for Geological Survey of Ireland Historic Monitoring Points

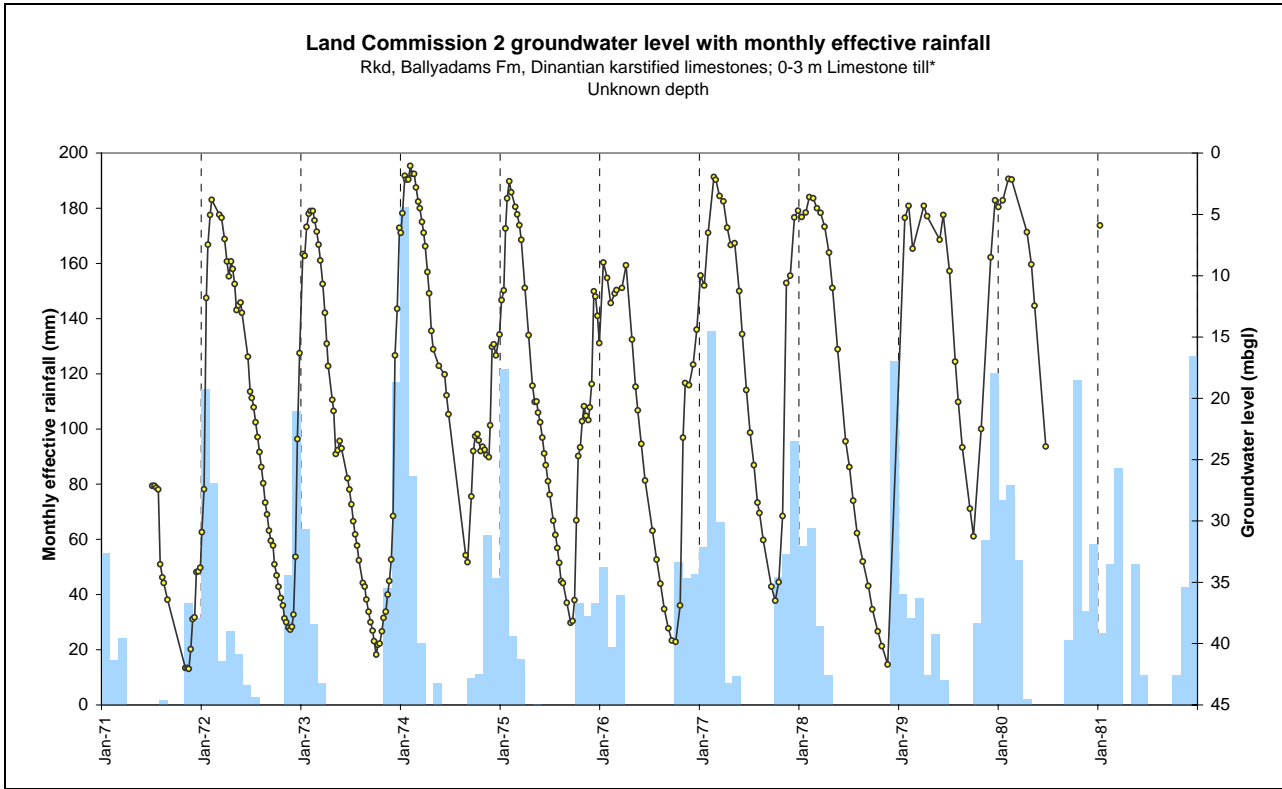


Figure D.1. Groundwater hydrograph for Land Commission 2 monitoring point.

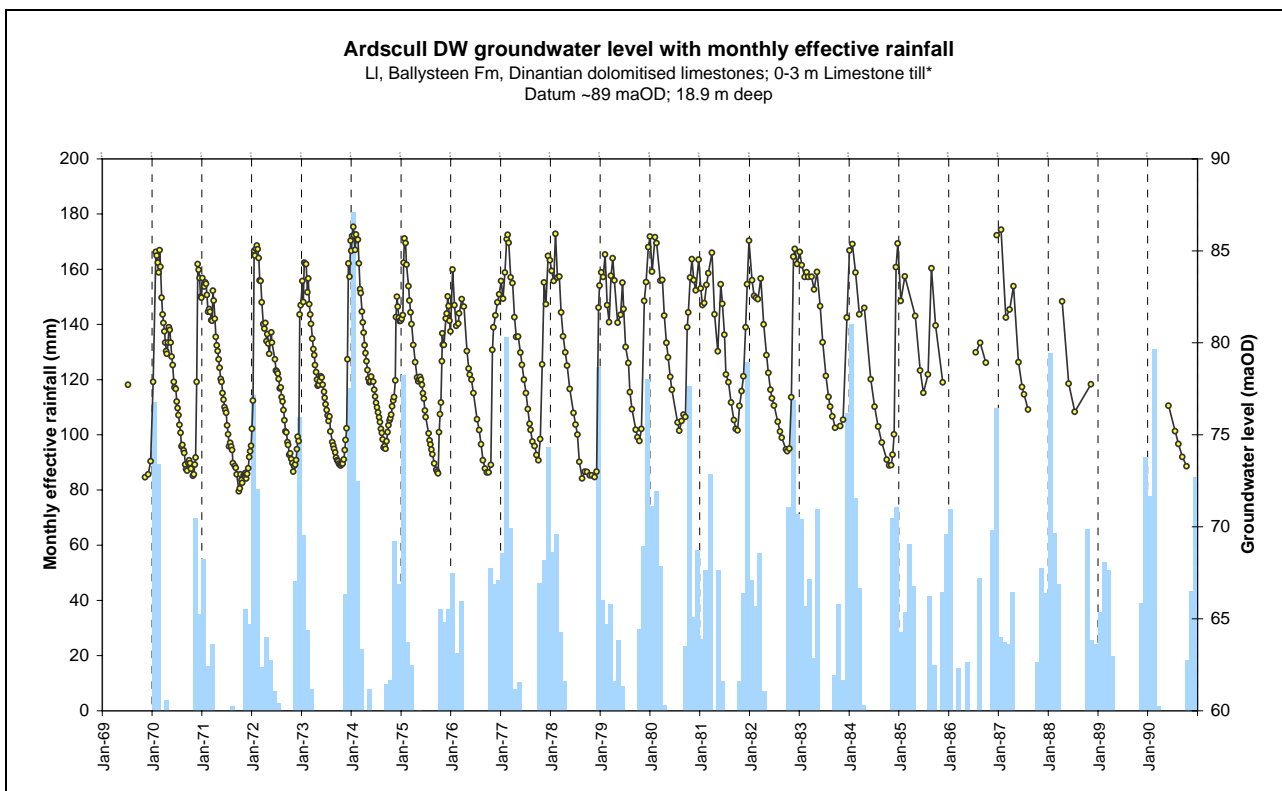


Figure D.2. Groundwater hydrograph for Ardsall DW monitoring point.

