Offaly County Council

# Establishment of Groundwater Source Protection Zones

## Tullamore Water Supply Scheme

## Ardan Boreholes


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## Document control information

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| | | | | |

# Project description

Since the 1980's, the Geological Survey of Ireland (GSI) has undertaken a considerable amount of work developing Groundwater Protection Schemes throughout the country. Groundwater Source Protection Zones are the surface and subsurface areas surrounding a groundwater source, *i.e*. a well, wellfield or spring, in which water and contaminants may enter groundwater and move towards the source. Knowledge of where the water is coming from is critical when trying to interpret water quality data at the groundwater source. The Source Protection Zone also provides an area in which to focus further investigation and is an area where protective measures can be introduced to maintain or improve the quality of groundwater.

Offaly County Council contracted GSI to delineate source protection zones for the groundwater public water supply source boreholes at Ardan, Tullamore, Co. Offaly.

This report documents the delineation of the source protection zones for the Ardan boreholes.

A suite of maps and digital GIS layers accompany this report and the reports and maps are hosted on the GSI website (www.gsi.ie).

# TABLE OF CONTENTS

# TABLES



# FIGURES



# APPENDICES

# 1 Introduction

Groundwater Source Protection Zones (SPZ) have been delineated for the Tullamore (Ardan) Public Water Supply Scheme according to the principles and methodologies set out in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999) and in the GSI/EPA/IGI training course on Groundwater SPZ Delineation.

The Ardan Boreholes comprise two production boreholes, which are labelled Ardan Borehole No.1 and Ardan Borehole No.2 by Offaly County Council. Henceforth in this report they are called PW01 and PW02. There is a further trial borehole in the area (labelled the "Chip Depot Borehole" by Offaly County Council) which has not yet been commissioned. Offaly County Council have plans to bring the borehole into supply at some point in the future. The Chip Depot Borehole is called BH07 in this report.

Tullamore WSS is currently supplied from a number of sources. These are: the Clodiagh and Gorragh Rivers (combined abstraction of 1,000 $m^3$/day June to October and 2,270 $m^3$/day November to May); the Clonsalee Boreholes (in Co. Laois, 1,700 $m^3$/day); Sillogue Spring (3,410 $m^3$/day); and the Ardan Boreholes (2,380 $m^3$/day). It is anticipated that a further 1,000 $m^3$/day will be provided by the Chip Depot Borehole at Ardan once it has been commissioned. The source protection zones for PW01 and PW02 only are described in this report.

The objectives of the study were:

- To outline the principal hydrogeological characteristics of the Ardan area where the production and trial boreholes are located.
- To delineate source protection zones for the production and trial boreholes.
- To assist Offaly County Council in protecting the water supply from contamination.

The protection zones are intended to provide a guide in the planning and regulation of development and human activities to ensure groundwater quality is protected. More details on protection zones are presented in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

# 2 Methodology

The methodology applied to delineate the SPZ consisted of data collection, desk studies, site visits and field mapping, and subsequent data analysis and interpretation.

A desk study of existing data sources was carried out prior to a site visit. Site visits and walk-over, and field mapping of the study area were conducted on 22/06/2011 and, 14, 21 and 22/07/2011. An interview with the scheme caretaker was carried out on 22/06/2011.

While specific fieldwork was carried out in the development of this report, the maps produced are based largely on the readily available information and mapping techniques using inferences and judgements from experience at other sites. As such, the maps may not be definitively accurate across the whole area covered, and should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

# 3 Location, site description and well head protection

Ardan boreholes PW01 and PW02 are located 80 m apart on the site of the Ardan water treatment works (WTW) in the townland of Ardan, Tullamore, Co. Offaly. The WTW site is located adjacent to the R421 road, approximately 2.5 km north of Tullamore town centre. Trial borehole BH07 is located on a County Council storage yard located 460 m southwest of the WTW site. The two sites and the positions of the three boreholes are shown on Figure 1.

Both production boreholes are set in 1 m by 3 m, flat concrete plinths which are set approximately 0.1 m above ground level (Photos 1 and 2). In each case the mouth of the borehole casing rises approximately 0.1 m above the floor of the plinth. Each plinth is covered by a stainless steel chamber with a lockable, hinged, peaked roof for access, which houses the borehole and digital flow meter. The ventilation grill is missing from the chamber of borehole PW02, thereby exposing the chamber to ingress of small animals. Raw water sampling taps for each borehole are located on the outside of the water treatment plant building and are connected to their respective boreholes by 12 mm diameter pipes. The borehole log for borehole PW01 records the installation of a grout seal to a depth of 24 mbgl. There are no data with respect to a grout seal for borehole PW02.

The storage yard containing borehole BH07 is located on the opposite side of the R421 road (Photo 3). The yard is used for storage of road chippings. The borehole casing rises 0.22 m above the ground surface and is capped by a lockable, hinged steel lid. There are no data with respect to a grout seal for borehole BH07.


Photo 1: Borehole PW01


Photo 2: Borehole PW02


Photo 3: Borehole BH07

# 4 Summary of well details

The well details are derived from various hydrogeological investigation reports and accompanying borehole logs prepared between 1999 and 2008 by Geotechnical & Environmental Services Ltd. (GES). The borehole logs for boreholes PW01, PW02 and BH07 are provided in Appendix 1.

Borehole PW01 was drilled by Dunnes Water Services Ltd. with GES as hydrogeological consultants in September 1999. Boreholes PW02 and BH07 were drilled in May – June 2001 (PH McCarthy, 2008).

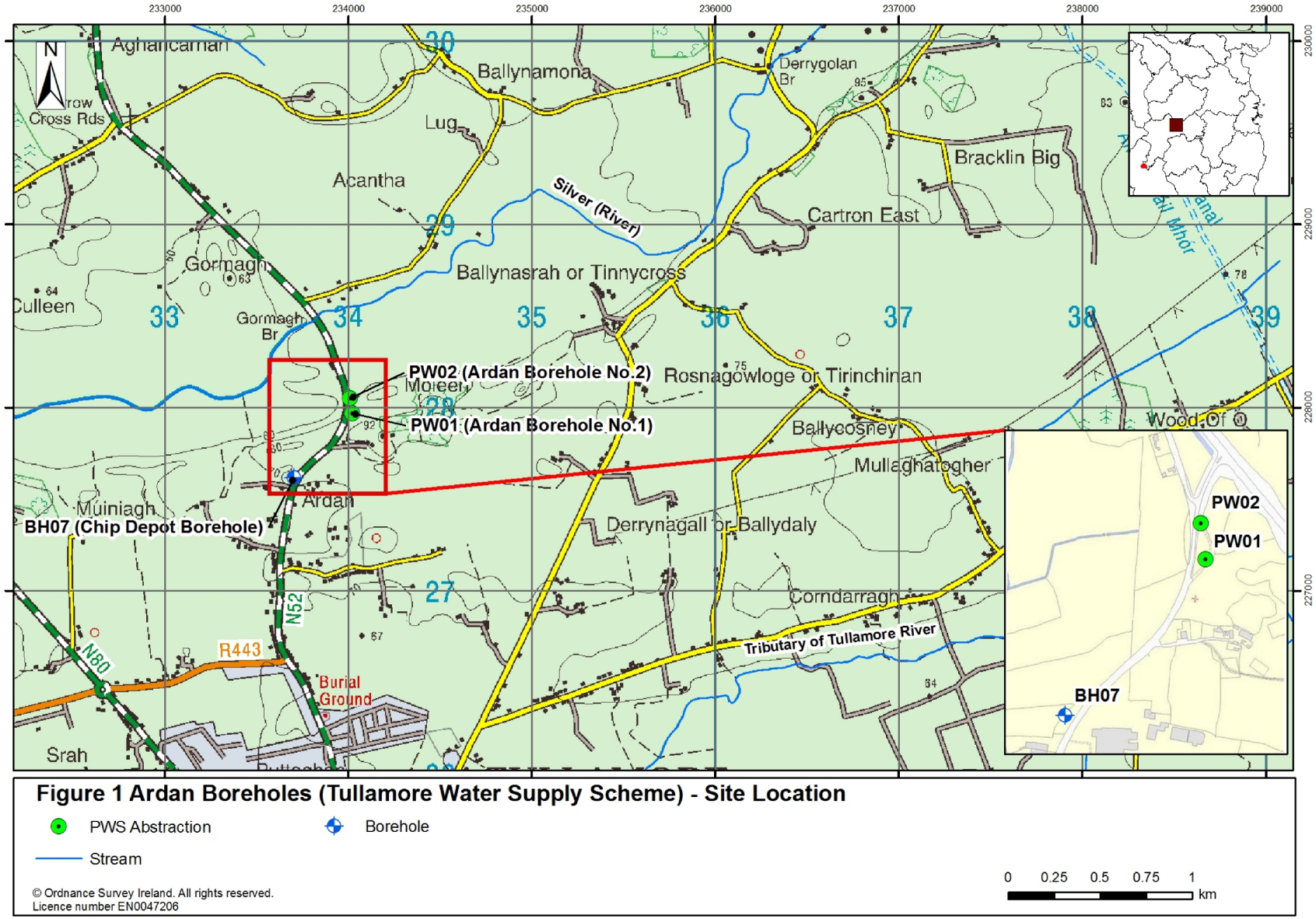


**Figure 1 Ardan Boreholes (Tullamore Water Supply Scheme) - Site Location**

PWS Abstraction
Borehole
Stream

0 0.25 0.5 0.75 1 km



**Figure 1 Ardan Boreholes (Tullamore Water Supply Scheme) – Site Location**

**Table 1: Well Details for Ardan Boreholes**

| | PW01 | PW02 | BH07 |
|---|---|---|---|
| Grid ref. (GPS) (ING) | X: 234019<br>Y: 227969 | X: 234008<br>Y: 228050 | X: 233703<br>Y: 227618 |
| Other Names | Ardan Borehole No.1 | Ardan Borehole No.2 | Ardan Chip Depot Borehole |
| Townland | Ardan | | |
| Source type | Borehole | | |
| Drilled | 1999 | 2001 | 2001 |
| Owner | Offaly County Council | | |
| Elevation (ground level) (mAOD) | 68.92 | 65.16 | 71.36 |
| Elevation (top of casing (tc)) (mAOD)<br>(i.e. datum for water level readings) | 68.98<br>(305 mm casing) | 65.27<br>(254 mm casing) | 71.57<br>(203 mm casing) |
| Depth (m) | 103.6 | 35 | 49 |
| Depth of casing | 0-12 mbgl @ 406 mm dia;<br>0-24 mbgl @ 305 mm dia. | 0-17.5 mbgl @ 250 mm dia;<br>0-25 mbgl @ 200 mm dia;<br>21-35 mbgl @ 160 mm dia. (slots cut with torch @ 21-33 mbgl) | 0-15 mbgl @ 250 mm dia;<br>0-35 mbgl @ 200 mm dia;<br>33-45 mbgl @ 160 mm dia. (slots cut with torch @ 33 to 45mbgl);<br>open hole 45-49 mbgl |
| Grout Seal | Yes | None recorded on Borehole Log | None recorded on Borehole Log |
| Diameter (mm) | 300 | 250 | 200 |
| Depth to rock (m) | 12.2 | 15 | 15 |
| Water Strikes | > 2,180m$^3$/day from 72 to 103 mbgl | Fissure @ 35 mbgl with silty dirty water | unknown |
| Static water level (mbtc) | 11.78 (11/10/99) | unknown | 14.11 (22/07/11) |
| Pumping water level (mbtc) | 14.69 (22/07/11) | 11.00 (22/04/11) | not applicable |
| Consumption (Co. Co. records) (m$^3$/day) | 1,325 | 761 | not applicable |
| Pumping test summary:<br>(i) abstraction rate (m$^3$/day) | 2,560 | 1,579 | 1,320 |
| (ii) specific capacity (m$^3$/day/m) | 370 | 1,070 – 3,948 | 237 |
| (iii) transmissivity (m$^2$/day) | 318 | unknown | 275 - 740 |

# 5 Topography, surface hydrology, landuse

The production boreholes and trial boreholes are located on an east to northeast trending esker at elevations between 65.2 m and 71.4 mAOD. The esker dominates the study area topography and extends for over 20 km west to east to the north of Tullamore, reaching an elevation of 92 mAOD in the vicinity of the boreholes. Once off the steep-sided esker, regionally the land slopes gently southwest. On the local scale slopes have a component toward the major surface water features in the study area, *i.e.* the Silver River and Tullamore River respectively (Figure 1).

The wells are located between the Silver and Tullamore rivers, which run parallel to each other in a westerly direction, on either side of the gravels. The Silver River flows along the north-western

flank of the esker while the Tullamore river course is between 3 km and 5 km further south. A visual survey of the Silver River between Gormagh Bridge and Derrygolan Bridge identified several river reaches flowing directly over bedrock, suggesting that the river is not perched above groundwater within the study area.

The Grand Canal flows west to east through Tullamore approximately 2.5 km south of the source boreholes, but is perched above the natural hydrological catchment.

Drainage density is low in the area immediately east of the source boreholes, with several square kilometres showing no mapped surface water features. Apart from areas of bog and alluvial flats adjacent to the main rivers, the land surface is well drained with no indicators of poor drainage conditions.

The landuse in the catchment is predominantly agricultural with most fields given over to pasture, and occasional tillage. The esker has been quarried extensively and there are several pits and a large concrete works in close proximity to the boreholes. The Tullamore urban area is located 1.3 km south of the source boreholes. There are numerous domestic residences and residential farms along the roadsides to the north and east of the source boreholes.

# 6 Hydrometeorology

Establishing groundwater source protection zones requires an understanding of general hydrometeorological trends across the area of interest. This information was obtained from Met Éireann.

***Annual rainfall:*** 834 mm. The closest meteorological stations to the study area are Daingean (13.5 km east) and Boora (18 km west-southwest), which record annual average rainfall from 1961 to 1990 as 838 mm and 829 mm per annum respectively (Fitzgerald and Forrestal, 1996). This gives an average of 834 mm/yr for the study area.

***Annual evapotranspiration losses:*** 423 mm. The closest synoptic weather stations to the study area are Mullingar (27km north) and Birr (35 km southwest), and which record average potential evapotranspiration (P.E.) of 446 and 445 mm/yr between 1961 and 1990 (Fitzgerald and Forrestal, 1996) respectively. This gives an average of 445 mm/yr. Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits giving an Actual Evapotranspiration of 423 mm/yr.

***Annual Effective Rainfall:*** 411 mm. The annual effective rainfall (*i.e.* potential recharge) is calculated by subtracting Actual Evapotranspiration from rainfall.

# 7 Geology

## 7.1 Introduction

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

The desk study data used comprised the following:

- Reports on groundwater resources investigations in the Ardan area for the Tullamore Regional Water Supply Scheme between 1999 and 2008 (GES, 1999 to 2008);
- Boreholes' logs of trial wells and production wells from the Ardan study area by Dunnes Water Services Ltd and GES, 1999 to 2008;
- Geology of Galway - Offaly. Bedrock Geology 1:100,000 Scale Map, Sheet 15. Geological Survey of Ireland (Gatley *et al*, 2005);
- EPA Subsoils Map (Teagasc, 2006).

## 7.2 Bedrock geology

Sheet 15, the Geology of Galway - Offaly published by the GSI indicates that the area is underlain by the bedrock types described in Table 2. Table 2 shows the strata in stratigraphic order from youngest to oldest. The distribution of the various bedrock units is shown in Figure 2.

**Table 2: Bedrock Descriptions around the Ardan locality**

| Bedrock Formation | Generalised Rock Unit Classification | Geological Description | Thickness (m) (Gatley *et al*, 2005) |
|---|---|---|---|
| Lucan Formation (LU) (also known as "Calp") | Dinantian Upper Impure Limestones | Dark, well-bedded, fine grained clayey limestone with calcareous mudstones | 500 to approx. 800 m |
| Visean Limestones (undifferentiated) | Dinantian Pure Bedded Limestones (DPBL) | Undifferentiated Limestone | approx. 550 m |
| Allenwood Formation (AW) | Dinantian Pure Bedded Limestones (DPBL) | Poorly-bedded, medium to coarse grained limestone. Widespread dolomitisation. | 400 m |
| Waulsortian Formation (WA) | Dinantian Pure Unbedded Limestone (DPUL) | Pale grey, poorly-bedded, fine grained limestone containing frequent fossils. Small dolomitised pockets in the east of County Offaly. | Average of 200 to 300 m |
| Ballysteen Formation (BA) | Dinantian Lower Impure Limestone (DLIL) | Dark muddy limestone, shale | 150 to 400 m |

The bedrock in the east of the study area comprises an extensive belt of Lucan Formation limestone with interbedded shales. This area is separated from the undifferentiated Visean pure bedded limestones – which underlie the source boreholes and the western and south-western parts of the study area – by the SSW to NNE trending Knockshigowna Fault. This fault lies 2.7 km east of the source boreholes. An east to west trending cross fault abuts the Knockshigowna Fault 1.1 km north of the source boreholes, and separates the Visean limestones from the Waulsortian and Allenwood limestones that occur in the north-western part of the study area.