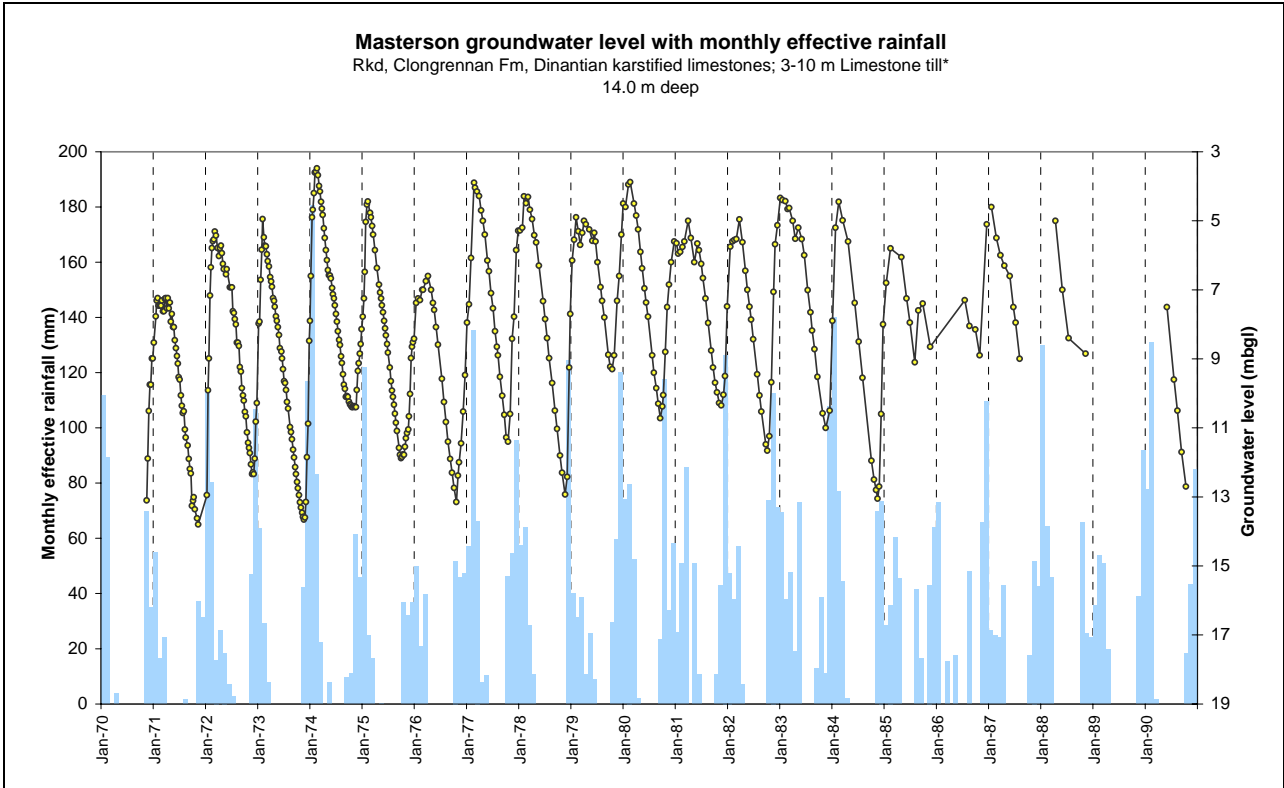


Figure D.3. Groundwater hydrograph for Masterson monitoring point.

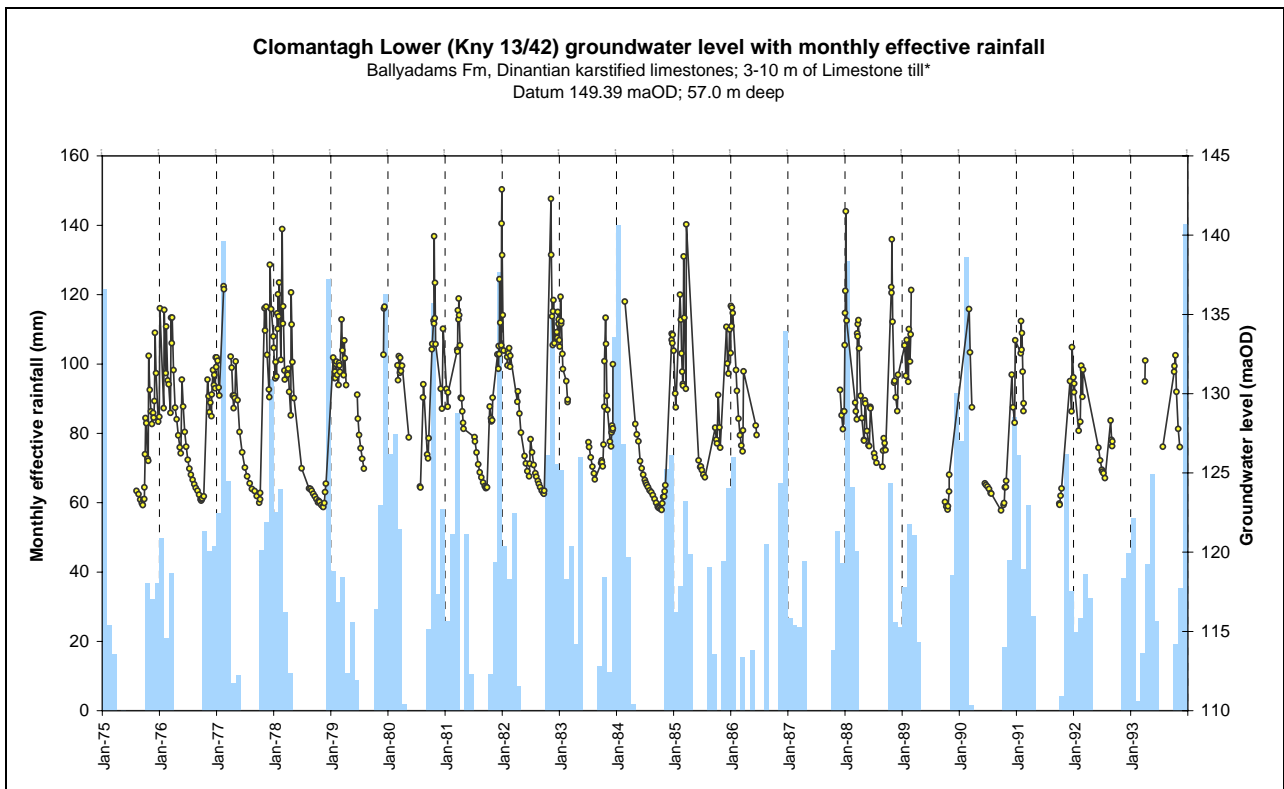


Figure D.4. Groundwater hydrograph for Clomantagh Lower monitoring point.

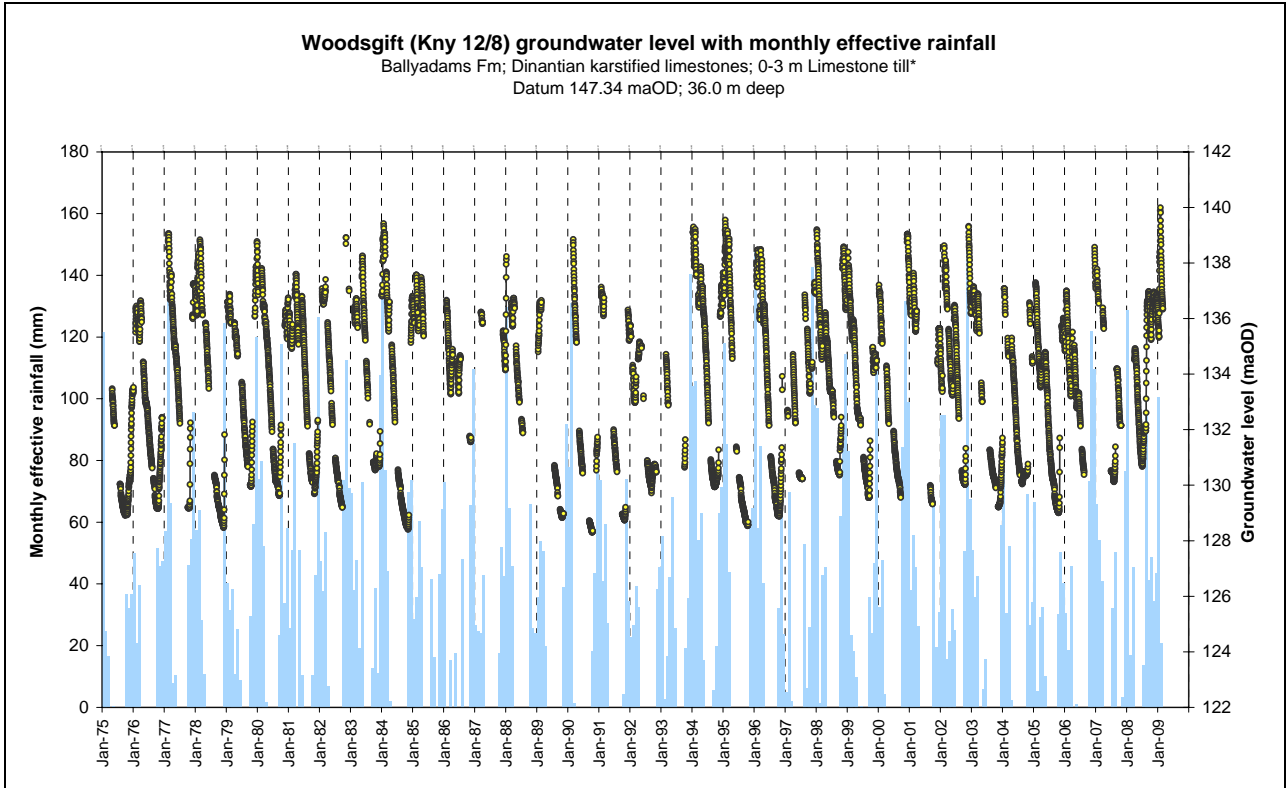


Figure D.5. Groundwater hydrograph for Woodsgift monitoring point.

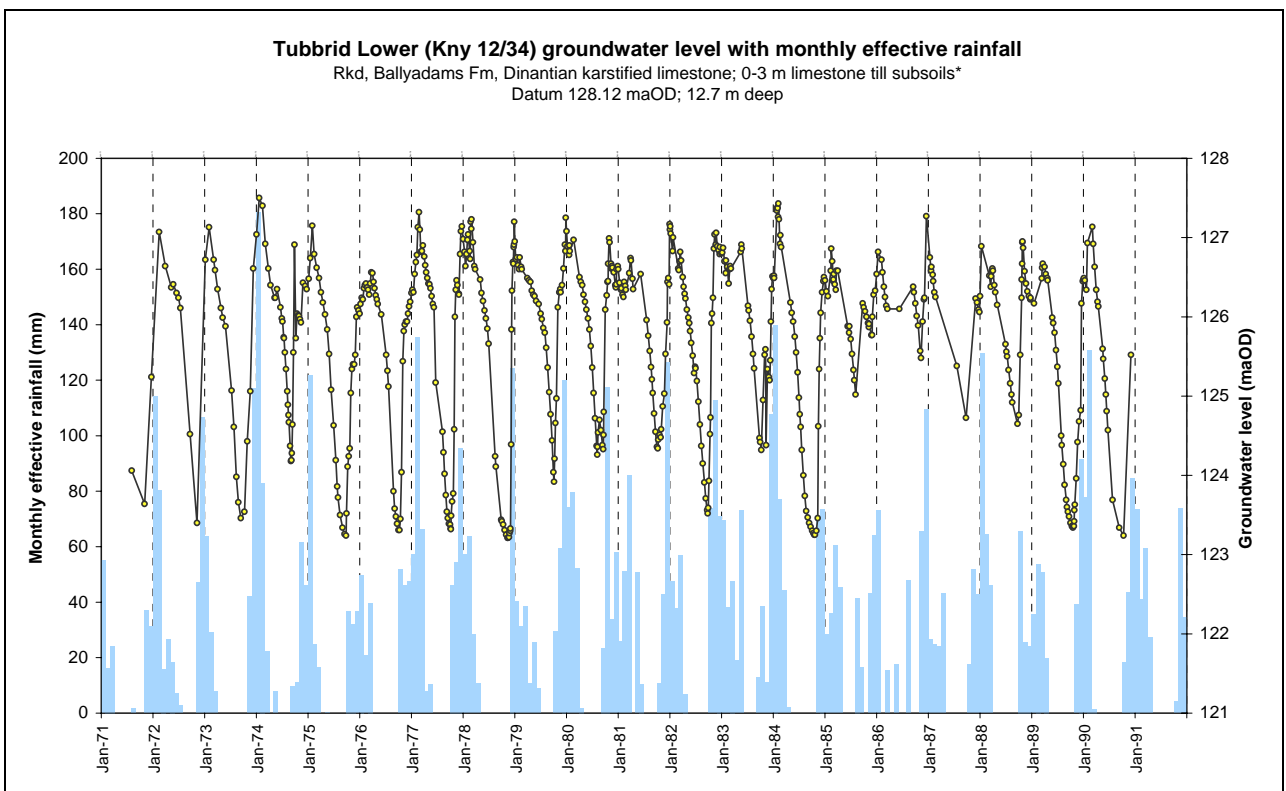


Figure D.6. Groundwater hydrograph for Tubrid Lower monitoring point.