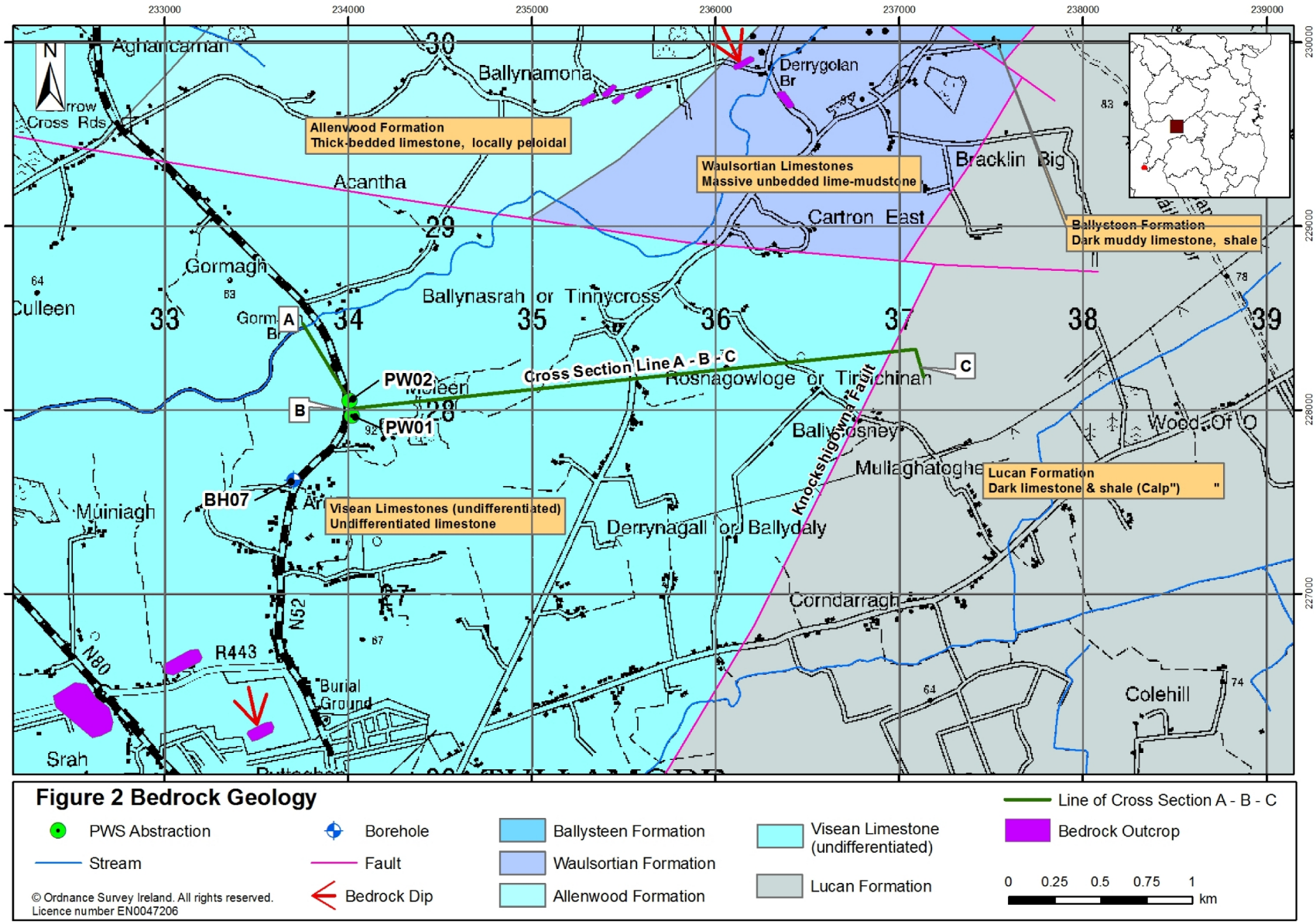


**Figure 2 Bedrock Geology of the Study Area**

The limestone layers dip south southeast at a low angle within the study area. Two major fault sets are present: NE-SW and SE-NW. The joint pattern is likely to have similar orientations (GSI, 1999).

The sequence of rock units in the vicinity of the source boreholes is recorded in the log for borehole BH06. BH06 was drilled at the Arden WTW as a trial borehole prior to the development of borehole PW01 (Appendix 1). This borehole encountered rock comprising dark grey to black, coarse grained limestone interbedded with weak, brittle, blue-grey, coarse grained limestone with clay-filled fissures from 12 mbgl. The bedrock was predominantly blue-grey limestone below 21 mbgl. In borehole PW01 fissured bedrock with clay-filled cavities was encountered between 72 m and 103 mbgl.

Several karst features are recorded in the GSI karst database in the Tinnycross area, 1.5 km east-northeast of the source boreholes. These include two springs, a swallow hole and a borehole with karst. During hydrogeological mapping of the area for this project several additional features were identified in the Tinnycross area, including a second swallow hole, a karst spring/dug well and several shallow enclosed depressions. Landowners in this area indicated that “land breaks” occur occasionally in the Tinnycross area. This is where underground collapse of a karst feature results in the appearance of a void at the ground surface. These features occur in the vicinity of the fault boundary between the Visean and Waulsortian limestones. Further east on the Calp limestone a landowner reported that land breaks also occur occasionally in the Derrygrogan Little area (not shown on maps), 6.7 km east of the source boreholes. Details of the karst features encountered are provided in Appendix 1 (Table A1.2 and Figure A1.1). Due to the regional NE to SW trend in the faults and the bedding strike, it is likely that karstification will have developed preferentially with the same northeast to southwest orientation.

## 7.3 Soil and subsoil geology

The distribution of subsoil and soil across the area are illustrated in Figures 3 and 4 respectively.

The subsoils in the vicinity of the source boreholes are dominated by esker and other glaciofluvial SAND and GRAVEL deposits derived from limestone. The esker deposits are comprised of coarse GRAVEL, COBBLES and BOULDERS. The esker ridge is flanked by, and in places smothered by, outwash SAND and GRAVEL deposits. In places where the subsoil map shows the esker truncated by the outwash deposits the core of the feature is known to be comprised of esker gravels (R. Meehan, personal communication, 21/07/2011). The SAND and GRAVEL deposits extend across a large area to the southeast of the source boreholes.

Away from these areas, the subsoils are predominantly comprised of till derived from limestone. Till is an unsorted mixture of gravels, sand, silt and clay, deposited by glacier ice. Large areas of peat also occur with large, cutover, raised bogs to the east and south of the SAND and GRAVEL deposits. Alluvial subsoils are mapped along the courses of the Tullamore and Silver Rivers, while isolated pockets of marl and lacustrine deposits occur in places. Extensive made ground occurs in the Tullamore urban area.

Small pockets of bedrock outcrop occur on the northwest side of Tullamore and along the Silver River. Additional areas of bedrock outcrop were identified along the Silver River during hydrogeological mapping for this project and these new areas are shown on Figure 3.

Borehole logs for boreholes PW01, BH02, BH06, BH07, BH09 and BH13 and anecdotal evidence for BH15 indicate that at these locations the esker and SAND and GRAVEL deposits lie directly on bedrock. At borehole BH12 in Ballyduff, 2.1 km to the west of the source boreholes, boulder clay was encountered beneath GRAVEL deposits on top of bedrock.

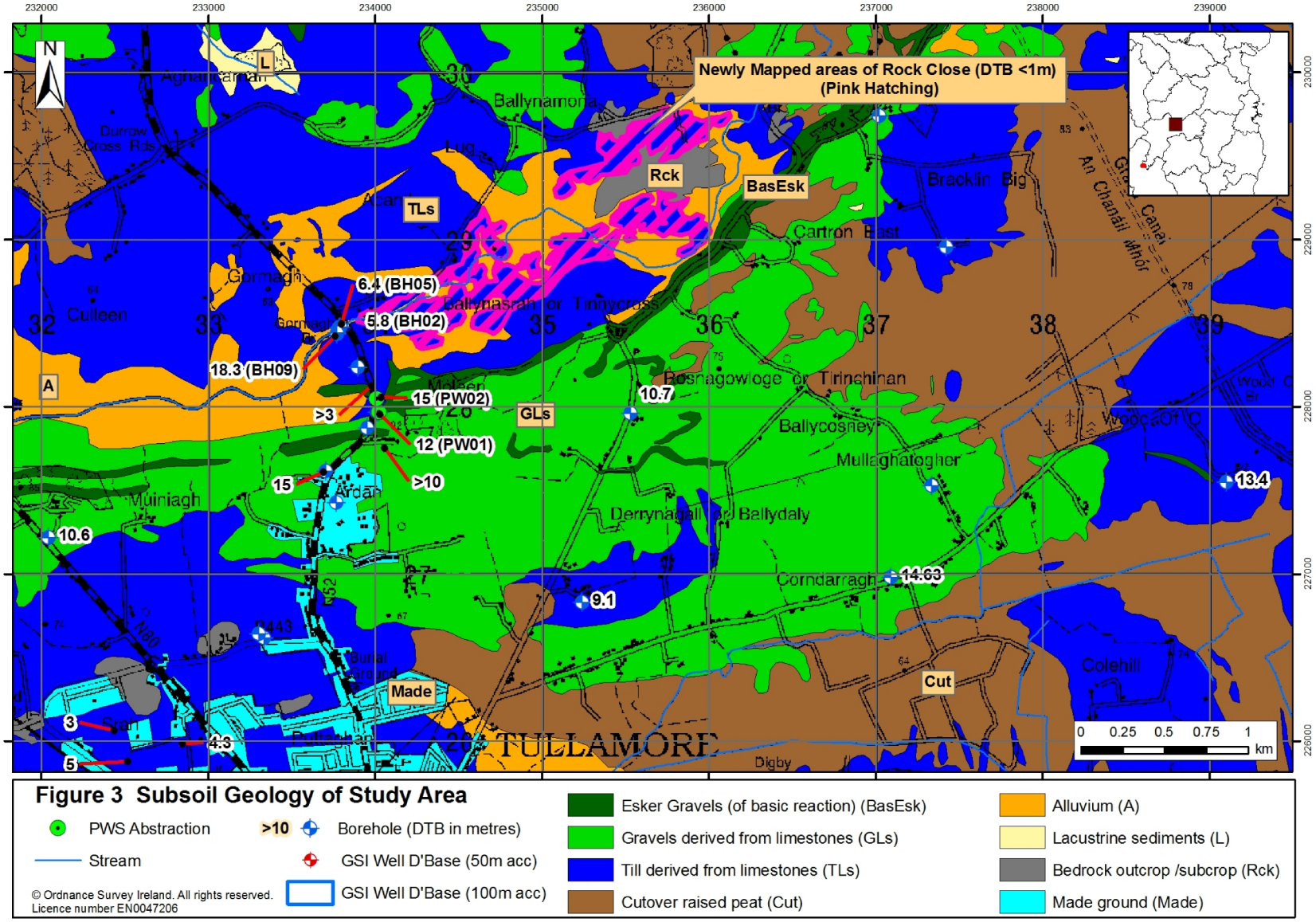


**Figure 3 Subsoil Geology of Study Area**

PWS Abstraction
>10 Borehole (DTB in metres)
Stream
GSI Well D'Base (50m acc)
GSI Well D'Base (100m acc)

Esker Gravels (of basic reaction) (BasEsk)
Gravels derived from limestones (GLs)
Till derived from limestones (TLs)
Cutover raised peat (Cut)

Alluvium (A)
Lacustrine sediments (L)
Bedrock outcrop /subcrop (Rck)
Made ground (Made)



**Figure 3 Subsoil Geology of Study Area**

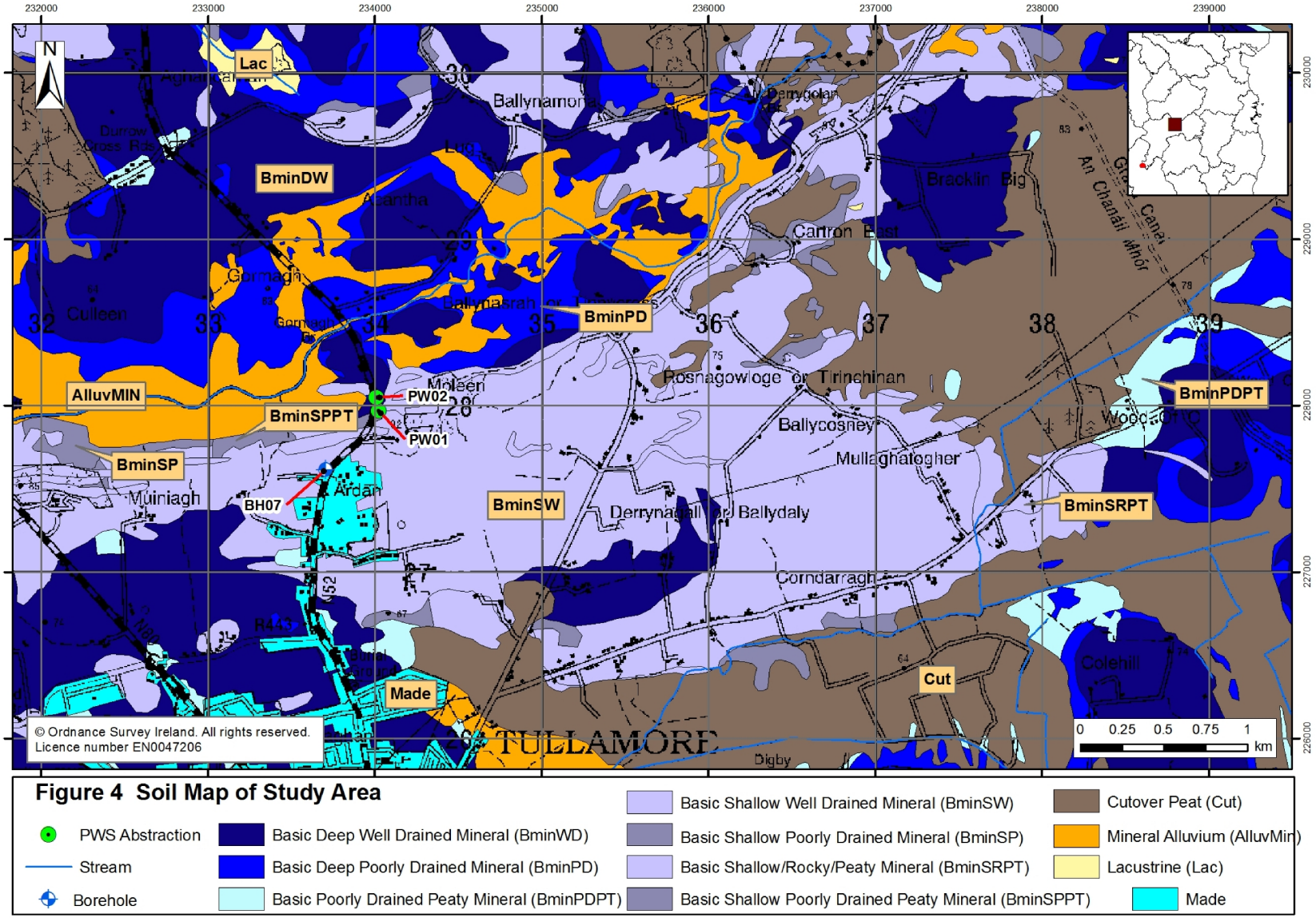


**Figure 4 Soil Map of Study Area**

PWS Abstraction
Stream
Borehole

Basic Deep Well Drained Mineral (BminWD)
Basic Deep Poorly Drained Mineral (BminPD)
Basic Poorly Drained Peaty Mineral (BminPDPT)

Basic Shallow Well Drained Mineral (BminSW)
Basic Shallow Poorly Drained Mineral (BminSP)
Basic Shallow/Rocky/Peaty Mineral (BminSRPT)
Basic Shallow Poorly Drained Peaty Mineral (BminSPPT)

Cutover Peat (Cut)
Mineral Alluvium (AlluvMin)
Lacustrine (Lac)
Made

**Figure 4 Soils Map of Study Area**

Four GSI auger holes were excavated into the limestone tills at distances between 6.3 and 8.5 km to the east and west of the source boreholes (beyond the map extremities in Figure 3). The tills at these locations were found to comprise slightly gravelly to gravelly SILT in three auger holes and gravelly SILT/CLAY in the fourth.

The esker gravels, glaciofluvial sands and gravels, and the limestone till deposits, are overlain by well drained soils, which are shallow on the gravels and deep on the till. Soils on limestone till are mapped as poorly drained in places where adjacent to surface watercourses or peat bogs. Poorly drained soils also occur over marl, lacustrine and alluvial subsoils.

The esker gravels and glaciofluvial sands and gravel deposits are considered to have high permeability. The limestone tills in the area are predominantly comprised of gravelly SILT and are considered to have moderate permeability. The peat, alluvial, lacustrine and marl deposits are considered to have low permeability.

The subsoil permeability observations correlate with the mapped soil types and are supported by field observations of generally well drained lands in the sand and gravel and till areas, and poorly drained soils where the peat, alluvial, lacustrine or marl deposits occur.

### 7.4 Depth to bedrock

Depth to bedrock (DTB) data for the area are shown on Figure 3. These show that in the areas underlain by esker or glaciofluvial sand and gravel deposits, the DTB is generally greater than 10 m. Across the limestone till areas, DTB varies between 4 and 15.2 m, but is generally between 5 and 10 m in the northwest and southeast, and greater than 10 m in the east of the study area.

Cut peat deposits are considered to be at least 1 m thick and are likely to be underlain by lacustrine and / or marl deposits such that the total DTB is considered to exceed 3 m. These deposits are likely to reach their maximum thickness at the centre of the cutover peat areas. Borehole BH09 on mapped alluvium adjacent to the Silver River at Gormagh Bridge encountered 18.3 m of subsoils, which were 9.5 m of CLAY and SILT alluvial deposits over GRAVEL. This suggests that DTB in some of the alluvial areas is likely to exceed 10 m.

Areas of bedrock outcrop and encompassing areas of “rock close” (*i.e.* DTB <1 m) are shown on the GSI groundwater vulnerability map. These occur on the northwest side of Tullamore and along the Silver River between the Gormagh and Derrygolan bridges. Additional areas of bedrock outcrop were mapped in this area during this project and are shown on Figures 3 and 5.

## 8 Groundwater vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater ‘target’. This means that the vulnerability relates to the permeability and thickness of the subsoil. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes document (DELG/EPA/GSI, 1999) and in the draft GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination (Fitzsimons *et al*, 2003).

The vulnerability map is shown in Figure 5. In terms of subsoil coverage within the catchment of the wells, the area can be divided into the following zones:

- The esker and glaciofluvial sand and gravel deposits and the limestone till deposits in the northwest and southeast of the study area are classified as high vulnerability.