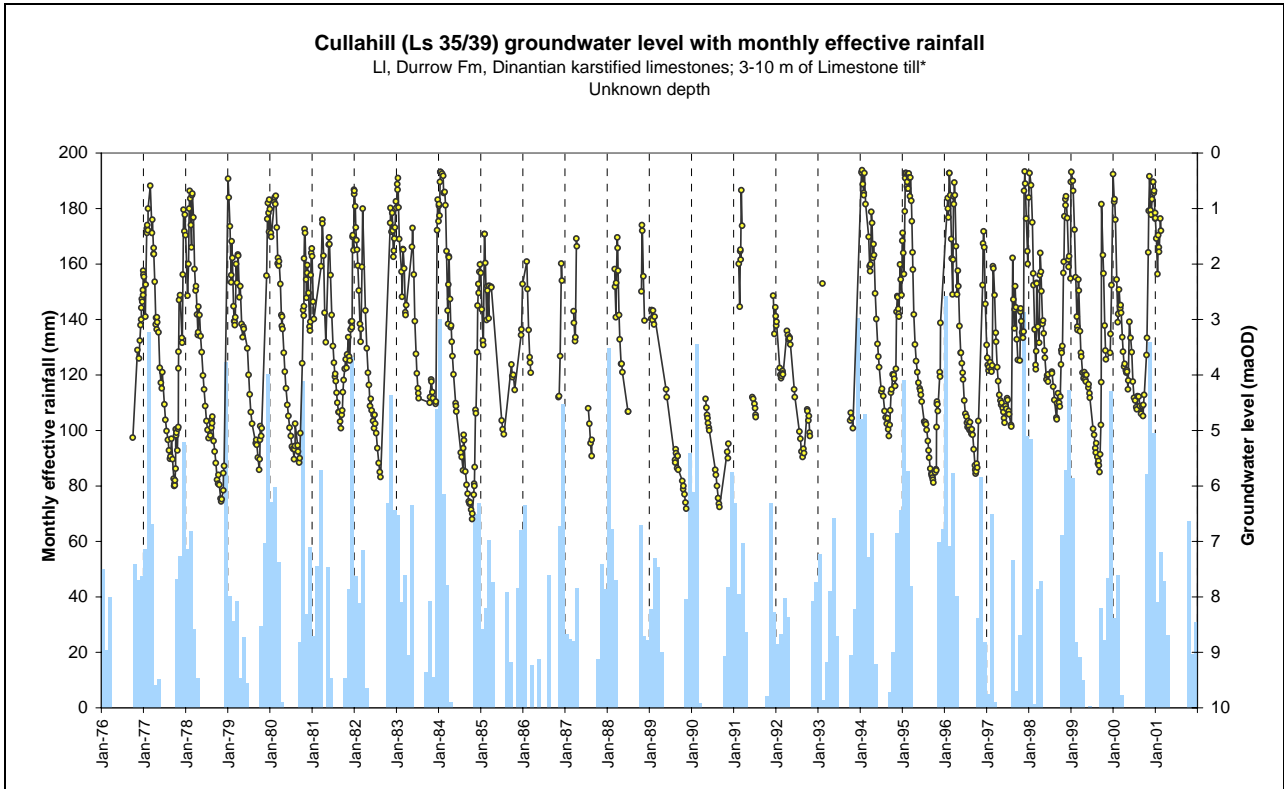


Figure D.7. Groundwater hydrograph for Cullahill monitoring point.

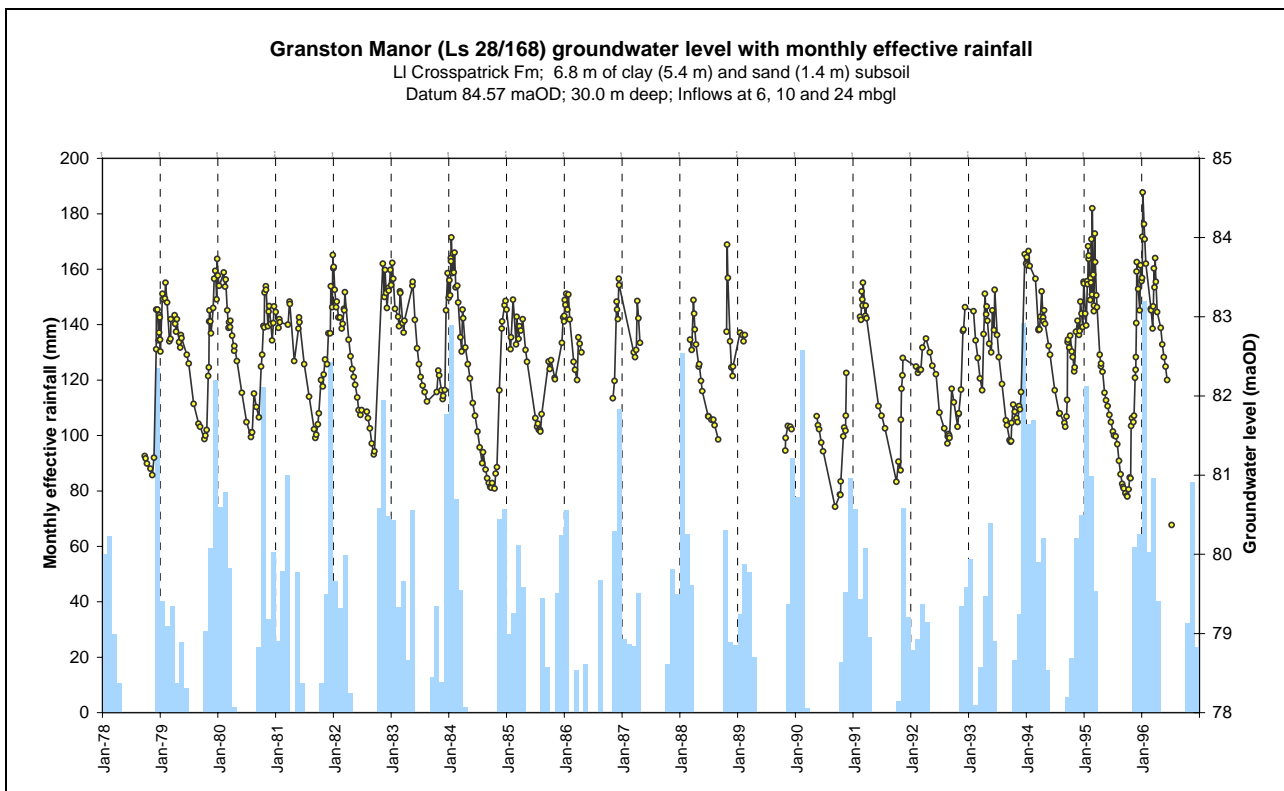


Figure D.8. Groundwater hydrograph for Granston Manor monitoring point.

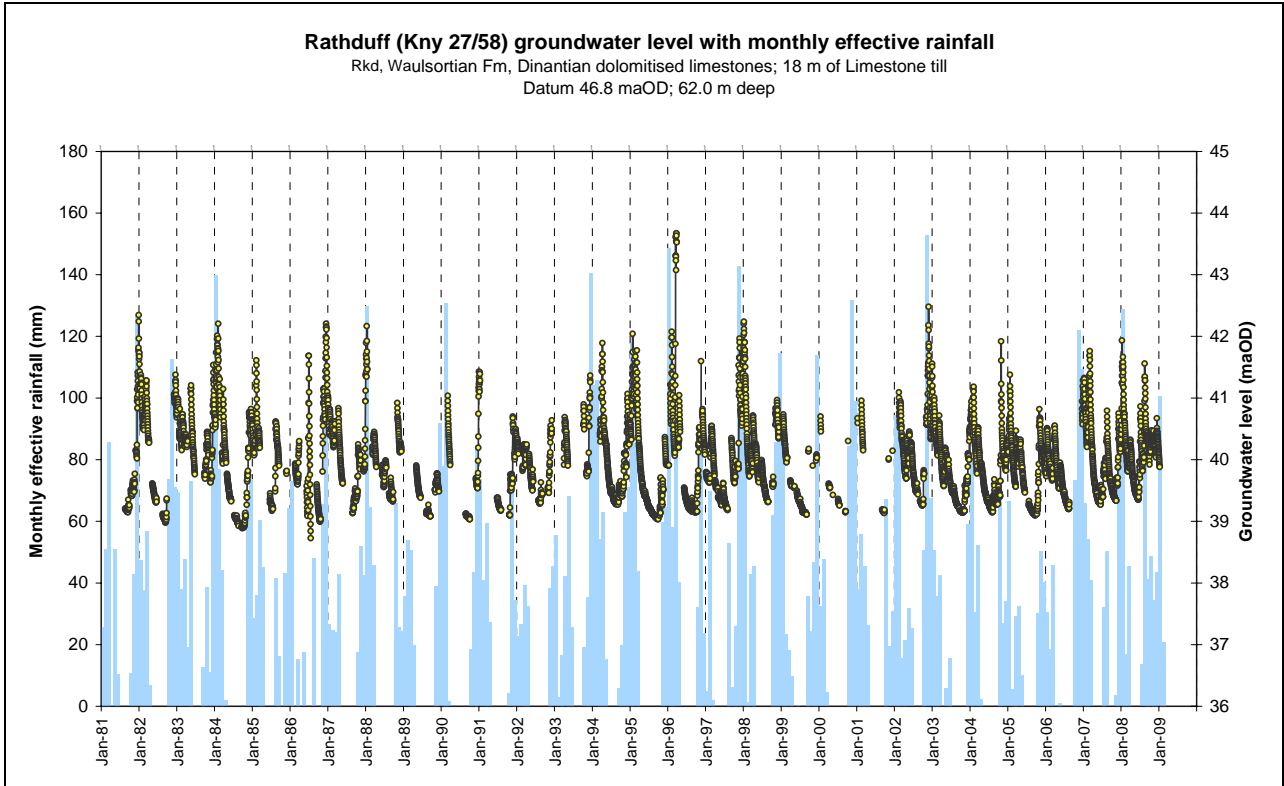


Figure D.9. Groundwater hydrograph for Rathduff monitoring point.