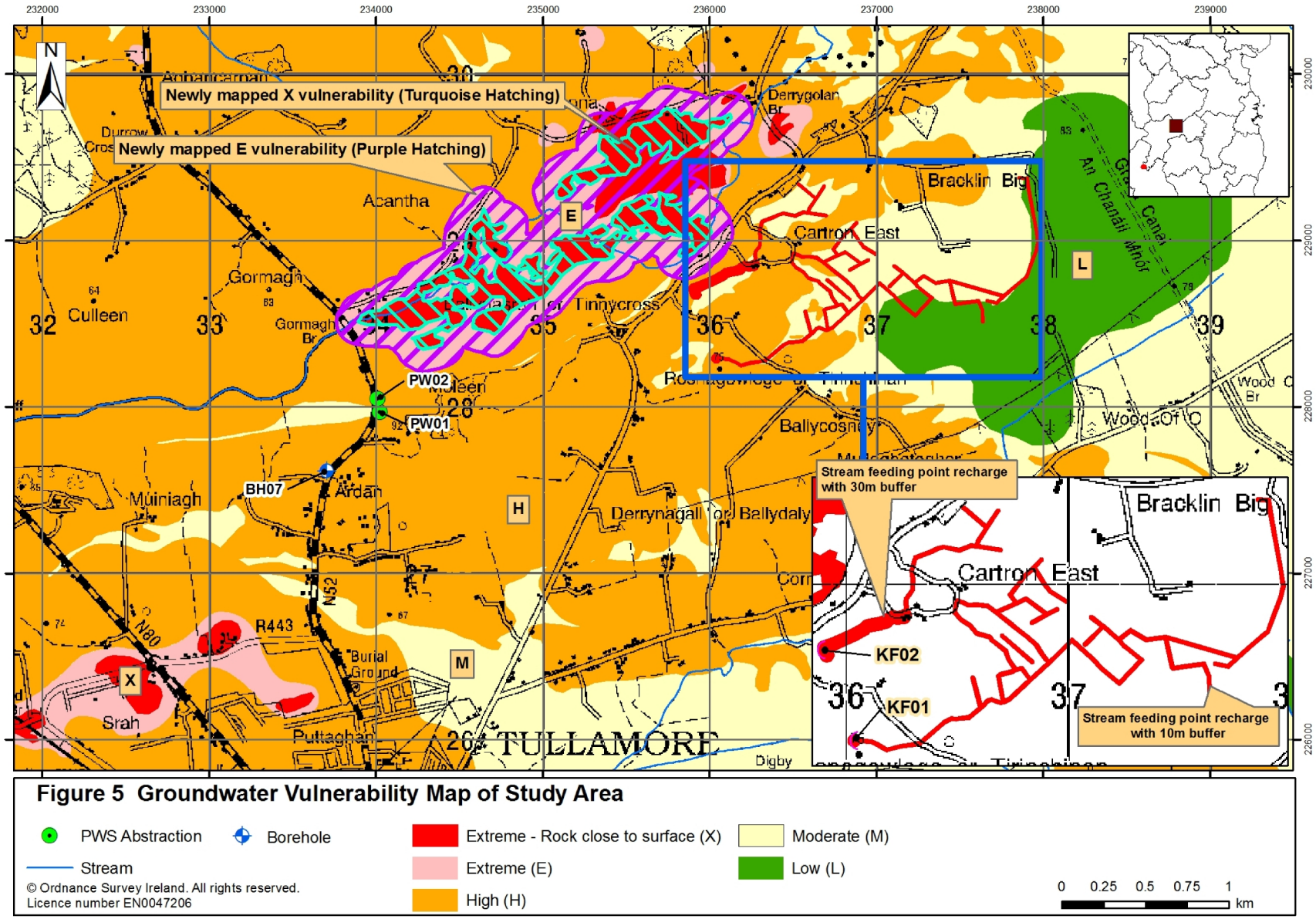


**Figure 5 Groundwater Vulnerability Map of Study Area**

- The limestone till deposits in the east of the study area and the majority of the areas of cut peat are classified as moderately vulnerable.
- The centre of the cut peat, where the bulk of the material has not been cut and as such these low permeability deposits are likely to be thickest, are classified as low vulnerability.
- Areas of bedrock outcrop; rock close to surface; or within 3 m of the surface (*i.e.* DTB <3 m) are classified as extremely vulnerable. Areas of extreme vulnerability deriving from newly mapped bedrock outcrop are shown on Figure 5.
- The streams flowing into the swallow holes KF01 and KF02 have been mapped and, together with the swallow holes, have been buffered to create additional areas of extreme "X" vulnerability (Figure 5 inset). The stream flowing into swallow hole KF01 was identified as having a losing reach stretching 400 m upstream of the swallow hole (Daly, 1988). The swallow holes and losing reach have been given a 30 m "X" vulnerability buffer. The remainder of the streams feeding the swallow holes are not considered to be losing and have been given a 10 m "X" vulnerability buffer (Figure 5 inset).

# 9 Hydrogeology

This section describes the current understanding of the hydrogeology in the vicinity of the wells. Hydrogeological and hydrochemical information was obtained from the following sources:

- GSI Website, Databases, Offaly GWPS, and WFD Groundwater Body Initial Characterisation Summaries;
- County Council Staff and Groundwater Monitoring database;
- EPA website;
- Reports on groundwater resources investigations in the Ardan area for the Tullamore Regional Water Supply Scheme between 1999 and 2008 (GES, 1999 to 2008);
- Boreholes' logs of trial wells and production wells from the Ardan study area by Dunnes Water Services Ltd and GES, 1999 to 2008.

## 9.1 Groundwater body and status

The source boreholes are situated in the Tullamore GWB (IE_SH_G_232) close to its northeaster boundary. This GWB is underlain by DPBL bedrock. The Tullamore Urban (north and south) GWBs lie nearby to the south, while the Geashill GWB (IE_SH_G_103) includes the DUIL bedrock to the east of the Knockshigowna Fault. All of the GWBs in question have been classified as being of Good Status. The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the Water Framework Directive website: www.wfdireland.ie/maps.html.

## 9.2 Groundwater levels, flow directions and gradients

A groundwater level survey was carried out at a selection of public and private boreholes, dug wells and springs distributed across the study area, on 22/07/2011. A topographic survey was carried using GPS equipment to determine the elevation of the water level reference datum at each site to an accuracy of +/- 0.015 m. The results of the survey and a map of survey locations are provided in Table A1.3 and Figure A1.1 in Appendix 1. Further details of each survey point can be seen in Table A1.1 in Appendix 1. The groundwater elevation data from the survey and interpreted contours of bedrock groundwater elevation can be seen in Figure 6. Interpreted contours of bedrock groundwater elevation from spring in 2000 for the area northwest of the Silver River at Gormagh Bridge have been extracted from the Sillogue Well SPZ report (GES, 2000), and plotted on Figure 6 for reference. The data interpretation is summarised in Table 3.

**Table 3: Interpretation of groundwater level and flow data**

| Summary Interpretation | Detailed Justification |
|---|---|
| Groundwater levels decrease from east to west;<br><br>Cone of depression at source boreholes; | • Groundwater level (GWL) 70 mAOD to the ENE up-gradient of the source boreholes;<br>• GWL55 mAOD to the west down-gradient of source boreholes;<br>• Rest groundwater level at the source boreholes is approximately 57.4 mAOD (boreholes BH07 and BH20);<br>• Groundwater abstraction at boreholes PW01 and PW02 has generated a localised cone of depression, giving a GWL at the boreholes of 54.2 mAOD. |
| Groundwater is generally unconfined. | • Bedrock groundwater rest water levels at the source boreholes reside in the overlying esker deposits. The esker gravels lie directly on the bedrock resulting in unconfined conditions.<br>• Across the wider study area the bedrock groundwater is unconfined where high permeability deposits lie directly on top of the bedrock (e.g. BH15) and, semi-confined (leaky) to confined where the overburden comprises moderate permeability till (e.g. BH12)<br>• In places adjacent to the Silver River, the hydraulically continuous gravel and bedrock may be semi-confined by alluvial deposits in places (*e.g.* BH09) however; frequent bedrock outcrop in the river bed ensures that there is hydraulic continuity with the river |
| The interpreted watertable contours suggest various characteristics of the system. | • Groundwater divide runs ENE to WSW through study area;<br>• The groundwater hydraulic gradient upgradient of the source boreholes is ENE to WSW at 0.005 gradient;<br>• Groundwater flow is in a generally WSW direction;<br>• Some groundwater flow is directed towards the Silver and Tullamore Rivers. There is bedrock outcrop and sand and gravel in the riverbeds. This indicates that groundwater will discharge to the rivers;<br>• Some groundwater flow from Waulsortian and Calp Limestone in the ENE of the study area could follow flow lines to the source boreholes; however the majority of flowlines from these areas are likely to discharge to either the Silver or Tullamore Rivers. |
| There is a hydraulic gradient from the groundwater into the Silver River, which would drive groundwater discharge into the river | • The topographic survey shows that the invert and water levels of the Silver River adjacent to dug well GW04 are below the GW04 groundwater level. |
| Flow from the Silver River towards the source boreholes is unlikely | • The groundwater level survey shows that at BH11 – located between PW01 and the river – the groundwater level remains 0.04 m above the river level at Gormagh Bridge;<br>• Nonetheless the low magnitude of the mound means that natural groundwater and river level fluctuations and/or increased PWS abstraction at Ardan could induce a direct hydraulic gradient from the river to the source boreholes. |

**Table 3: Interpretation of groundwater level and flow data (continued)**

| Summary Interpretation | Detailed Justification |
|---|---|
| Seasonal groundwater level changes are low | • The GWL adjacent to the Silver River was 57.96 mAOD in Spring 2000 (GES, 2000) compared to 56.45 mAOD on 22/07/2011. This is a variation of only 1.5 m;<br>• This is a small change for a karstified aquifer and reflects the position of the source boreholes in a regional groundwater discharge zone. |
| Water levels are not declining significantly over time | • In the Tinnycross area, the groundwater levels at BH16 and GW04 were 5.88 m below the top of the casing (mbtc) and 0.7 mbgl on 03/08/1988, respectively. At the same locations on 22/07/2011, the water levels were measured at 6.46 mbtc and 0.67 mbgl. |
| The source boreholes may be linked to point recharge occurring at up-gradient swallow holes | • Sinking streams flowing into two swallow holes that were identified in the Tinnycross area at KF01 and KF02;<br>• Historical tracer tests show a link between the swallow holes and the spring at GW03, which is WSW of the swallow holes;<br>• The source boreholes are also down-gradient and roughly WSW of these karst features. Karst cavities were encountered in the source boreholes;<br>• Bacterial water quality suggests a possible link between the swallow holes and source boreholes;<br>• Tracer tests should be carried out to investigate the possible link. |

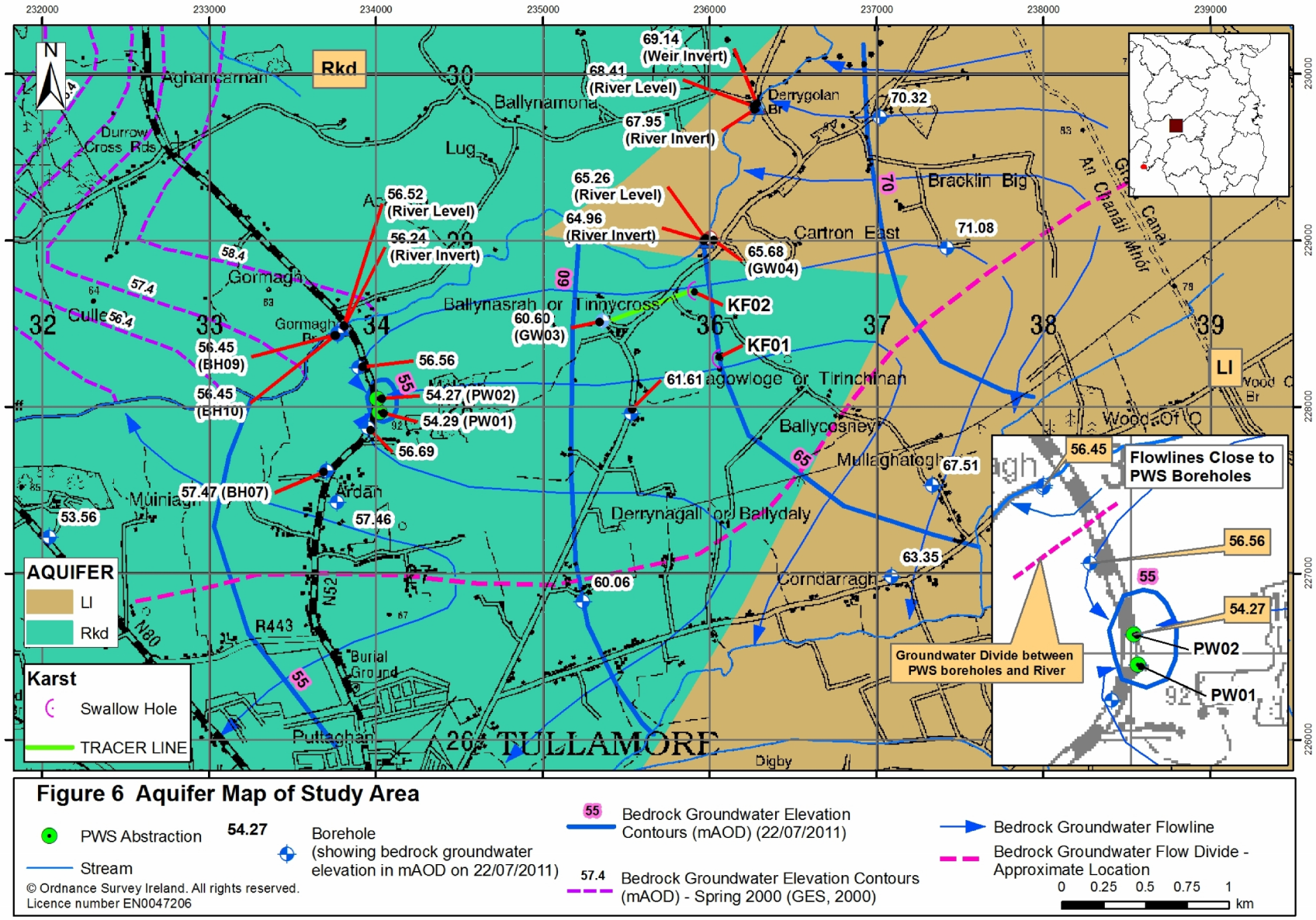


**Figure 6 Aquifer map of Study Area, including interpolated groundwater contours**

## 9.3 Hydrochemistry and water quality

Thirty four untreated water quality samples have been collected from each of boreholes PW01 and PW02, between October 1999 and December 2010. Four more samples were collected from borehole PW01 during a pumping test in October 1999. The laboratory results for the samples have been compared to the EU Drinking Water Directive 98/83/EC Maximum Admissible Concentrations (MAC) and the European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. No. 9/2010). The data are summarized graphically in Figures 7 to 10. The data interpretation is summarised below. The available data are tabulated in Table A1.4 in Appendix 1.

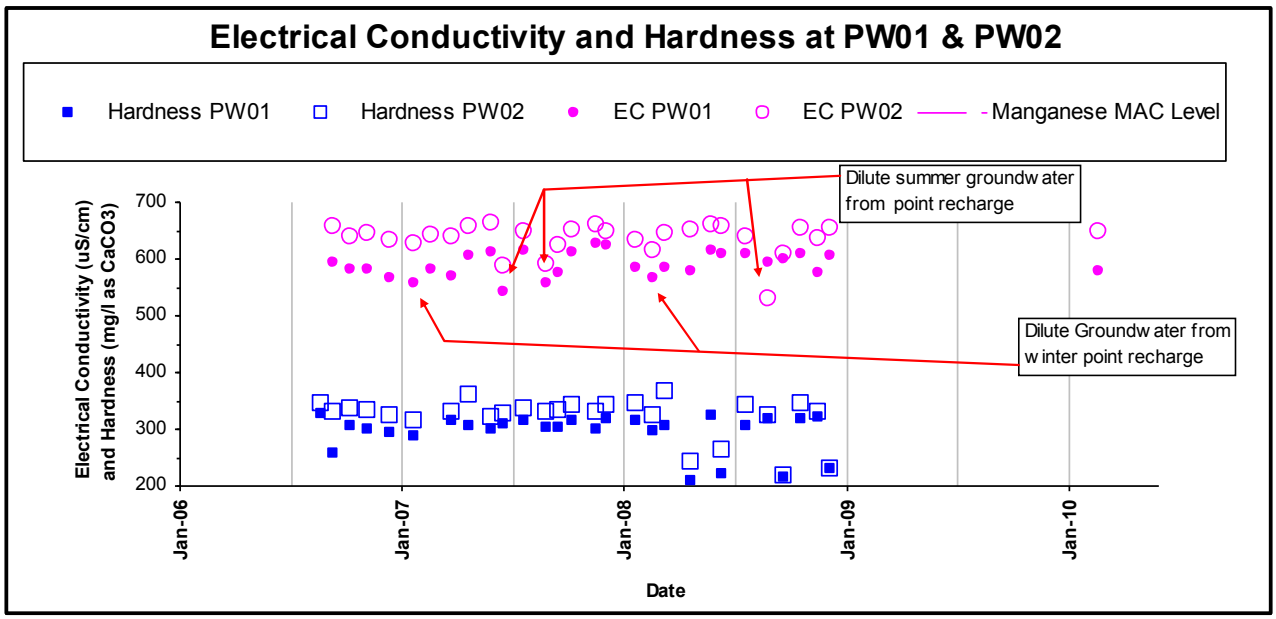


**Figure 7 Electrical Conductivity and Hardness at PW01 and PW02**

Water quality at borehole PW01 has the following characteristics:

- The water is moderately hard to hard (total hardness 210 to 328 mg/l as $CaCO_3$), has an average electrical conductivity (EC) of 582µS/cm and, has an average pH of 7.4.
- The graph of EC over time in Figure 7 shows EC is generally highest in summer months and drops to a low in winter and spring. Occasional short-lived low EC events also occur in summer (Figure 7).
- Faecal coliforms were detected on a single occasion (1 cfu/100ml on 23/07/07). Total coliforms were detected on 13 occasions at concentrations between 1 and 24 cfu/100ml. Detection occurred in all seasons with the peak event recorded on 26/08/08. Ammonium was below the detection limit on all occasions when analysed.
- Chloride was below the EPA threshold on all occasions when monitored and had an average concentration of 20.7 mg/l. Nitrate ranged from 22 mg/l to 38.8 mg/l as $NO_3$ with an average concentration of 28.6 mg/l as $NO_3$, which is below the EPA threshold of 37.5 mg/l as $NO_3$. The data show that concentrations of nitrate and chloride peaked between late 2006 and early 2007 and have since shown a slight downward trend. The above-background nitrate concentrations and absence of ammonia suggest an aerobic system.