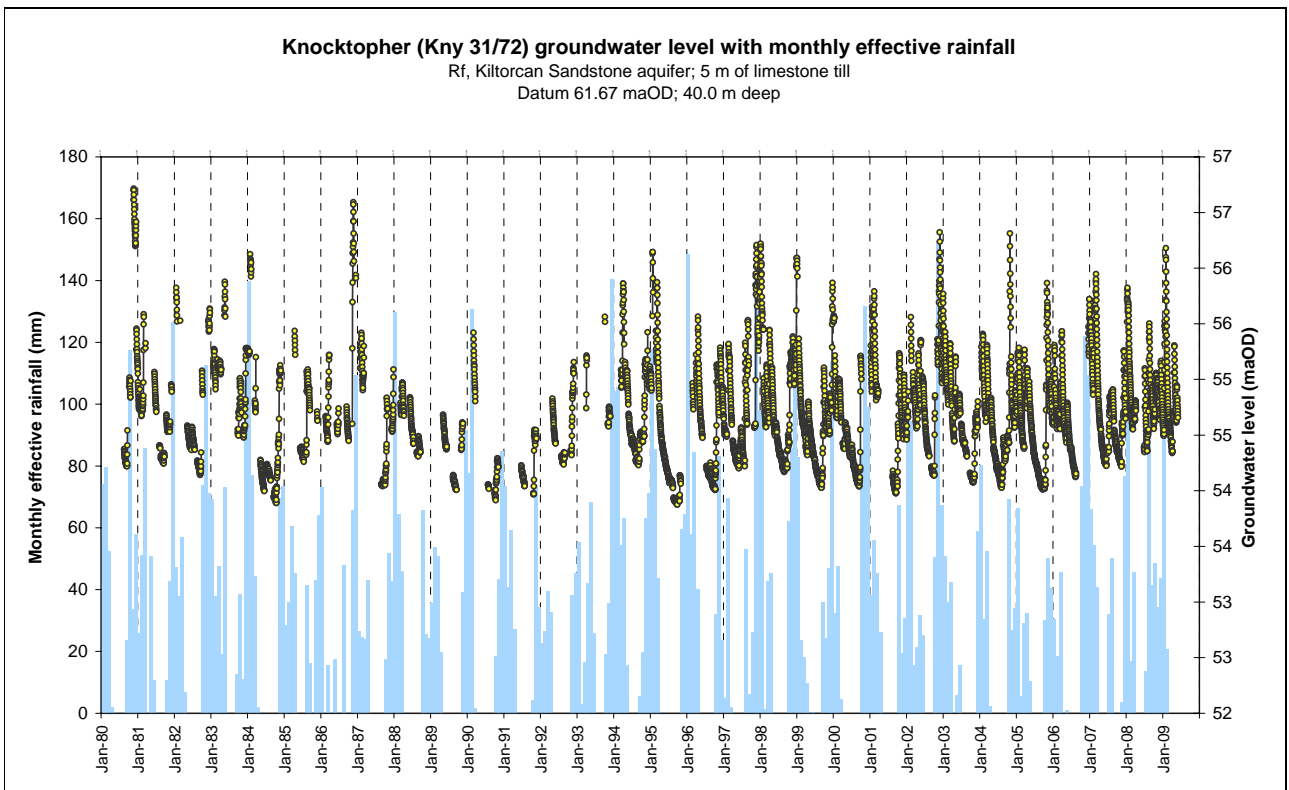


Figure D.10. Groundwater hydrograph for Knocktopher Manoir monitoring point.

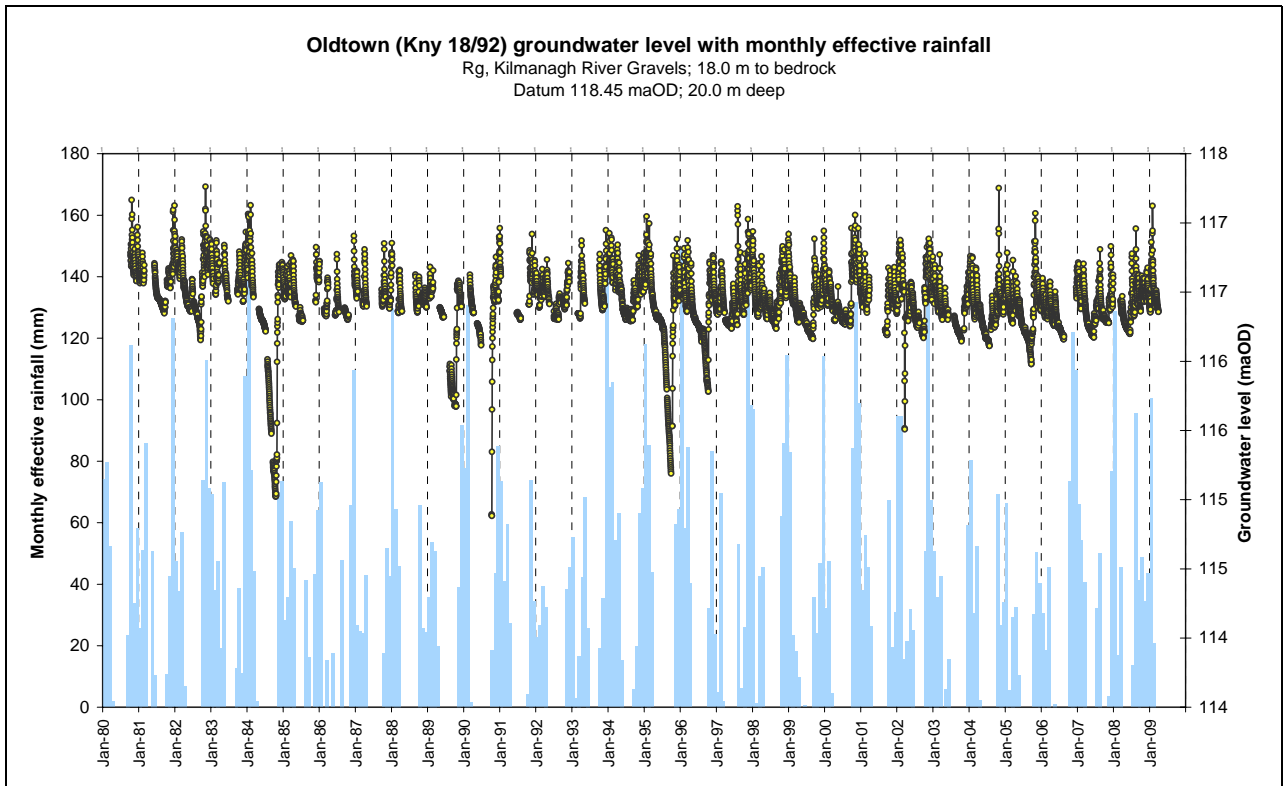


Figure D.11. Groundwater hydrograph for Oldtown monitoring point.