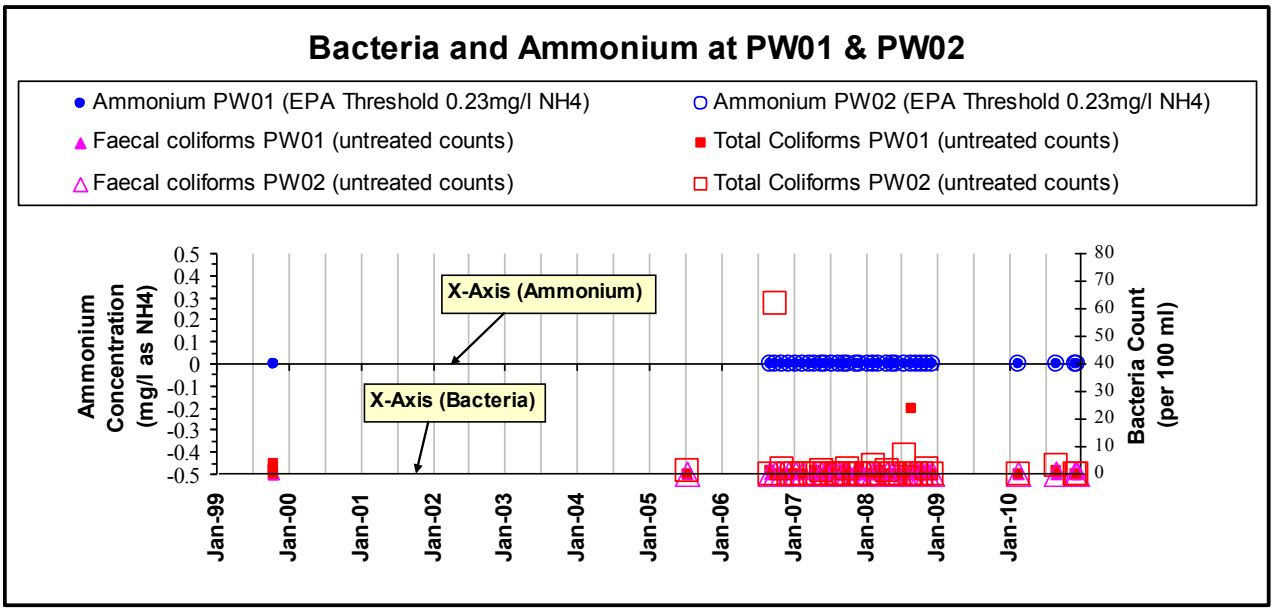


**Figure 8 Key Indicators of Agri and Domestic Contamination: Bacteria and Ammonium**

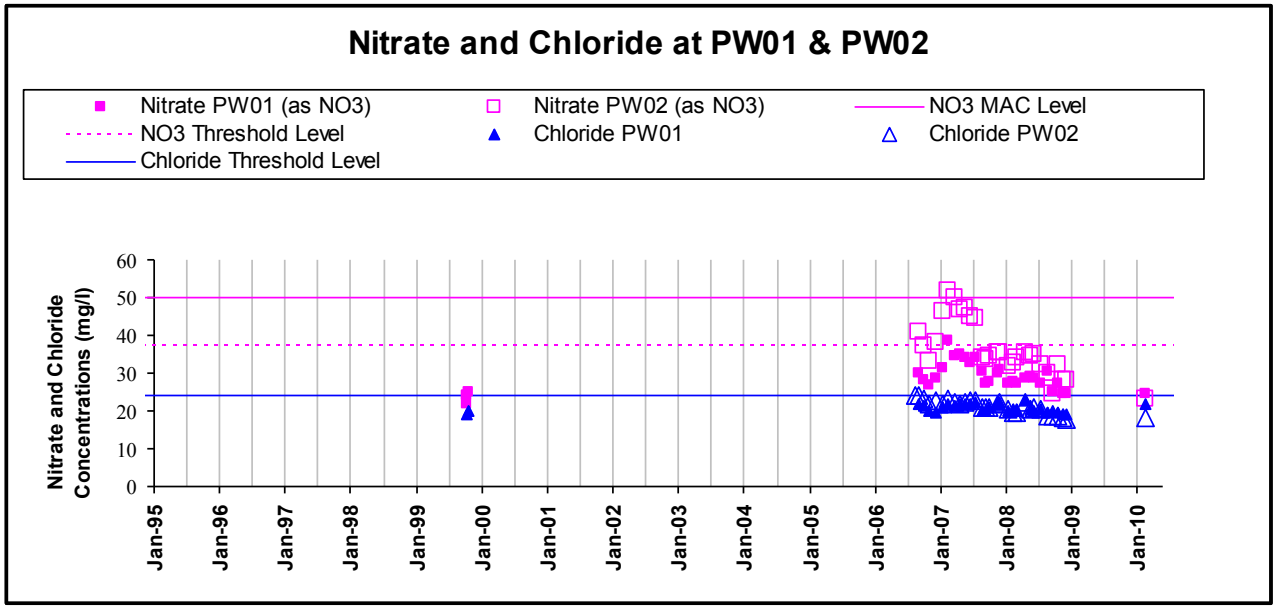


**Figure 9 Key Indicators of Agri and Domestic Contamination: Nitrate and Chloride**

- The sulphate, sodium and calcium levels are within normal ranges. Average turbidity is greater than 1 NTU suggesting the intersected karst network has significant clay/silt infill or may be bringing in turbid surface waters.
- Borehole PW01 was initially commissioned at an abstraction rate of 2,420 $m^3$/d in 2001 but this eventually led to deteriorating water quality with elevated iron, aluminium and turbidity. The abstraction rate was reduced to 1,340 $m^3$/d at some point between 2001 and 2006. Since 2007 no elevated iron or aluminium concentrations have been recorded. Manganese was below the detection limit on all occasions when analysed.
- Other trace metals were either within the normal range for good quality drinking water or were not detected. Similarly, organic compounds and herbicides have not been detected.

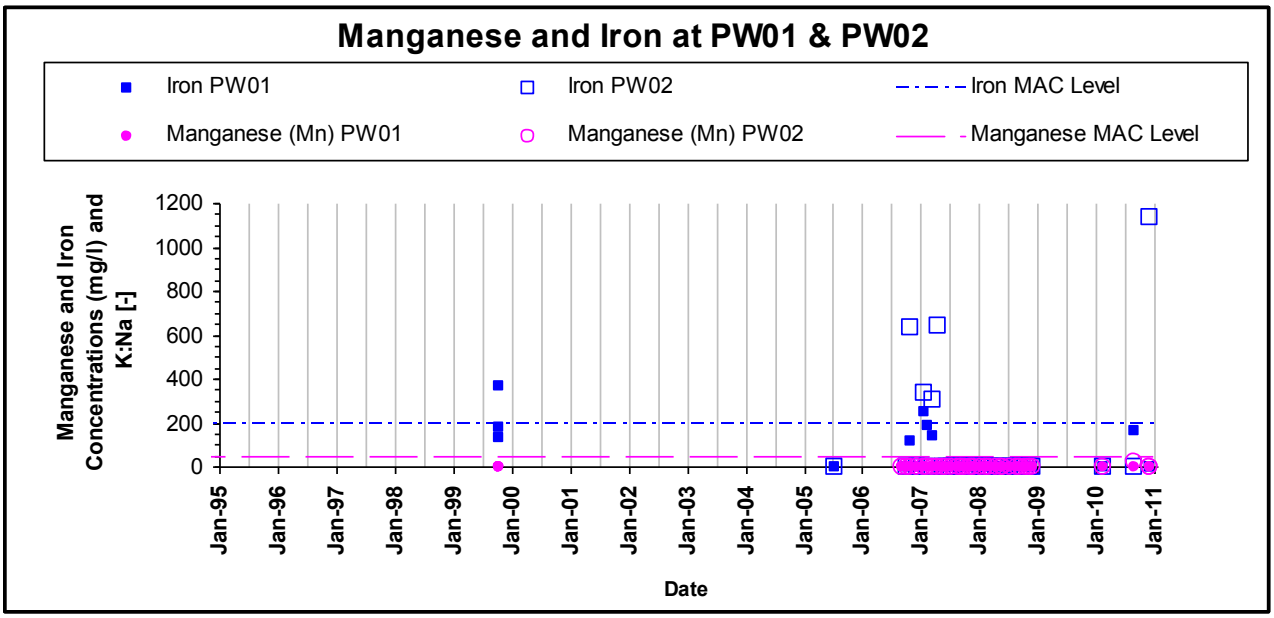


**Figure 10 Key Indicators of Agri and Domestic Contamination: Mn and Fe**

Water Quality at borehole PW02 is summarised as follows:

- The water is moderately to excessively hard (218 to 366 mg/l as $CaCO_3$), has an average electrical conductivity (EC) of 638µS/cm and, has an average pH of 7.3.
- The EC and hardness data show that PW01 and PW02 follow very similar trends (Figure 7). Also in summer 2008 PW02 shows a point recharge event not reflected in the PW01 data.
- No faecal coliforms have been detected at the borehole in 30 samples analysed. Total coliforms have been detected on 10 occasions, across all seasons, with a peak of 62 cfu/100 ml on 09/10/06. Ammonium was below the detection limit on all occasions when analysed.
- Chloride was below the EPA threshold on all occasions when monitored and had an average concentration of 21.1 mg/l. Nitrate ranged from 23.4 mg/l to 51.6 mg/l as $NO_3$. The average concentration of 36 mg/l as $NO_3$ is just below the EPA threshold of 37.5 mg/l as $NO_3$. Nitrate concentrations peaked between December 2006 and July 2007 with all values in the period above the EPA threshold, and twice exceeding the MAC level. Since then all concentrations have been below the EPA threshold and, along with chloride, show a declining trend as per PW01.
- Average turbidity is greater than 1 NTU.
- Total aluminium exceeded the MAC in February and March 2007, with a peak of 304 ug/l in March. The remainder of the total Al and all of the dissolved Al data are below the MAC. Iron concentrations have intermittently exceeded the MAC level with both dissolved and total concentrations, on two and five occasions respectively. Peak iron concentrations of 579 ug/l (dissolved Fe) and 1,136 ug/l (total Fe) were detected on 21/07/08 and 30/08/10 respectively. The exceedences have occurred in all seasons.
- Other trace metals were within either within the normal range for good quality drinking water or were not detected. Similarly, organic compounds and herbicides have not been detected.

Overall the data suggest that the groundwater from both boreholes is contaminated by above background nitrate concentrations, which are likely to derive from wastewater or agricultural sources, and is occasionally polluted by high metal concentrations.

The metals exceedences at high abstraction rates may be associated with inflows from the Lucan Formation (Calp) limestone, which is a muddy limestone that is known to have reducing conditions and naturally high metal concentrations (GSI, 2004b). Higher water levels in the Calp in winter or excessive abstraction rates may provide a gradient to drive additional iron rich water west into the karst limestone, resulting in the observed iron exceedences. The greater number of exceedences at PW02 compared to PW01 suggests a stronger connection between PW02 and the Calp than is the case with PW01. This suggests differentiation between the karst systems supplying the two boreholes.

The winter troughs and summer peaks in the EC data correlate with increased point recharge in winter and spring when swallow holes are flooded. Flashy rainfall in summer also generates point recharge resulting in occasional, short-lived low EC events in summer. These data suggest that a component of the groundwater abstracted from the boreholes derives from point recharge to the karst system. Potential point recharge sources include the swallow holes KF01 and KF02. The isolated point recharge dilution event at PW02 in Summer 2008 again shows that the boreholes may interact with different components of the karst system.

Water quality at borehole BH07 (Chip Depot) was monitored on three occasions and has similar pH and conductivity to PW01 and PW02. To date, nitrate and chloride have been lower than at PW01 and PW02 and no elevated metal concentrations have been detected.

Severe iron pollution led to the decommissioning of the Silver River PWS boreholes at nearby Gormagh Bridge in the mid-1990s, 450 m north-northwest of the source boreholes. Private boreholes with low domestic scale abstraction rates in the Tinnycross area (Daly, 1988), and Corndarragh and Mullaghtogher areas (anecdotal information from landowners contacted during groundwater level survey) do not suffer from iron contamination. These domestic abstractions may be skimming shallow groundwater recharged through the limestone gravel subsoil and thereby avoiding high iron levels, despite being close to or on the Calp limestone. Nitrate contamination appears to be a catchment scale issue with the former group water scheme borehole BH15 in Corndarragh having been decommissioned in 2000 due to elevated nitrate concentrations.

A physico-chemical survey of stream electrical conductivity, pH and temperature was carried out across the area east of the source boreholes on 14/07/2011, after several consecutive dry days (see Table A1.1 Appendix 1). The data show high electrical conductivity and pH at all locations and suggest that the main rivers and tributaries are in hydraulic continuity with groundwater and receive significant baseflow.

## 9.4 Aquifer characteristics

Boreholes PW01 and PW02 abstract water from karstified limestone in the undifferentiated Visean limestone bedrock. The limestone is classified by the GSI as a *Regionally Important Karstified Aquifer characterised by diffuse flow ($Rk_d$)*. The Lucan Formation muddy limestone bedrock unit 3 km east of the boreholes is classified as a *Locally Important Aquifer – bedrock which is moderately productive only in local zones (LI).* The aquifer map of the study area is shown in Figure 6.

The bedrock in the $Rk_d$ aquifer is generally devoid of intergranular permeability. Groundwater will flow through a highly weathered layer a couple of metres thick at the top of the bedrock with a zone of interconnected fissures below this (GSI, 2004a). In the source boreholes and other boreholes significant deep groundwater flow occurred, with major water strikes intersected in partially infilled

karst conduits at depth in boreholes PW01 (> 2,000 $m^3$/day inflow at 72 to 103 mbgl) and BH12 (648 $m^3$/day at 69, 80 and 81 mbgl). Flow in these zones is generally well developed and interconnected, and can support flow paths of up to several kilometres in length. Given these occurrences the main flow mechanism in the aquifer may be via deep karstified zones in faults and fissures. These are connected to storage in the coarse gravel overburden and weathered zone where the fault zones intersect the top of the bedrock. Overall therefore, groundwater flow in the bedrock aquifer only occurs in fissures and conduits. No contaminant attenuation occurs in the fissures and conduits. Contaminant attenuation will only occur in the overlying subsoils as recharge infiltrates down to the bedrock aquifer.

Karst features have a significant influence on groundwater flow as indicated by tracing between the swallow hole at KF02 and springs in the Tinnycross area (*e.g.* GW03) (Daly, 1988). Karst fissures and cavities were recorded in borehole logs for PW01, PW02, BH06, BH08, BH09 and BH12 and those intersected in PW01 and PW02 appear to be influenced by point recharge (see Section 9.3).

Groundwater flow mechanisms are likely to be similar in the Calp *LI* aquifer but any karstification is likely to be limited and flow paths are likely to be shorter (*e.g.* < 300 m) (GSI, 2004b). In general, discharge to the Silver River or Tullamore River is more likely than long flow paths westwards to the source boreholes. As such, in episodes where the source boreholes induce Calp aquifer inflows, the area of Calp aquifer contributing to the flow is likely to be restricted to a zone within 0.5 km from the boundary with the $Rk_d$ aquifer.

Analysis of the pumping test data for boreholes PW01 (72 hour test), BH07 (48 hour test), and BH09 (72 hour test) suggests a transmissivity range for the $Rk_d$ aquifer at Arden of 275 $m^2$/day to 6,100 $m^2$/day (geometric mean of 796 $m^2$/day) (GES, 1999 and 2008). There are no data with respect to pumping interactions between the two source boreholes. Analysis of pumping test data for PW01 suggests a barrier boundary was encountered after 1000 mins of pumping (GES, 1999). This may indicate the boundary with the *LI* aquifer, which agrees with the hypothesis that the intermittent high iron concentrations may be related to increased contribution from the LI aquifer at times of increased abstraction. Transmissivity at borehole BH12 located 2.1 km west-southwest of the source boreholes is recorded be 26 to 870 $m^2$/day (GES, 2008). The average bedrock aquifer thickness intersected by boreholes PW01, BH07 and BH09 is 46 m.

Bulk aquifer permeability (K) has been estimated from transmissivity by dividing by the average aquifer thickness intersected by the boreholes and is shown in Table 4.

The velocity of water moving through the aquifers to the boreholes is estimated using Darcy's Law:

$$\text{Velocity (V)} = (\text{K x Groundwater Gradient (i)}) / \text{porosity (n)}$$

The average natural gradient in the study area is estimated at 0.005. Bedrock porosity for the $Rk_d$ aquifer was estimated at 0.01 based on GSI experience of karst aquifers.

**Table 4: Indicative Aquifer Hydraulic Parameters**

| **Parameters** | **Source of Data** | **$Rk_d$ aquifer** |
|---|---|---|
| Transmissivity ($m^2$/d) | Calculated (based on pumping test data) | 796 |
| Permeability (m/d) | Estimated from T value (average) divided by the average screen/open hole length | 17.3 |
| Effective Porosity | Based on GSI experience of karst aquifers | 0.01 |
| Groundwater gradient | Based on groundwater levels | 0.005 |
| Velocity (m/d) | Calculated based on above | 8.65 |

The average velocity of groundwater moving through the $Rk_d$ aquifer is estimated as 8.65 m/d. The aquifer parameters are summarized in Table 4.

# 10 Zone of Contribution

The Zone of Contribution (ZOC) is the complete hydrologic catchment area to the source boreholes, or the area required to support an abstraction from long-term recharge. The size and shape of the ZOC is controlled primarily by (a) the total discharge, (b) the groundwater flow direction and gradient, (c) the subsoil and rock permeability and (d) the recharge in the area. This section describes the conceptual model of how groundwater flows to the source, including uncertainties and limitations in the boundaries, and the recharge and water balance calculations which support the hydrogeological mapping techniques used to delineate the ZOC.

## 10.1 Conceptual model

The source boreholes abstract groundwater from the karstified limestone ($Rk_d$) aquifer. The abstracted water is mainly sourced from the karstified limestone bedrock, but a component may also derive from the Calp (*Ll)* aquifer located 3 km to the east. This component is considered to be limited to an area within 500 m of the $Rk_d$ / *Ll* aquifer boundary, due to the localised nature of flow systems in the impure limestone (Calp) aquifer.

The bedrock aquifers are recharged by infiltration through the high permeability esker and glaciofluvial sand and gravel deposits, and through moderate permeability limestone till, that cover the majority of the study area. The newly mapped areas of extreme vulnerability along the Silver River will also facilitate recharge, but in this area the recharge will be likely to discharge rapidly into the river.

Recharge creates a groundwater mound in the bedrock aquifer between the Silver and Tullamore Rivers. This drives groundwater flow in a generally WSW direction. There is a WSW – ENE oriented groundwater divide running between the rivers. North of the groundwater divide groundwater flow has a north-westerly component, which discharges into the Silver River. Similarly, to the south, groundwater discharges to the Tullamore River. The rivers are generally in hydraulic continuity with the bedrock aquifers. The bedrock aquifers are unconfined in places and in hydraulic continuity with the overlying gravels, which supplement the storage capacity of the system. In other places they will be semi-confined by till deposits or confined by low permeability subsoils.

Groundwater flow is dominated by karstic and fissure flow pathways. Diffuse recharge to the system is supplemented by point recharge of runoff from Bracklin Big townland (up to 4 km east of the source) *via* swallow holes at Tinnycross. Some of this point recharge discharges at springs in the Tinnycross area, but a component of it is likely to contribute to abstraction from karst pathways intersected by the source boreholes.

Water quality is generally unpolluted. Elevated nitrate and iron concentrations have occurred in the past. The elevated iron concentrations may be related to an increased proportion of groundwater from the impure limestone aquifer during times of particularly high winter water levels in the Calp or increased abstraction at the source boreholes.