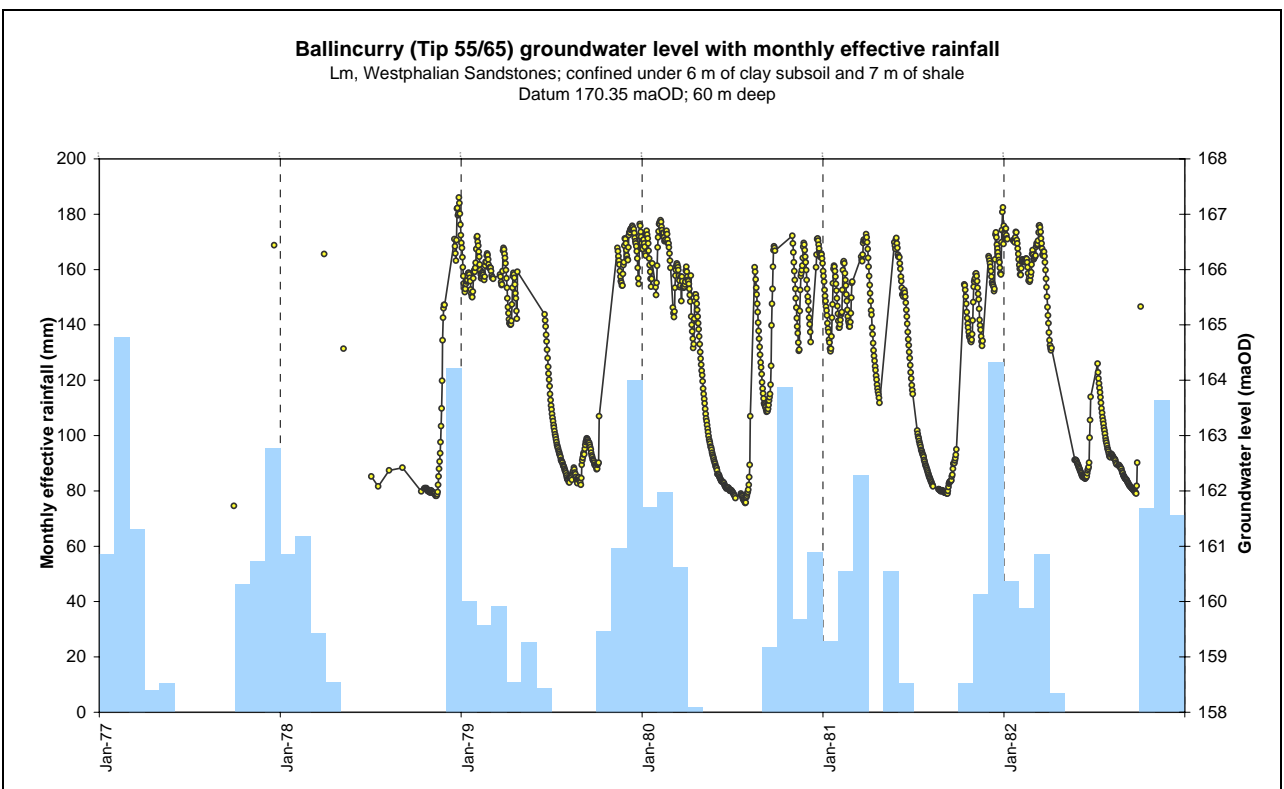


Figure D.12. Groundwater hydrograph for Ballincurry monitoring point.

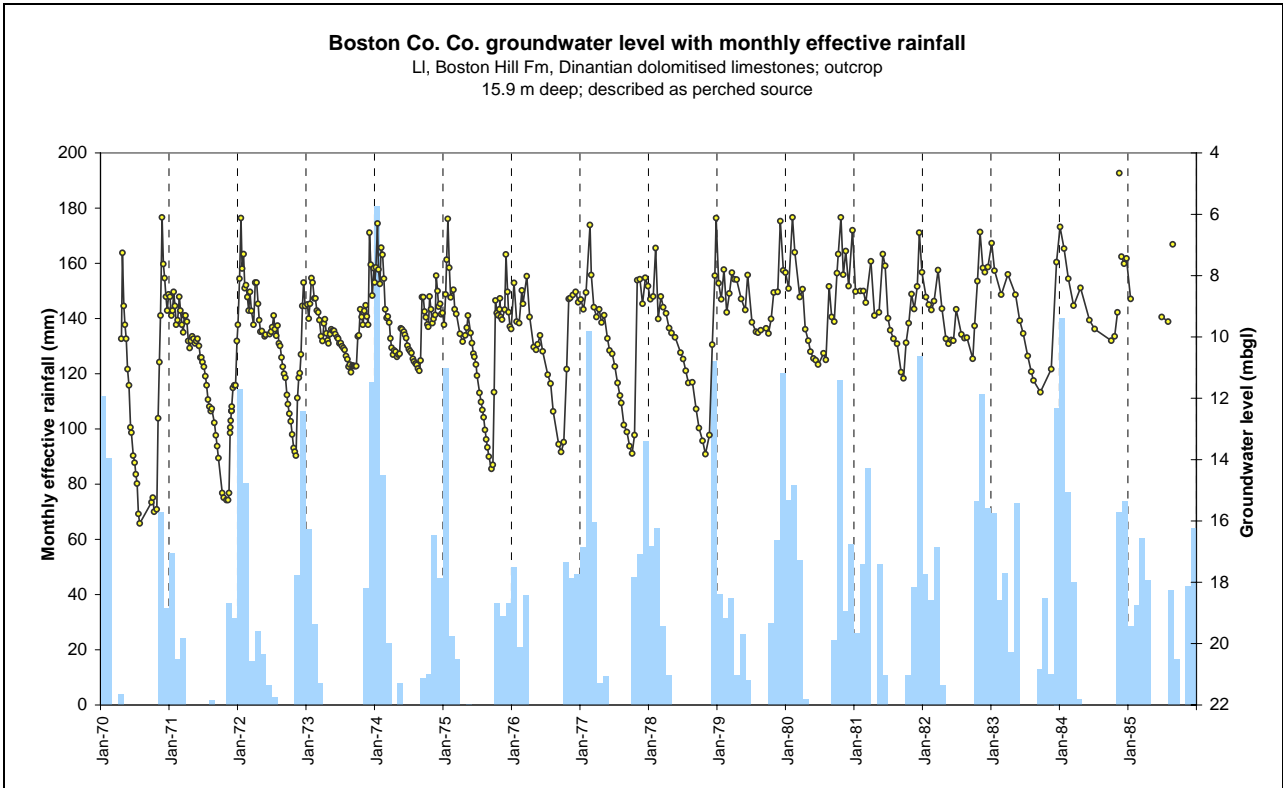


Figure D.13. Groundwater hydrograph for Boston Co. Co. monitoring point.