Water level data suggest that the regional hydraulic gradient is directed towards the WSW. At current abstraction rates, there is a cone of depression around the source boreholes. This is close to the point of lowering water levels enough to induce leakage of river water into the source boreholes. As such, increased abstraction from the Ardan area could lead to river inflows to the

source boreholes or increased iron concentrations due to greater interaction with the impure limestone aquifer.

The conceptual model for the study area is illustrated in the cross section in Figure 11.

## 10.2 Boundaries of the ZOC

The ZOC has been delineated across both the *$Rk_d$* and *LI* aquifers. The borehole logs for boreholes PW01 and PW02 intersect conduits in the karst aquifer system at different depths. This is reflected in their slightly different behaviour in terms yield and water quality. Nonetheless, due to their proximity and the groundwater flow direction, the boreholes are likely to have generally overlapping catchments. As such, a single ZOC has been delineated for both boreholes. The boundaries of the areas contributing groundwater flow to the boreholes from diffuse recharge are considered to be as follows (Figure 12):

The **western boundary** is the down-gradient boundary of the ZOC. The down-gradient separation distance ($X_L$) from the borehole is based on the Uniform Flow Equation (Todd, 1980). This is conservatively calculated to be 125 m based on the average parameters from Table 4 and 150% of the current abstraction:

$x_L = Q / (2\pi * T * i)$ where:
Q is the daily pumping rate (150% of current demand for the scheme = 3,122 $m^3$/day);
T is the *$Rk_d$* aquifer Transmissivity (taken from aquifer characteristics); and
i is the hydraulic gradient in the *$Rk_d$* aquifer.

The **northern and southern boundaries** follow groundwater flowlines from the western boundary back to their origin at the groundwater divide to the east and southeast of the source boreholes.

The **south-eastern boundary** of the ZOC is formed by the groundwater divide which runs through the study area between the Silver River and Tullamore River. A 100m buffer has been added on the south-eastern side of the divide to cover natural seasonal variation of its position. The northern two-thirds of the boundary lie naturally within the Calp impure limestone. As a conservative measure the southern third of the boundary has also been extended into the Calp impure limestone. This accounts for potential inaccuracy in the position of the groundwater divide in the vicinity of the geological boundary between the pure limestones and the Calp.

The delineated boundaries provide a wide ZOC which conservatively slightly exceeds 150% of the current demand. Abstraction from the source boreholes could be increased to this level but this would result in an increased component of the abstraction deriving from the Calp (approximately 5% based on recharge contribution), which is reflected by the ZOC. The private borehole BH11 is inside the ZOC and its minimal domestic abstraction rate is also covered by the ZOC.

The streams feeding point recharge to swallow holes KF01 and KF02 were identified and buffered to identify “X” groundwater vulnerability areas (Section 8). The reaches of these streams which lie upstream of the diffuse groundwater recharge footprint, have also been included in the ZOC (Figure 12).

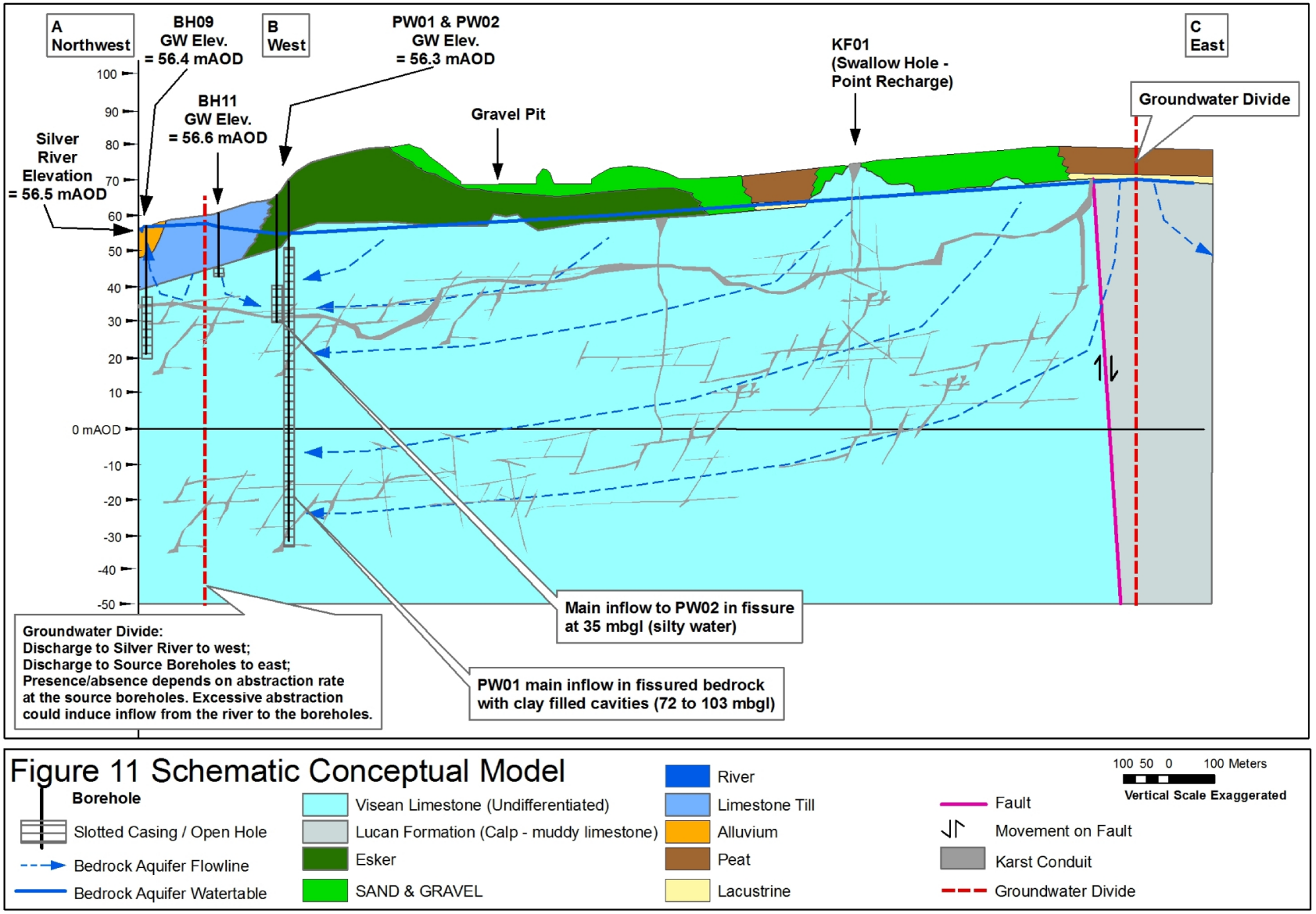


Figure 11 Schematic Conceptual Model

Borehole
Slotted Casing / Open Hole
Bedrock Aquifer Flowline
Bedrock Aquifer Watertable
Visean Limestone (Undifferentiated)
Lucan Formation (Calp - muddy limestone)
Esker
SAND & GRAVEL
River
Limestone Till
Alluvium
Peat
Lacustrine
Fault
Movement on Fault
Karst Conduit
Groundwater Divide
100 50 0 100 Meters
Vertical Scale Exaggerated

**Figure 11 Schematic Conceptual Model**

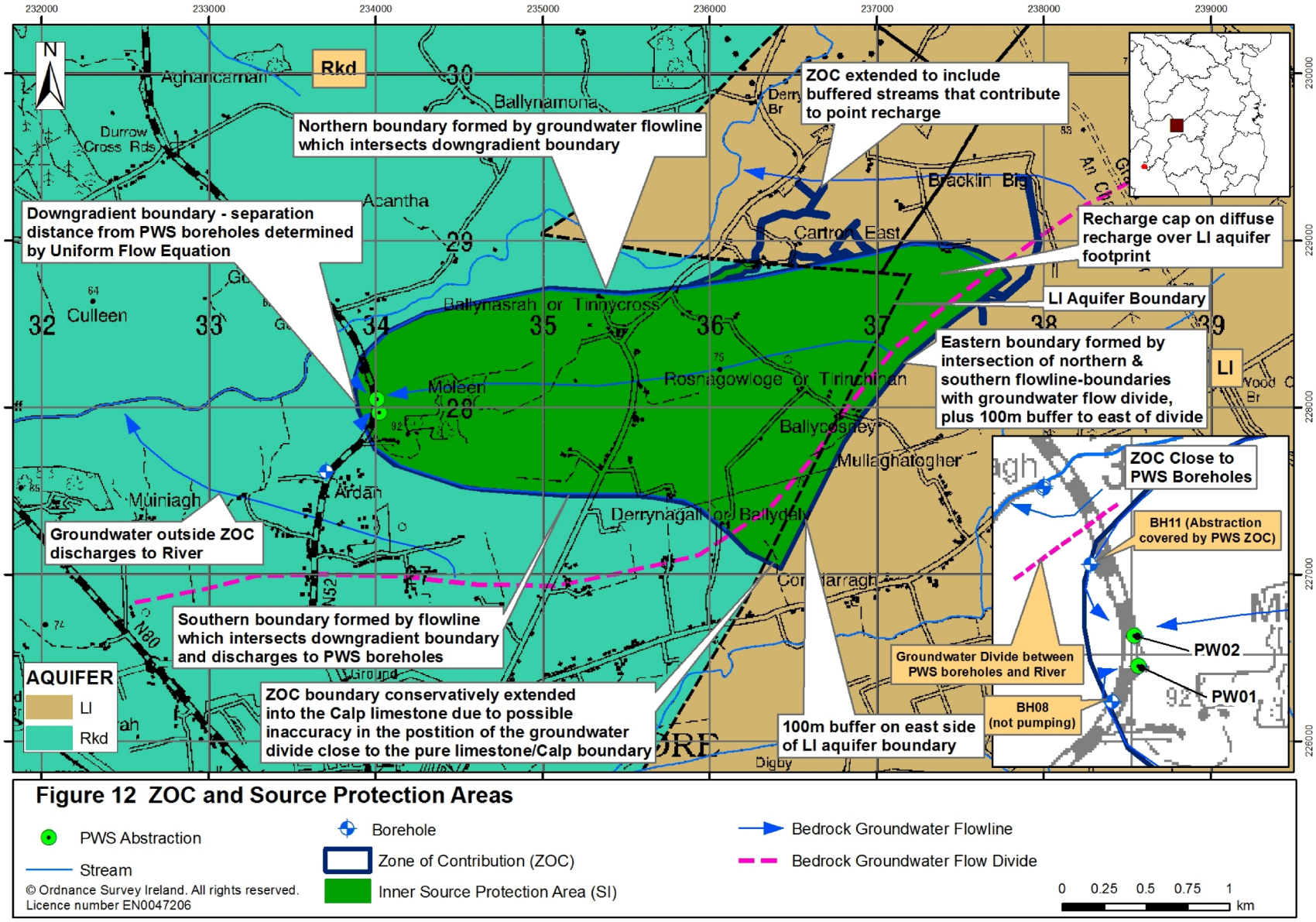


**Figure 12 ZOC and Source Protection Areas**

PWS Abstraction
Stream
Borehole
Zone of Contribution (ZOC)
Inner Source Protection Area (SI)
Bedrock Groundwater Flowline
Bedrock Groundwater Flow Divide



0 0.25 0.5 0.75 1 km

**Figure 12 Zone of contribution and Source Protection Areas**

## 10.3 Recharge and water balance

The term 'recharge' refers to the amount of water replenishing the groundwater flow system. The recharge rate is generally estimated on an annual basis, and assumed to consist of input (*i.e.* annual rainfall) less water loss prior to entry into the groundwater system (*i.e.* annual evapotranspiration and runoff). The estimation of a realistic recharge rate is important in source protection delineation, as it will dictate the size of the ZOC to the source (and therefore the Outer Source Protection Area). The recharge is estimated as follows:

***Potential recharge*** is equivalent to 411 mm/yr (*i.e.* Annual Effective Rainfall, see Section 6).

***Actual recharge*** has been estimated to be 307 mm/yr, which is 75% of potential recharge; this value is based on averaging of the recharge for different settings across the ZOC, as detailed in Table A1.5 in Appendix 1.

***Runoff losses:*** 104 mm (25% of potential recharge). This proportion of potential recharge is assumed to runoff to surface water *via* surface and interflow.

These calculations are summarised in Table 5. The calculations are based on diffuse recharge in the Zone of Contribution only.

Recharge contributions from runoff *via* karst point recharge are difficult to quantify and, have not been included in the ZOC delineation calculations. The resulting ZOC is likely to be conservative. Rough calculations based on runoff of 104 mm/yr and a runoff catchment area of 2.6 km for swallow holes KF01 and KF02 suggests a potential additional recharge volume of 726 $m^3$/day. Part of this additional input is known to be lost as groundwater discharge to the spring at GW03.

For a water supply's source to be sustainable, the recharge over the area contributing to the source should equal the discharge at the source. Current combined abstraction from PW01 & PWO2 amounts to 2,081 $m^3$/day. To provide a factor of safety in case of peaks in demand, drought periods or an increase in the abstraction rate, the ZOC has been delineated to cover a footprint equal to 150% of the current abstraction rate, *i.e.* 3,122 $m^3$/day. This delineation does not assess the risk that abstraction at this elevated rate could induce inflow from the Silver River or increase the potentially iron rich contribution from the impure limestone aquifer.

**Table 5 Recharge Calculation Summary for diffuse recharge component of the ZOC area**

| Parameter | Coefficient | Rate |
|---|---|---|
| Average rainfall (R) | | 834 mm/yr |
| Estimated P.E. | | 445 mm/yr |
| Estimated A.E. (95% of P.E.) | | 423 mm/yr |
| Effective rainfall | | 411 mm/yr |
| Potential recharge | | 411 mm/yr |
| Averaged runoff losses | (25%) | 104 mm/yr |
| Bulk recharge coefficient | 0.75 | |
| **Recharge** | | 307 mm/yr |

At a recharge of 307 mm/yr, an abstraction rate of 3,122 $m^3$/day would require a recharge area of 3.71 $km^2$. The ZOC described above has a diffuse groundwater component and a point recharge component. The area of the ZOC delineated using hydraulic boundaries is 4.2 $km^2$ (equivalent to 3,554 $m^3$/day). This is slightly above the target area with respect to the water balance but, given the uncertainties in the recharge figures this is considered reasonable. The ZOC is shown in Figure 12.

The ZOC area related to point recharge *via* swallow holes KF01 and KF02 provides an additional 0.08 $km^2$ to the ZOC. Some of the point recharge discharges via the spring GW03; however the remainder will increase the total available recharge volume further above 150% current demand value. Overall this amounts to a conservative ZOC delineation for the source boreholes.

A 48 hour pumping test on borehole BH07 in June 2008 was carried out at a rate of 1,320 $m^3$/day. It is not known if this abstraction rate is sustainable at borehole BH07 in the long-term. If an abstraction of this magnitude at BH07 is added to the current PWS abstraction, it would give a total of 3,406 $m^3$/day. This is also slightly greater than 150% of the current abstraction. Borehole BH07 does not fall within the current ZOC delineation but it is considered to intersect the same karst system as boreholes PW01 and PW02. If BH07 is commissioned, the impact of the increased abstraction on groundwater flow directions will need to be assessed and the ZOC shape adapted accordingly to include the new source. This would require collection of further water level and water quality data to determine the impact of the additional abstraction once BH07 has been commissioned.

# 11 Source Protection Zones

The Source Protection Zones are a landuse planning tool which enables an objective, geoscientific assessment of the risk to groundwater to be made. The zones are based on an amalgamation of the source protection areas and the aquifer vulnerability. The source protection areas represent the horizontal groundwater pathway to the source, while the vulnerability reflects the vertical pathway. Two source protection areas are typically delineated, the Inner Protection Area and the Outer Protection Area.

The Inner Protection Area (SI) is designed to protect the source from microbial and viral contamination and it is based on the 100-day time of travel (TOT) to the supply (DELG/EPA/GSI 1999). Based on the indicative aquifer parameters presented in section 8.5, the groundwater velocity is 8.65 m/d. The 100-day TOT distance therefore, is 865 m.

The majority of the ZOC lies outside the calculated 100-day TOT limit, however flow paths in individual karst conduits can greatly exceed the calculated average for the bulk aquifer. As such, the entire ZOC is conservatively classified as SI.

The extension of the ZOC to account for buffered streams which contribute to point recharge within the ZOC is also classified as SI, because point recharge from this area is likely to enter the karst system rapidly.

No Outer Protection Area has been delineated. The source protection areas are illustrated in Figure 12.

The groundwater Source Protection Zones across the entire ZOC are shown in Figure 13 and are listed in Table 11-1. They include SI/X, SI/E, SI/H, SI/M and SI/L. Approximately 6% of the ZOC is designated as SI/X or SI/E (this takes account of the main body of the ZOC and the additional “X” vulnerability, buffered-stream areas associated with point recharge).

**Table 6 Source Protection Zones for Entire ZOC Area**

| Source Protection Zone | | % of Total Area | Area ($km^2$) |
|---|---|---|---|
| SI/X | Inner Source Protection area / Extreme vulnerability, ≤1 m subsoil | 6 | 0.26 |
| SI/E | Inner Source Protection area / Extreme vulnerability, <3 m subsoil | 5 | 0.21 |
| SI/H | Inner Source Protection area / High vulnerability | 72 | 3.06 |
| SI/M | Inner Source Protection area / Moderate vulnerability | 13 | 0.56 |
| SI/L | Inner Source Protection area / Low vulnerability | 3 | 0.14 |

# 12 Potential pollution sources

Boreholes PW01 and PW02 currently have good well head protection. The ventilation grill is missing from the side of the PW02 cover and the borehole also does not have a grout seal. Borehole PW02 is therefore vulnerable to direct contamination from surface spills or animal activity as well as from lateral migration of contaminants in the unsaturated zone.

The landuse within the ZOC is primarily agricultural with numerous residential farms and pastureland for grazing animals. Agricultural activities, such as grazing and landspreading of agricultural waste, and septic tank discharges present a potential risk of microbial pollution to the boreholes as well as the potential for elevated concentrations of ammonia, nitrate, phosphate, chloride, potassium, BOD, COD, TOC and pesticides. Testing to date suggests that the water quality at the boreholes is particularly vulnerable to nitrate contamination from these sources. Given the $Rk_d$ aquifer classification, point recharge and presence of large areas of extreme vulnerability within the ZOC/SI, the potential risk from cryptosporidium and viruses is high.

Several large sand and gravel quarries and a concrete works operate in close proximity to the source boreholes. Hydrocarbons stored on these sites are the main potential contaminant and together with the high groundwater vulnerability constitute a risk to bedrock groundwater. Several national primary and smaller roads traverse the ZOC. The main potential contaminants from these sources are surface water runoff contaminated with hydrocarbons and metals.

# 13 Conclusions

The Ardan component of the Tullamore Water Supply Scheme currently comprises two production boreholes PW01 and PW02. The boreholes abstract water from a karstified limestone bedrock aquifer. The current demand on the boreholes is 2,081 $m^3$/day. This is reduced from a combined proven yield of 4,139 $m^3$/day due to issues with excessive iron concentrations at high pumping rates. The ZOC for the test wells has been delineated conservatively and slightly exceeds 150% of the current demand, *i.e.* 3,122 $m^3$/day. Offaly County Council intend to commission the nearby borehole BH07 as an additional production well at some point in the future.

Due to the karst limestone nature of the aquifer, the delineated ZOC only contains an SI source protection area. Parts of the SI are classified as Extreme vulnerability with rock at or very close to the surface in places. Groundwater quality is susceptible to nitrate contamination from agricultural and domestic wastewater sources, and to iron and aluminium contamination from natural sources.

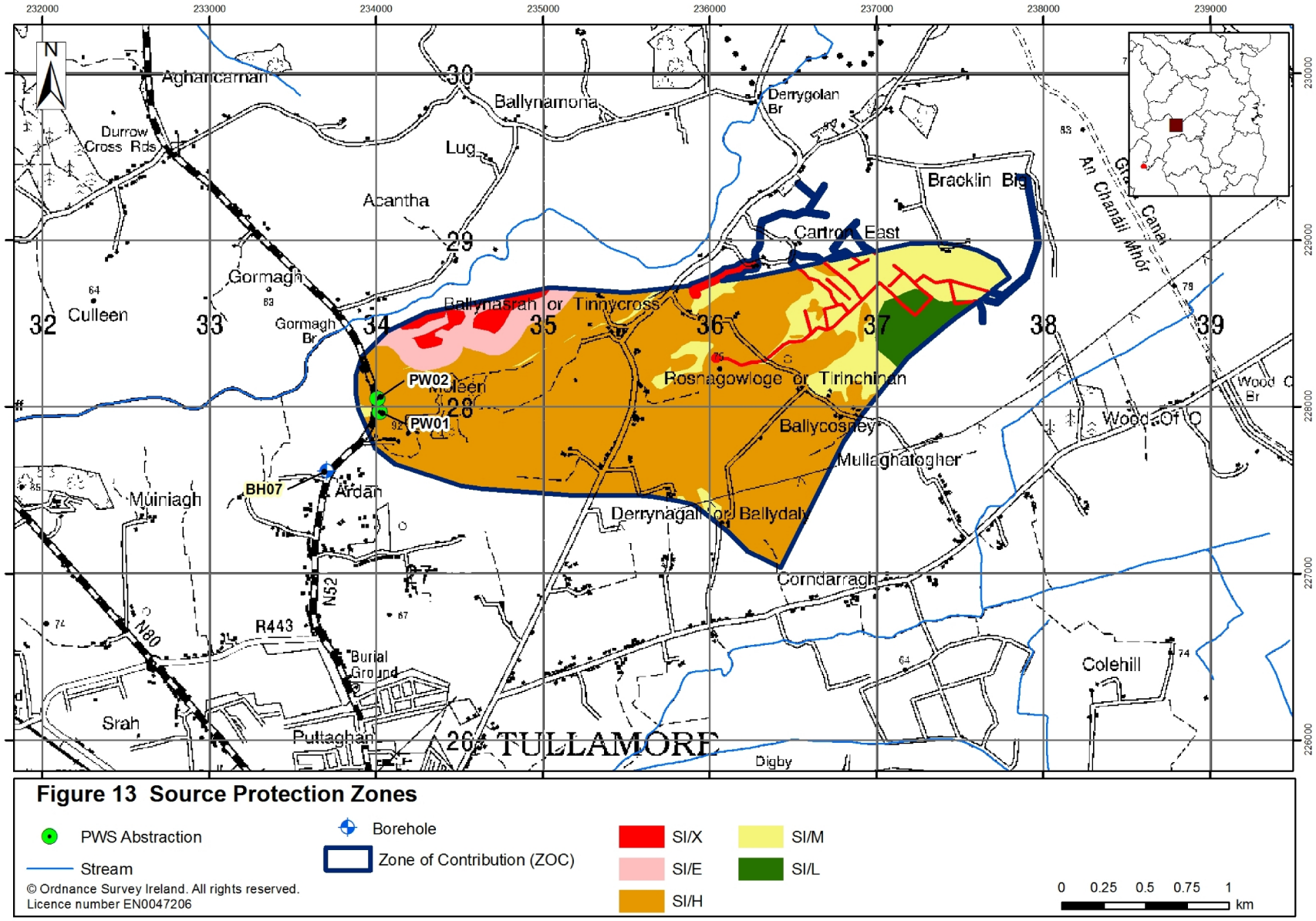


**Figure 13 Source Protection Zones**

The Source Protection Zones are based on the current understanding of the groundwater conditions and the available data. Additional data obtained in the future may require amendments to the protection zone boundaries.

## 14 Recommendations

Comprehensive well head protection should be implemented at all trial well locations across the study area. This should include either conversion to capped, grouted production or monitoring wells, or abandonment in line with best practice.

A suitable groundwater level monitoring regime should be set up across the ZOC to identify annual fluctuation in the groundwater flow directions. This is particularly relevant with respect to interaction between the source boreholes and the Silver River, and the intention to commission borehole BH07.

Groundwater quality at the boreholes should continue to be monitored closely at the source boreholes. The monitoring schedule should be extended to include all major ions (*i.e.* Ca, Mg, K, Na, $NH_4^+$, Cl, $SO_4$, Alkalinity and $NO_3$.

The ZOC contains SI/X and SI/E designations. Source specific landspreading exclusion zones should be developed for the source boreholes to take account of the landspreading risk associated with this designation.

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# APPENDIX 1

- Borehole Logs – PW01, PW02, BH06, BH07
- Table A1.1 – Surface Water Quality Survey Data
- Table A1.2 – Point Data For Arden SPZ Study Area
- Table A1.3 – Groundwater Level Survey Data
- Table A1.4– Groundwater Quality Data
- Table A1.5 - Recharge coefficients for the diffuse recharge component of the ZOC area
- Figure A1.1 – Data Point Locations
- Figure A2.2 – Surface Water Quality Point Locations

PW01

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# BOREHOLE LOG

Production Borehole

Sheet 1 of 1

| | | | |
|---|---|---|---|
| Method: Mud Rotary | Date: September 1999 | Site: Arden Treatment Works, Tullamore Co. Offaly | |
| Dia mm | Coord: 234050, 227800 | Ground Level m.OD | Client: Tullamore U.D.C. |

| Soil Samples/Tests: Type/Test | Depth m. | Water & Progress | Casing (Internal diameter) | Depth m. | Description of Strata | Legend |
|---|---|---|---|---|---|---|
| | | | | 00.0m | | |
| | | | | | CLAY, GRAVEL & STONE | |
| | | | | 06.1m | | |
| | | | | | SAND and GRAVEL | |
| | | | | 12.2m | ROCK-HEAD | |
| | | | | | GREY Weathered & Solid ROCK | |
| | | | | 24.4m | | |
| | | | | | Solid BEDROCK | |
| | | | | 72.0m | | |
| | | | | | FISSURED BEDROCK, with CLAY and WATER filled CAVITIES | |
| | | | | 103.6m | | |

Remarks
1. Rock-head @ 12.2m
2. 16-inch Steel Casing from 0m to 12m
   12-inch Steel Casing from 0m to 24m
   Grout in both Casings
3. Major groundwater inflows between 72m and 103.6m
4. Estimated Yield (by driller) is 2,180m3/day

| Logged by | Scale | End Casing Depth | Job No. |
|---|---|---|---|
| Dunnes Drill. | | | |

PW02

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# Borehole Log

BH1

Sheet 1 of 1

| | | | |
|---|---|---|---|
| Method: ROTARY | Date: May 2001 | Site: Ardan, Tullamore, Co. Offaly. | |
| Dia.mm: 160 | Coords: | G.L.mO.D. | Client: Tullamore U.D.C./ PH McCarthy & Partners |

| Water and Progress | Completion | Depth | Description of Strata | Legend |
|---|---|---|---|---|
| | | 0.00m | | |
| | | -5.00 | LIMESTONE Boulders & Cobbles | |
| | | -9.00 | | |
| | | -10.0 | SAND & Coarse GRAVEL | |
| | | -15.0 | | |
| -17.5m x 250mm Casing | | -20.0 | Light Grey weathered LIMESTONE ROCK | |
| 21.0m | | -25.0 | | |
| 25m x 200mm Casing | | -30.0 | | |
| 12m x 160mm Torch Cut Screen | | -35.0 | | |
| 33.0m | | -40.0 | End of Borehole | |
| End of Hole @ 35m (160mm) | | -45.0m | | |

Remarks:

1. BH @ existing site of Production BH.
2. Estimated output; 60 cubic mtrs/hr.
3. Water level (static)= 8m below G.L.
4. Fissure @ 35m (Water silty/dirty @ 35m)
5. Heavily weathered @ 15-24m, 26.5-31m, 32-35m).

| Logged by: | Scale: | End Casing Depth: | Job No: |
|---|---|---|---|
| JK | 1/250 | 33m | 98-47 |

BH06

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# BOREHOLE LOG

Trial Borehole



| | | | |
|---|---|---|---|
| Method: Rotary | Date: 22 June 1999 | Site: Arden Treatment Works, Tullamore Co. Offaly | |
| Dia mm: 200mm to 13.5m, 155mm to 85m | Coord: 234050, 227800 | Ground Level m.OD | Client: Tullamore U.D.C. |

| Soil Samples/Tests: Type/Test | Depth m. | Water & Progress | Casing (Internal diameter) | Depth m. | Description of Strata | Legend |
|---|---|---|---|---|---|---|
| | | | | 00.0m | | |
| | | | 160mm Steel Casing | 00.6m | FILL material (Gravel) | |
| | | | | 04.0m | Coarse SAND and GRAVEL (pebbles and cobbles) | |
| | | | | 07.0m | GRAVEL with very little SAND matrix (large Boulder @ 5.6m) | |
| | | | | 08.5m | Coarse SAND and GRAVEL | |
| | | | | 09.5m | Medium to Coarse grained SAND | |
| | | | | 12.0m | Clayey Silty SAND (Boulder @ 10.5m) | |
| | | | 13.5m | | ROCK-HEAD | |
| | | +80gph | 125mm Steel Casing | 18.0m | Dark grey to black, coarse grained LIMESTONE with STIFF, light brown, CLAY (weathered zone) | |

| Remarks | Logged by | Scale | End Casing Depth | Job No. |
|---|---|---|---|---|
| | M.C. | | | |

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BOREHOLE LOG

Trial Borehole



| | | | |
|---|---|---|---|
| Method: Rotary | Date: 22 June 1999 | Site: Arden Treatment Works, Tullamore Co. Offaly | |
| Dia mm: 200mm to 13.5m, 155mm to 85m | Coord: 234050, 227800 | Ground Level m.OD | Client: Tullamore U.D.C. |

| Soil Samples/Tests: Type/Test | Depth m. | Water & Progress | Casing (Internal diameter) | Depth m. | Description of Strata | Legend |
|---|---|---|---|---|---|---|
| | | | | 18.0m | | |
| | | | 125mm Steel Casing | 19.5m | Black, fine grained, LIMESTONE (brittle and weak) | |
| | | +200gph | | 21.0m | Black, fine grained LIMESTONE and blue-grey, coarse grained LIMESTONE, with light brown CLAY | |
| | | | | 23.5m | Black, fine grained LIMESTONE with blue-grey, coarse grained LIMESTONE (competent rock) | |
| | | | 25m Open Hole | 36.0m | Blue-grey, coarse grained LIMESTONE | |

| Remarks | Logged by | Scale | End Casing Depth | Job No. |
|---|---|---|---|---|
| | M.C. | | | |

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BOREHOLE LOG

Trial Borehole



| Method | Date | Site |
|---|---|---|
| Rotary | 22 June 1999 | Arden Treatment Works, Tullamore Co. Offaly |

| Dia mm | Coord | Ground Level m.OD | Client |
|---|---|---|---|
| 200mm to 13.5m<br>155mm to 85m | 234050, 227800 | | Tullamore U.D.C. |

| Soil Samples/Tests: Type/Test | Soil Samples/Tests: Depth m. | Water & Progress | Casing (Internal diameter) | Depth m. | Description of Strata | Legend |
|---|---|---|---|---|---|---|
| | | | | 36.0m | | |
| | | | Open Hole | | Blue grey, coarse grained LIMESTONE | |
| | | +150gph | | 41.0m | | |
| | | | | 42.0m | Discoloured, broken LIMESTONE and STIFF CLAY | |
| | | | | | Blue grey, coarse grained LIMESTONE | |
| | | | | 51.0m | | |
| | | | | 52.0m | Discoloured LIMESTONE and CLAY (no extra water) | |
| | | | | | Blue grey, coarse grained LIMESTONE | |
| | | | | 54.0m | | |

Remarks

| Logged by | Scale | End Casing Depth | Job No. |
|---|---|---|---|
| M.C. | | | |

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BOREHOLE LOG

Trial Borehole

Sheet 4 of 5

| Method | Date | Site |
|---|---|---|
| Rotary | 22 June 1999 | Arden Treatment Works, Tullamore Co. Offaly |

| Dia mm | Coord | Ground Level m.OD | Client |
|---|---|---|---|
| 200mm to 13.5m<br>155mm to 85m | 234050, 227800 | | Tullamore U.D.C. |

| Soil Samples/Tests | | Water & Progress | Casing (Internal diameter) | Depth m. | Description of Strata | Legend |
|---|---|---|---|---|---|---|
| Type/Test | Depth m. | | | | | |
| | | | | 54.0m | | |
| | | | Open Hole | | Blue grey, coarse grained LIMESTONE | |
| | | | | 65.0m | | |
| | | +500gph | | 66.0m | Blue LIMESTONE, with brown discolouration, calcite veining | |
| | | | | | Blue grey, coarse grained LIMESTONE | |
| | | | | 72.0m | | |

Remarks

| Logged by | Scale | End Casing Depth | Job No. |
|---|---|---|---|
| M.C. | | | |

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BOREHOLE LOG

Trial Borehole



| | | | |
|---|---|---|---|
| Method: Rotary | Date: 22 June 1999 | Site: Arden Treatment Works, Tullamore Co. Offaly | |
| Dia mm: 200mm to 13.5m, 155mm to 85m | Coord: 234050, 227800 | Ground Level m.OD | Client: Tullamore U.D.C. |

| Soil Samples/Tests: Type/Test | Depth m. | Water & Progress | Casing (Internal diameter) | Depth m. | Description of Strata | Legend |
|---|---|---|---|---|---|---|
| | | | | 72.0m | | |
| | | 5000gph | Open Hole | 79.0m | Blue grey, coarse grained LIMESTONE | |
| | | | | 85.0m | Blue grey, coarse grained LIMESTONE, with bands of black, fine grained LIMESTONE with brown discoloured, brittle LIMESTONE high calcite content | |
| | | | | | END OF BOREHOLE | |

| Remarks | Logged by | Scale | End Casing Depth | Job No. |
|---|---|---|---|---|
| | M.C. | | | |

BH07

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Borehole Log

BH3

Sheet 1 of 1

| Method: | Date: | Site: |
|---|---|---|
| ROTARY | May 2001 | Ardan, Tullamore, Co. Offaly. |

| Dia.mm: | Coords: | G.L.mO.D. | Client: |
|---|---|---|---|
| 160 | | | Tullamore U.D.C./ PH McCarthy & Partners |

| Water and Progress | Completion | Depth | Description of Strata | Legend |
|---|---|---|---|---|
| | | 0.00m | | |
| | | -4.00 | Large LIMESTONE Boulders | |
| | | -5.00 | Cemented GRAVEL Boulders | |
| | | -9.00 | | |
| | | -10.0 | SAND & Coarse GRAVEL | |
| 15.0m x 250mm Casing | | -15.0 | | |
| | | -20.0 | Pale Grey weathered LIMESTONE | |
| 35.0m x 200mm Casing | | -25.0 | | |
| | | -30.0 | | |
| | | -35.0 | | |
| 12m x 160mm Torch Cut Screen | | -40.0 | | |
| End of Hole @ 45m | | -45.0m | | |
| 4m x 155mm Open Hole | | -49.0m | | |

| Logged by | Scale | End Casing Depth | Job No: |
|---|---|---|---|
| JK | 1/250 | 45m | 98-47 |

Remarks:

1. Water level [illegible] 13m below G.L.
2. Estimated output 50 cubic [illegible]

End of Borehole

1001 - GSI Sources
Ardan Boreholes SPZ

Table A1.1 Surface Water Quality Data

| Number | Name | X | Y | EC | pH | T |
|---|---|---|---|---|---|---|
| 1 | SWQ01 | 233433 | 224832 | 792 | 7.69 | 16.6 |
| 2 | SWQ02 | 234991 | 225551 | 741 | 7.74 | 15.6 |
| 4 | SWQ04 | 239241 | 224743 | 729 | 8.04 | 14.6 |
| 5 | SWQ05 | 241202 | 223921 | 807 | 7.69 | 13.5 |
| 3 | SWQ03 | 238713 | 224072 | 695 | 7.52 | 14.8 |
| 6 | SWQ06 | 242120 | 224444 | 581 | 8.18 | 15.4 |
| 7 | SWQ07 | 244895 | 222109 | 638 | 8.20 | 13.8 |
| 8 | SWQ08 | 244319 | 223864 | 743 | 7.84 | 13.8 |
| 9 | SWQ09 | 242542 | 225709 | 443 | 8.03 | 18.8 |
| 10 | SWQ10 | 237461 | 226003 | 643 | 7.59 | 13.7 |
| 11 | SWQ11 | 239445 | 225571 | 774 | 7.85 | 15.6 |
| 12 | SWQ12 | 241219 | 226981 | 718 | 7.86 | 14.7 |
| 13 | SWQ13 | 238217 | 228185 | 786 | 7.73 | 13.7 |
| 14 | SWQ14 | 237602 | 227297 | 697 | 7.56 | 14.8 |
| 15 | SWQ15 | 237243 | 226690 | 726 | 8.26 | 20.0 |
| 16 | SWQ16 | 233802 | 228469 | 708 | 8.13 | 15.1 |
| 17 | SWQ17 | 236281 | 229799 | 704 | 8.00 | 14.9 |
| 18 | SWQ18 | 238552 | 232151 | 771 | 7.93 | 13.2 |
| 19 | SWQ19 | 238437 | 231779 | 706 | 8.20 | 14.5 |
| 20 | SWQ20 | 238758 | 230652 | 604 | 7.95 | 16.5 |
| 21 | SWQ21 | 241448 | 230353 | 419 | 7.26 | 14.4 |