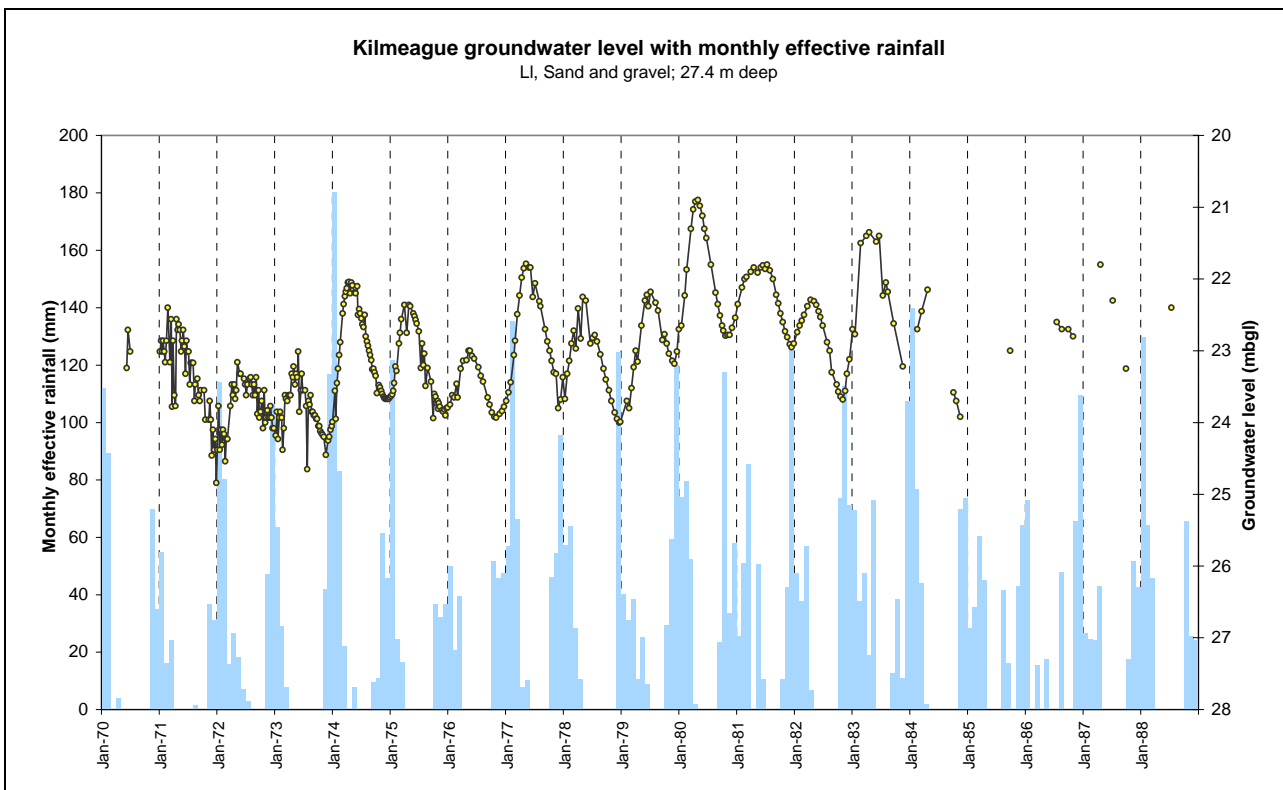


Figure D.14. Groundwater hydrograph for Kilmeague monitoring point.

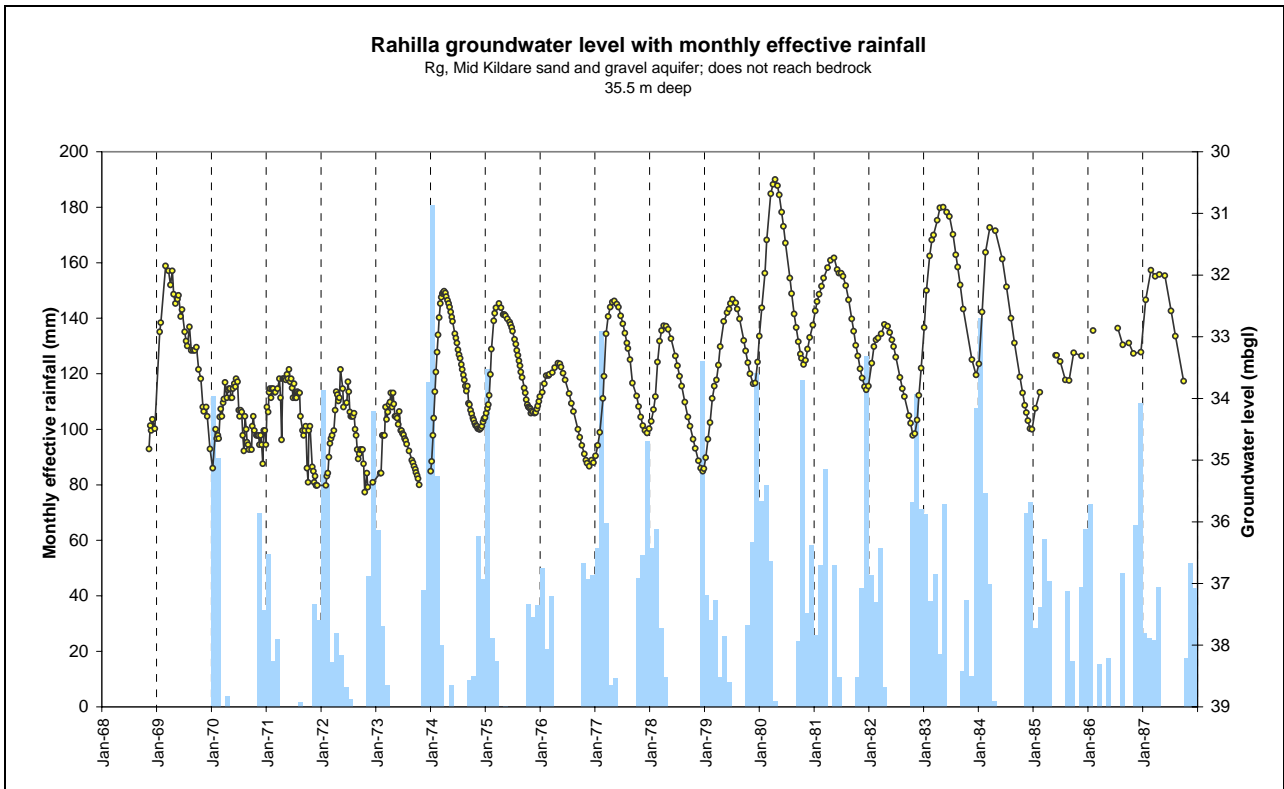


Figure D.15. Groundwater hydrograph for Rahilla monitoring point.

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaoil do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomhnithe a bhfuilimid gníomhach leo ná comhshaoil na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil, Pobal agus Rialtais Áitiúil.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaoil i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistriúcháin dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreal;
- scardadh dramhuisce.

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí chomhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaoil mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOIL

- Monatóireacht ar chaighdeán aer agus caighdeán aibhneacha, locha, uisce taoide agus uisce talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntiú a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdeán aer agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaoil na hÉireann (cosúil le plananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaoil a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózón.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaoil na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstíúrthóir agus ceithre Stíúrthóir.

Tá obair na Ghníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Chomhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

The EPA's Environmental Research Centre (ERC) was established as a centre of excellence under the National Development Plan (NDP) to build capacity in environmental data handling, modelling, assessment and guidance. The objective of the ERC is to allow for a more structured approach to environmental research, through the development of advanced innovative techniques and systems to address priority environmental issues and thereby support environmentally sustainable development.