Table A1.2 Point Data for Arden Boreholes SPZ Study Area

| Name | Source | Other Names | X | Y | Drill Date | Driller | BH Log | Casing | Screen / OH | Final Diameter | Water Strikes | Top of Casing | Type | TD | DTB | Subsoil (KTC logs) | Lithology | GWLDatum | RWL | RWL Date | Yield | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | mm | mbgl | mAOD Malin | | m | m | | | GWLDatum | | Assumed | | |
| PW01 | GES 98/47/05 (1999) | Arden Borehole No.1 | 234019 | 227969 | Sep-99 | Dunnes Drilling Ltd. | Yes | 406mm SC 0-12m; 305mm SC 0-24m; both grouted | 24 to TD (OH) | 305 | Major inflows between 72 to 103.6mbgl. Yield est = 2180m3/d | 68.979 | BH | 103.6 | 12.2 | CLAY, GRAVEL & Stone (0-6.1)/ SAND & GRAVEL (6.1-12.2) | Grey weathered & solid rock (12.2-24.4) / Solid bedrock (24.4-72) / Fissured bedrock with clay & water filled cavities. | Top of 12" steel casing | Dynamic WL 14.915 mbtc | 11:50am on22/06/11 by PC | 2180 m3/d | Drilled 5 m from trial borehole (i.e. BH06).; Sediment laden water for duration of well development. Pumped at 2420m3/d from 2001 - led to poor WQ with elevated Fe, Al & turbidity; Decreased Q to 1340m3/dand WQ improved. Q on 22/06/11 @ 11:50am = 1310 m3/d |
| PW02 | GES 98/47/05 (1999) | Arden Borehole No.2; BH1 | 234008 | 228050 | | | Yes | 250 mm SC 0 to 17.5m; 200mm SC 0 – 25m; ; No grout mentioned in log | 160mm SC dropped into hole to sit at 21 to 35 mbgl with slots cut with torch @ 21 to 33mbgl | 160mm | Fissure @ 35 mbgl with silty dirty water | 65.267 | BH | 35 | 15 | Lst Co & Bo 0-9m / SAND & Coarse GRAVEL 9-15m | Light grey weathered LST rock 15-35m. | Top of 8" steel casing | RWL = 8 mbgl. Dynamic WL =11.165 mbtc | RWL:BH Log May 2001 DWL: 12:07 on 22/06/2011 | 60 $m^3$/hr (1440 $m^3$/d) | Q on 22/06/11 @ 12:07 = 823 m3/d |
| BH01 | GES 98/47 | BH1 Spollanstown | 234400 | 224750 | 1975 | GEOX | No | | | | | | BH | | | | | | | | | |
| BH02 | GES 98/47 | BH2 (@ Silver River) | 233785 | 228477 | 1975 | GEOX | Yes | Blank casing to 5.8 | 15.8 - TD (OH) | 200 | 4.9mbgl (minor)/15.2m (1310m3/d)/27.4m (330m3/d) | | BH | 22.8 | 5.8 | Limstone GRAVEL with minor CLAY content | Pale grey, medium grained bioclastic limestone. Solution feature at 16.8mbgl. | | | | | Decommissioned & abandoned during construction of Tullamore Bypass (N52). Replaced by BH09 & BH10. |
| BH03 | GES 98/47 | Sillogue BH...BH3? | 231490 | 231050 | 1975 | GEOX | No | | | | | | BH | | | | | | | | | |
| BH04 | GES 98/47 | BH4 (@ Silver River) | 233780 | 288476 | 1977 | GEOX | Yes | Casing installed to >5.2mbgl ...possibley to 10.5mbgl | ~10.5 to TD (OH) | 305 | | | BH | 31 | 5.2 | Gravelly CLAY subsoil | dk & light grey LST; Caving in at 23.5 mbgl; Silted up to 28 mbgl | | | | | Decommissioned & abandoned during construction of Tullamore Bypass (N52). Replaced by BH09 & BH10. |
| BH05 | GES 98/47 | BH5 (@ Silver River) | 233790 | 228478 | 1977 | GEOX | Yes | Blank steel casing to 10.3mbgl | 10.3 to TD (OH) | 305 | | | BH | 22.8 | 6.4 | Gravelly CLAY subsoil | dk & light grey LST; Caving in at 23.5 mbgl; Silted up to 20.7 mbgl | | | | | Decommissioned & abandoned during construction of Tullamore Bypass (N52). Replaced by BH09 & BH10. |
| BH06 | GES 98/47/05 (1999) | Arden Trial Borehole | 234010 | 227970 | Jun-99 | Fogarty Drilling Ltd. | Yes | 160mm blank SC to 13.5m; 125mm steel casing to 25 m | 25m to TD (OH) | 200mm to 13.5m; 155mm to 85m | Minor inflows up to 50m3/d @ 14m, 21m, 41m & 65m; 500m3/day @ 79m. | | BH | 85 | 12 | SAND & GRAVEL (0-4)/ GRAVEL (4-7)/ SAND & GRAVEL (7-8.5)/ SAND (8.5-9.5)/ Clayey, silty SAND (9.5-12) | Dk grey to balck coarse grained LST (12-23)/ blue-grey coarse grained LST (25-79) with discolured broken LST & CLAY @ 41-42; brown discolouration & calcite veining 65-66 / Blue-grey coarse grained LST with bands of black fine gr LST, with disoloured brown brittle LST, high calcite content | | 12 mbgl | Post development Sept. 1999 | 545 m3/d | Co-ords estimated based on comment in GES 98/47/05 (1999) that BH06 (tiral well) is 5m from PW01 (Production well) |
| BH07 | GES 04/46 (2008) | Borehole at Chip Depot, Arden; BH3 | 233703 | 227618 | (Originally 2002) Redril in 2007 | - | Yes (2002) | 250 mm SC 0 to 15m; 200mm SC 0 – 35m; | 160mm SC dropped into hole to sit at 33 to 45 mbgl with slots cut with torch @ 33 to 45mbgl; 4m Open Hole 45 to 49m…(collapsed?) | 160mm | | 71.571 | BH | 45 | 15 | Large LST boulders 0-4m / Cemented GRAVEL boulders 4-9m / SAND & Coarse GRAVEL 9-15 m | Pale grey Limestone (15 - 49m) | Top of 8" steel casing | 14.3 mbtc | 13:00 on 22/06/11 by PC | 1200 m3/d | Re-drill of an existing borehole (from 2002?) that was 49 m deep but was filled with road chippings. TC = 0.205m agl |
| BH08 | GWL Survey | Borehole at Lay-by, Arden; BH2 | 233950 | 227876 | | | Yes | 250mm SC 0-7m; 200mm SC 0-15m; 160mm SC - 12 m - looks like depth interval is 12 to 24mbgl | looks like open hole 24m to TD | 160mm | Fissure @ 66mbgl with silty/dirty water | 73.436 | BH | 68 | 14 | LST boulder > 1m dia 0 to 9m / SAND & Coarse GRAVEL 9 to 14m | Loose weather Bedrock 14 to 16m / Loose weather LST Bedrock (Lost Circulation) 16 to 25m / Light, Pale grey LST 25 to TD. Brown weathered vein at 50m & 63m | Top of 8" steel casing | 16.965 mbtc | 12:43 on 22/06/11 by PC | 336 m3/d | Well Cover has "No.2" Etched into it. Water sampling bailer hanging inside BH. |
| BH09 | GES 04/46 (2008) | New Silver River BH1 | 233770 | 228437 | Apr-08 | | Yes | 8" Steel casing at surface | | 200 | Main inflows between 18 & 36mbgl | 57.617 | BH | 36 | 18.3 | 3m CLAY / 6.5m SILT/ 9.5m GRAVEL/I loose LST to 24mbgl | Broken Limestone | Top of 8" steel casing | 1.5 mbtc | from GES report; 28/04/08 on BH log | 2112m3/d | 2 new Silver river boreholes shown to PC by J Connolly on 22/06/11. Both on south bank of Silver River on west side of main road; BHs 3.1m apart; BH09 outer casing = 8" therefore assume this corresponds to silver river BH from GES (2008). Other BH (BH10) has 6" dia. outer casing. Both boreholes welded shut on 22/06/11. |
| BH10 | GWL Survey | New Silver River BH2 | 233771 | 228444 | | | No | 6" Steel casing at surface | | | | 57.619 | BH | - | | | | Top of 6" steel casing | | | | 3.1m north of other new silver river BH (i.e. BH09). BH10 is the closer to the river of the 2 BHs. Both boreholes welded shut on 22/06/11. |
| BH11 | GES 98/47/05 (1999) | Private BH, Arden | 233893.7 | 228238.4 | | | | | | | | 60.539 | BH | 18.288 | | | | Top of 6" steel casing | | | | |
| BH12 | GES 04/46 (2008) | Ballyduff BH; TW7 | 232041 | 227219 | Dec-07 | Dunnes Drilling Ltd. | Yes | 12.19m of 305mm SC; 43.89m of 200mm SC. | 43.89 to TD (OH) | 200 | Inflows at 69.33, 79.8 & 80.8m; most water at 79.8m; $Q_{est}$ = 6000gph | 68.51 | BH | 81 | 10.6 | soft CLAY / GRAVEL / Boulder Clay / to 10.5m | Broken weathered rock to 27.4m / broken weathered brown rock to 58.9m / Weathered brown rock into grey rock to 75.6m / Broken grey & Brown rock to 79.8 / grey rock medium hard into broken rock at 80.8 (collapsing) | Top of 6" steel casing | 14.585 mbtc | 14:05 on 22/06/11 by PC | 648m3/d | Drilling stopped at 80.8m due to collapsing conditions. 1 bag of bentonite & airlift for 3 hours. Top 6" SC = 0.56magl |
| BH13 | GES 04/46 (2008) | Durrow GWS BH; TW11 | 232606 | 230515 | Jan-08 | | Yes | 400mm SC to 8.23mbgl/ 200mm SC to 12.19m | 8" SC slotted from 8.4 to 12.2m | 200 | GW encountered in the broken rock @ 6 – 8 mbgl. $Q_{est}$ = 3000 to 4000gph | | BH | 91 | 6.1 | Gravel + Broken rock to 8m over competent bedrock | Grey rock, medium hard | | | | 324 - 432 m3/d | Borehole sealed shut with welded steel plate. 12" SC was pulled back 2.9 m from 11.2mbgl; BH annulus outside slotted 8"SC backfilled with pea gravel and sealed with 1 bag of bentonite. |
| BH14 | GSI Well Dbase | Mullaghtogher GWS BH; Wood of O BH; GSINAME 2321NWW005 | 239100 | 227550 | Mar-76 | | | | | 152 | 17m; 20.7m | | BH | 29.8 | 13.4 | | | | | | 79.6 | Data from Offaly GWPS report (GSI 1999). Specific capacity = 6.45m3/d/m. Mean NO3 = 23.9mg/l; Mean Cl = 16mg/l; Fecal Bact = 2. GSI DBASE: Abs ddn = 12.4m; |
| BH15 | GSI Well Dbase | Corndarragh GWS BH; Ballydaly GWS; GSINAME 2321NWW030 | 237090 | 226980 | - | | | | | | | 76.251 | BH | 36.9 | 14.6304 | 0-0.3m: Soil / 0.3-14.63m: Fine grained SAND / Limestone | Limestone | Top of 8" steel casing | | | 129.6 | Disused since 2000 because of elevated nitrate concentrations. Lithology, TD & yield data supplied by former caretaker. |
| BH16 | GWL Survey | Molloys Well Tinnycross | 235529 | 227962 | | | | | | | | 68.072 | BH | 21.3 | 10.7 | | | Top of 6" steel casing | | | | |

Table A1.2 Point Data for Arden Boreholes SPZ Study Area

| Name | Source | Other Names | X | Y | Drill Date | Driller | BH Log | Casing | Screen / OH | Final Diameter | Water Strikes | Top of Casing | Type | TD | DTB | Subsoil (KTC logs) | Lithology | GWLDatum | RWL | RWL Date | Yield | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | mm | mbgl | mAOD Malin | | m | m | | | GWLDatum | | Assumed | | |
| BH17 | GSI Well Dbase | Domestic BH in Tullamore; GSINAME 2321NWW003 | 234050 | 225100 | - | | | | | | | | BH | 4.9 | | | | | | | | |
| BH18 | GSI Well Dbase | Domestic BH in Tullamore; GSINAME 2321NWW081 | 233970 | 225300 | 1996 | | | | | | | | BH | 3 | 2.9 | | | | | | | |
| BH19 | GSI Well Dbase | Private BH, Ballydaly; GSINAME 2321NWW004 | 235240 | 226830 | 1969 | | | | | | | 63.548 | BH | 19.8 | 9.1 | | | Top of hole in concrete lid | | | | |
| BH20 | GWL Survey | Condrons BH; Creamery Well | 233766.7 | 227426.83 | | | | | | | | 67.363 | BH | - | | | | Top of 8" steel casing | | | | Approx. 100 m southeast of main entrance |
| BH21 | GWL Survey | Mullaghtogher Private BH | 237332.8 | 227528.8 | | | | | | | | 78.424 | BH | - | | | | Top of 6" steel casing | | | | |
| BH22 | GWL Survey | Private BH in Carton East | 237421.9 | 228958.3 | | | | | | | | 75.78 | BH | - | | | | Top of 4" plastic liner | | | | |
| BH23 | GWL Survey | Bracklin Big Private BH | 237019.3 | 229742.2 | | | | | | | | 84.73 | BH | - | | | | Top of 6" steel casing | | | | |
| BH24 | GWL Survey | SI piezometer adjacent to R443 in Tullamore | 233334.2 | 226620.3 | | | | | | | | 64.79 | BH | 3.47 | | | | - | | | | |
| BH25 | GWL Survey | SI piezometer adjacent to R443 in Tullamore | 233302.6 | 226641.8 | | | | | | | | 64.507 | BH | - | | | | - | | | | |
| GW01 | GES 04/46 (2008) | Durrow GWS Well | 232613 | 230523 | | | | | | 1.2 | | 59.738 | Dug Well | 4.15 | | | | Rim of Dug well manhole | 2.04 mbRef | 13:30 on 22/06/2011 by PC | 20 | Yield & WQ from Offaly GWPS report (GSI 1999). Mean NO3 = 21.1mg/l; Mean Cl = 24.3 mg/l; Fecal Bact = 8; |
| GW02 | GES 00/19/01 (2000) | Sillogue Spring | 231439 | 30263 | | | | | | | | | Spring | | | | | | | | 4000 | Yield from Offaly GWPS report (GSI 1999) |
| GW03 | GWL Survey | Molloy's Spring; GSI Karst D'Base 2321NWK011 | 235357 | 228516.6 | | | | | | | | 61.851 | Spring | 0.4 | | | | Steel walkway over spring | | | | |
| GW04 | GWL Survey | Dug well /spring in Carton East | 236004.4 | 229016.1 | | | | | | 2 m | | 67.469 | Dug Well | 1.12 | | | | Top of concrete roof on spring chamber @ access hole | | | | Dug well with bedrock outcrop in base of chamber - likely to be a karst spring originally |
| RL01 | GWL Survey | Silver River water level at Gormagh Bridge | 233796.8 | 228467.1 | | | | | | | | - | River Surface | - | | | | - | | | | |
| RL02 | GWL Survey | Silver River invert level at Gormagh Bridge | 233796.3 | 228467.7 | | | | | | | | - | River Invert | - | | | | - | | | | |
| RL03 | GWL Survey | Silver River invert level at Derrygolan Bridge | 236283.7 | 229800.8 | | | | | | | | - | River Invert | - | | | | - | | | | |
| RL04 | GWL Survey | Silver River water level at Derrygolan Bridge | 236283.5 | 229801.1 | | | | | | | | - | River Surface | - | | | | - | | | | |
| RL05 | GWL Survey | Main weir invert level at Derrygolan Bridge | 236287.6 | 229805.04 | | | | | | | | - | Weir Invert | - | | | | - | | | | Water level reading on OPW staff gauge on upstream side of main weir = 0.29 m at 11:23am on 22/07/2011 |
| RL06 | | Silver River water level adjacent to GW04 | 235983.6 | 228994.6 | | | | | | | | - | River Surface | - | | | | - | | | | |
| RL07 | | Silver River Invert level adjacent to GW04 | 235983.6 | 228994.7 | | | | | | | | - | River Invert | - | | | | - | | | | |
| GL01 | GWL Survey | Main Gates of Durrow Abbey | 232566.5 | 230708.3 | | | | | | | | - | Ground Level | - | | | | - | | | | This is the arbitrary datum used for Topographic survey in GES 00/19/01 (2000). GL measured is for the survey control point on a re-bar peg driven into the ground under the centre of the cattle grid at the Abbey gates |
| KF01 | GWL Survey | Locally referred to as the "Sumera" | 236037 | 228292 | | | | | | | | | Karst | | | | | | | | | Swallow hole fed by stream draining out of a pond/wetland. Pond is fed by stream draining out of Cartron East & Bracklin Big. |
| KF02 | GSI Karst Dbase | GSI FNUM: 2321NWK009 | 235890 | 228700 | | | | | | | | | Karst | | | | | | | | | Swallow Hole fed by stream draining out of Cartron East & Bracklin Big. Tracer test by GSI (1988) shows discharge at GW03 |
| KF03 | GWL Survey | | 236113 | 229273 | | | | | | | | | Karst | | | | | | | | | Shallow enclosed depression |
| KF04 | GWL Survey | | 236134 | 229283 | | | | | | | | | Karst | | | | | | | | | Shallow enclosed depression |
| KF05 | GWL Survey | | 236151 | 229288 | | | | | | | | | Karst | | | | | | | | | Shallow enclosed depression |
| KF06 | GWL Survey | | 236160 | 229321 | | | | | | | | | Karst | | | | | | | | | Shallow enclosed depression |
| KF07 | Aerial Photo | | 237156 | 229264 | | | | | | | | | Karst | | | | | | | | | Probable flooded enclosed depression. Clearly visible on aerial photo. Not ground truthed. Located on TLs over WA bedrock. Not shown on 6" Hist map, therefore possibly a recent feature - could be a "land break" or possibly an artificial (i.e. not karst) watering hole. |
| SW01 | GWL Survey | | 233892 | 228528 | | | | | | | | | SW Abs | | | | | | | | | Condron's Surface Water Abstraction |

Table A1.2 Point Data for Arden Boreholes SPZ Study Area

| Name | Source | Other Names | P Test | Pumping Test Rate (CDT) | SWL | SWL Date | Drawdown | Estimated Safe Yield | T | S | P Test achieved Steady State? | Pump Test Obs Wells | Pump Test Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | m3/day | mbREF | | m | m3/day | m2/d | | | | |
| PW01 | GES 98/47/05 (1999) | Arden Borehole No.1 | GES Step test 11/10/1999 & 72hr CDT 12/10/99 & Recovery; plus extra 71 hrs of development pumping | 2560 | TC | 11.78mbtc | 6.91 | 2180 | 314 to 318 | | | BH06 (trial well 5m away); Silver River borehole - BH04, 600m NNW; Private borehole - BH11, 230m NNW | Step Test: Steps 100, 100, 100, 45 mins; Q = 865; 1442; 2163 & 2595m3/d & SteadyState Ddn: 1.22; 2.83; 5.28; & 6.75m respectively. Recovery to 1.02mbRWL in 60sec. After 72hrs pump off for 220mins recovery, then pump on for another 71hrs to develop BH. DWL after 6 days = 18.7mbtc (ddn=6.91m) |
| PW02 | GES 98/47/05 (1999) | Arden Borehole No.2; BH1 | Cantwell Electrical Eng Ltd: 8 day VDT: 22/01/2002 start 12:45pm – 8 day test – finish 29/01/02 @ 13:50 (169hrs) | Q 0 – 31 hrs = 1177m3/d; Q 31 – 169hrs = 1,579 m3/d | 13.1 assume mbtc | 29/01/2002 | approx max ddn = 1.1 m (31hr). Approx. final ddn = 0.4 m(169hr) | | | | | | SWL data doesn't look reliable. No GWL for t= 0, SWL is for t = 0.5min. BH log says SWL = 8 mbgl…suggests ~ 5m of ddn in 30 sec, then steady. Ddn decreased when Q increased after 31 hrs --> development of cavities?? |
| BH01 | GES 98/47 | BH1 Spollanstown | Assume GEOX 1977 Pumping Test | | | | | | | | | | Fe = 600-1200 ug/l |
| BH02 | GES 98/47 | BH2 (@ Silver River) | 1975 GEOX pumping test - Step Test | | | | | | | | | | Step test average Qc = 467 m3/d/m. At Q = 2815m3/d, Qc = 403m3/d/m. WQ: 4 no. samples – Fe @ 500 to 600 ug/l . No micro organisms detected. |
| BH03 | GES 98/47 | Sillogue BH…BH3? | Assume GEOX 1977 Pumping Test | | | | | | | | | | Fe = 931 ug/l |
| BH04 | GES 98/47 | BH4 (@ Silver River) | Assume GEOX 1977 Pumping Test | | | | | | | | | | Qc = 462 & 552 m3/d/m @ 3160 & 3385 m3/d/m respectively. BH4: Fe = 700ug/l, Mn = 430 ug/l (stable final values). Q from BH4 decreased from 3164m3/d (1981) to 1746m3/d (1984); pump incrusted with iron deposits and aerobic Fe bacteria. OBS BH for GES 1999 @ PW01 - no signif impact |
| BH05 | GES 98/47 | BH5 (@ Silver River) | Assume GEOX 1977 Pumping Test | | | | | | | | | | Qc = 462 m3/d/m @ 2290 m3/d/m respectively. Fe fluctuated wildly at BH5. |
| BH06 | GES 98/47/05 (1999) | Arden Trial Borehole | GES Step test 11/10/1999 & 72hr CDT 12/10/99 & Recovery (BH06 = OBS Borehole) | | TC | 11.12mbtc | | | | | | | DWL in BH06 after 6 days = 15.65mbtc (ddn = 4.05m) |
| BH07 | GES 04/46 (2008) | Borehole at Chip Depot, Arden; BH3 | 1) Pumping test 07/07/2002 start 12:30pm – 8 day test finish 14/01/02 @ 21:40 (177hrs) 2) GES Step Test 23/06/08 & 48hr CDT 24/06/2008 | 1) Q =973 2) Q = 1320 | 1) 21.5 (assume mbtc | 1) 07/07/02 | 1) Approx. Final ddn @ 177hrs = 21.5-21.4 = -0.1 m 2) 5.56 | 2) 1000 | 2) 275 to 740 | | | | 1) SWL data doesn't look reliable. No GWL for t= 0, SWL is for t = 0.5min. SWL 22/07/2011 = 14.1 mbtc, suggests 7.4m ddn in 30 sec. 2) Step Test: 16.35m3/h increasing to 54 m3/h; max ddn = 5.25m; Recovery to 0.12mbRWL. CDT recovery = 100% in 9 hrs. WQ: 26/06/08 – All < DWS, No micro-orgs; NO3 = 13mg/l in 2002, rising to 16 mg/l in 2008. |
| BH08 | GWL Survey | Borehole at Lay-by, Arden; BH2 | NOT TESTED | | | | | | | | | | |
| BH09 | GES 04/46 (2008) | New Silver River BH1 | GES Step Test 2 & 72hr CDT (CDT start date: 07/06/2008 | 2112 | | | 1.78 | 1750m3/d | ~ 2045 to 6100 | | | | Step Test: 23m3/h inc. to 89 m3/h; max ddn = 1.67m after 21 hrs. CDT: possible rch barrier enc. At end of test; Recovery to 0.26mbRWL in 12 hrs. WQ: 13/06/08 – Fe = 0.44mg/l; Mn = 0.26mg/l. Much better than in 2007. Total coli detected but now Fecal Coli. |
| BH10 | GWL Survey | New Silver River BH2 | | | | | | | | | | | |
| BH11 | GES 98/47/05 (1999) | Private BH, Arden | | | | | | | | | | | OBS BH for GES 1999 @ PW01 - no signif impact |
| BH12 | GES 04/46 (2008) | Ballyduff BH; TW7 | GES Step Test 5/06/08 & 72 hr CDT on 6/06/08 | 521.04 | | | 10.42 | ~ 450m3/d | ~ 26 to 871 | | | | Step Test: 8.89m3/h inc. to 22.9 m3/h; max ddn = 9.47m after 22 hrs; Recovery to 0.29mbRWL in 20h. CDT recovery to 0.59mbRWL in 24 hrs. WQ: 6 & 12/06/08 (chem. WQ) + 27/6/08 (micro-org WQ): 1st sample [slightly elevated turbidity & Al (0.2mg/l Al); Cl = 48 mg/l]; 2nd sample – [all < DWS; NO3 = 40 mg/l; Cl = 39 mg/l]; No micro-orgs. |
| BH13 | GES 04/46 (2008) | Durrow GWS BH; TW11 | No Pumping Test | | | | | | | | | | |
| BH14 | GSI Well Dbase | Mullaghtogher GWS BH; Wood of O BH; GSINAME 2321NWW005 | | | | | | | | | | | |
| BH15 | GSI Well Dbase | Corndarragh GWS BH; Ballydaly GWS; GSINAME 2321NWW030 | | | | | | | | | | | |
| BH16 | GWL Survey | Molloys Well Tinnycross | | | | | | | | | | | |

Table A1.2 Point Data for Arden Boreholes SPZ Study Area

| Name | Source | Other Names | P Test | Pumping Test Rate (CDT) | SWL | SWL Date | Drawdown | Estimated Safe Yield | T | S | P Test achieved Steady State? | Pump Test Obs Wells | Pump Test Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | m3/day | mbREF | | m | m3/day | m2/d | | | | |
| BH17 | GSI Well Dbase | Domestic BH in Tullamore; GSINAME 2321NWW003 | | | | | | | | | | | |
| BH18 | GSI Well Dbase | Domestic BH in Tullamore; GSINAME 2321NWW081 | | | | | | | | | | | |
| BH19 | GSI Well Dbase | Private BH, Ballydaly; GSINAME 2321NWW004 | | | | | | | | | | | |
| BH20 | GWL Survey | Condrons BH; Creamery Well | | | | | | | | | | | |
| BH21 | GWL Survey | Mullaghtogher Private BH | | | | | | | | | | | |
| BH22 | GWL Survey | Private BH in Carton East | | | | | | | | | | | |
| BH23 | GWL Survey | Bracklin Big Private BH | | | | | | | | | | | |
| BH24 | GWL Survey | SI piezometer adjacent to R443 in Tullamore | | | | | | | | | | | |
| BH25 | GWL Survey | SI piezometer adjacent to R443 in Tullamore | | | | | | | | | | | |
| GW01 | GES 04/46 (2008) | Durrow GWS Well | | | | | | | | | | | |
| GW02 | GES 00/19/01 (2000) | Sillogue Spring | | | | | | | | | | | |
| GW03 | GWL Survey | Molloy's Spring; GSI Karst D'Base 2321NWK011 | | | | | | | | | | | |
| GW04 | GWL Survey | Dug well /spring in Carton East | | | | | | | | | | | |
| RL01 | GWL Survey | Silver River water level at Gormagh Bridge | | | | | | | | | | | |
| RL02 | GWL Survey | Silver River invert level at Gormagh Bridge | | | | | | | | | | | |
| RL03 | GWL Survey | Silver River invert level at Derrygolan Bridge | | | | | | | | | | | |
| RL04 | GWL Survey | Silver River water level at Derrygolan Bridge | | | | | | | | | | | |
| RL05 | GWL Survey | Main weir invert level at Derrygolan Bridge | | | | | | | | | | | |
| RL06 | | Silver River water level adjacent to GW04 | | | | | | | | | | | |
| RL07 | | Silver River Invert level adjacent to GW04 | | | | | | | | | | | |
| GL01 | GWL Survey | Main Gates of Durrow Abbey | | | | | | | | | | | |
| KF01 | GWL Survey | Locally referred to as the "Sumera" | | | | | | | | | | | |
| KF02 | GSI Karst Dbase | GSI FNUM: 2321NWK009 | | | | | | | | | | | |
| KF03 | GWL Survey | | | | | | | | | | | | |
| KF04 | GWL Survey | | | | | | | | | | | | |
| KF05 | GWL Survey | | | | | | | | | | | | |
| KF06 | GWL Survey | | | | | | | | | | | | |
| KF07 | Aerial Photo | | | | | | | | | | | | |
| SW01 | GWL Survey | | | | | | | | | | | | |

Table A1.3 Groundwater Level Survey Data (22 July 2011)

| Location | AKA | Type | X | Y | Time | Date | GL mOD | GWLDatum | Datum magl | Datum mOD | GWLmb Datum | GWL mOD | TD m | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PW01 | Arden Borehole No.1 | BH | 234019 | 227969 | 10:12 | 22-Jul | 68.919 | Top of 12" steel casing | 0.06 | 68.98 | 14.69 | 54.29 | 103.6 | BH pumping at 55.2 m3/hr. Couldn't open flap over borehole. Only surveyed top of concrete plinth (GL) adjacent to borehole |
| PW02 | Arden Borehole No.2; BH1 | BH | 234008 | 228050 | 10:21 | 22-Jul | 65.157 | Top of 8" steel casing | 0.11 | 65.27 | 11 | 54.27 | - | BH pumping at 34.6 m3/hr. Couldn't open flap over borehole. Only surveyed top of concrete plinth (GL) adjacent to borehole |
| BH01 | BH1 Spollanstown | BH | 234400 | 224750 | | | | | | | | | | |
| BH02 | BH2 (@ Silver River) | BH | 233785 | 228477 | | | | | | | | | 22.8 | |
| BH03 | Sillogue BH…BH3? | BH | 231490 | 231050 | | | | | | | | | | |
| BH04 | BH4 (@ Silver River) | BH | 233780 | 288476 | | | | | | | | | 31 | |
| BH05 | BH5 (@ Silver River) | BH | 233790 | 228478 | | | | | | | | | 22.8 | |
| BH06 | Arden Trial Borehole | BH | 234010 | 227970 | | | | | | | | | 85 | |
| BH07 | Borehole at Chip Depot, Arden; BH | BH | 233703 | 227618 | 09:55 | 22-Jul | 71.355 | Top of 8" steel casing | 0.18 | 71.571 | 14.105 | 57.47 | 47.2 | RWL (rest water level) |
| BH08 | Borehole at Lay-by, Arden; BH2 | BH | 233950 | 227876 | 10:31 | 22-Jul | 73.336 | Top of 8" steel casing | 0.09 | 73.436 | 16.75 | 56.69 | | RWL |
| BH09 | New Silver River BH1 | BH | 233770 | 228437 | 10:46 | 22-Jul | 57.329 | Top of 8" steel casing | 0.3 | 57.617 | 1.17 | 56.45 | 36 | RWL (Furthest from river of the 2 BHs) |
| BH10 | New Silver River BH2 | BH | 233771 | 228444 | 10:47 | 22-Jul | 57.355 | Top of 6" steel casing | 0.28 | 57.619 | 1.17 | 56.45 | - | RWL (Closest to river of the 2 BHs) |
| BH11 | Private BH, Arden | BH | 233893.7 | 228238.4 | 14:00 | 22-Jul | 60.49 | Top of 6" steel casing | 0.32 | 60.539 | 3.98 | 56.56 | 18.288 | RWL; No Fe problems; Hard limey water |
| BH12 | Ballyduff BH; TW7 | BH | 232041 | 227219 | 13:26 | 22-Jul | 68.084 | Top of 6" steel casing | 0.565 | 68.51 | 14.945 | 53.57 | 81 | RWL |
| BH13 | Durrow GWS BH; TW11 | BH | 232606 | 230515 | | 22-Jul | | | | | | | 91 | |
| BH14 | Mullaghtogher GWS BH; Wood of O BH | BH | 239100 | 227550 | | 22-Jul | | | | | | | 29.8 | |
| BH15 | Corndarragh GWS BH; Ballydaly GWS | BH | 237090 | 226980 | 12:50 | 22-Jul | 76.246 | Top of 8" steel casing | 0 | 76.251 | 12.9 | 63.35 | 36.9 | RWL |
| BH16 | Molloy's Well Tinnycross | BH | 235520 | 228310 | 12:32 | 22-Jul | 67.953 | Top of 6" steel casing | 0.12 | 68.072 | 6.46 | 61.61 | - | RWL |
| BH17 | Domestic BH in Tullamore | BH | 234050 | 225100 | | | | | | | | | 4.9 | |
| BH18 | Domestic BH in Tullamore | BH | 233970 | 225300 | | | | | | | | | 3 | |
| BH19 | Private BH, Ballydaly | BH | 235240 | 226830 | 12:41 | 22-Jul | 63.663 | Top of hole in concrete lid | 0 | 63.548 | 3.485 | 60.06 | 19.8 | RWL |
| BH20 | Condrons BH; "Creamery Well" | BH | 233766.65 | 227426.83 | 09:50 | 22-Jul | 67.009 | Top of 8" steel casing | 0.335 | 67.363 | 9.9 | 57.46 | - | RWL |
| BH21 | Mullaghtogher Private BH | BH | 237332.8 | 227528.8 | 13:05 | 22-Jul | 78.282 | Top of 6" steel casing | 0.1 | 78.424 | 10.915 | 67.51 | - | RWL |
| BH22 | Private BH in Carton East | BH | 237421.9 | 228958.3 | 11:52 | 22-Jul | 75.857 | Top of 4" plastic liner | 0.008 | 75.78 | 4.7 | 71.08 | - | RWL |
| BH23 | Bracklin Big Private BH | BH | 237019.3 | 229742.2 | 11:38 | 22-Jul | 84.7 | Top of 6" steel casing | 0 | 84.73 | 14.405 | 70.33 | - | RWL |
| BH24 | SI piezometer adjacent to R443 in Tullamore | BH | 233334.2 | 226620.3 | 13:30 | 22-Jul | 64.217 | - | - | 64.79 | >3.47 | - | 3.47 | Dry |
| BH25 | SI piezometer adjacent to R443 in Tullamore | BH | 233302.6 | 226641.8 | 13:30 | 22-Jul | 63.97 | - | - | 64.507 | - | - | - | Couldn't open allen key locking screw. |

Table A1.3 Groundwater Level Survey Data (22 July 2011)

| Location | AKA | Type | X | Y | Time | Date | GL mOD | GWLDatum | Datum magl | Datum mOD | GWLmb Datum | GWL mOD | TD m | Comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GW01 | Durrow GWS Well | Dug Well | 232613 | 230523 | 11:09 | 22-Jul | 59.738 | Rim of Dug well manhole | 0 | 59.738 | 2.18 | 57.56 | 4.15 | PWL?; Tree cover too dense to survey well head with GPS. GL at edge of road tarmac directly west of well = 59.738 mAOD; Estimate approx = GL at well head |
| GW02 | Sillogue Spring | Spring | 231439 | 30263 | | 22-Jul | | | | | | | | |
| GW03 | Molloy's Spring; GSI Karst D'Base 2321NWK011 | Spring | 235357 | 228516.6 | 12:25 | 22-Jul | 62.851 | Steel walkway over spring | - | 61.851 | 1.25 | 60.60 | 0.4 | Tree cover too dense to survey spring with GPS. GL taken from path beside gate which leads down to spring (~15m south of spring) = 62.851mAOD; Approx 1m above level of steel walkway; Spring overflows out of spring pond over a weir. |
| GW04 | Dug well /spring in Carton East | Dug Well | 236004.4 | 229016.1 | 12:05 | 22-Jul | 66.353 | Top of concrete roof on spring chamber @ access hole | 1.2 | 67.469 | 1.79 | 65.68 | 1.12 | RWL; Bedrock visible at base of well |
| RL01 | Silver River water level at Gormagh Bridge | River Surface | 233796.8 | 228467.1 | 10:53 | 22-Jul | 56.52 | - | - | - | - | 56.52 | - | Approx 30 m d/str of bridge |
| RL02 | Silver River invert level at Gormagh Bridge | River Invert | 233796.3 | 228467.7 | 10:53 | 22-Jul | 56.242 | - | - | - | - | 56.24 | - | Approx 30 m d/str of bridge |
| RL03 | Silver River invert level at Derrygolan Bridge | River Invert | 236283.7 | 229800.8 | 11:23 | 22-Jul | 67.947 | - | - | - | - | 67.95 | - | Just D/str of entire weir structure |
| RL04 | Silver River water level at Derrygolan Bridge | River Surface | 236283.5 | 229801.1 | 11:23 | 22-Jul | 68.408 | - | - | - | - | 68.41 | - | Just D/str of entire weir structure |
| RL05 | Main weir invert level at Derrygolan Bridge | Weir Invert | 236287.6 | 229805.04 | 11:23 | 22-Jul | 69.135 | - | - | - | - | 69.14 | - | Water level at OPW staff gauge upstream of main weir @ 11:23am = 0.29m on 22/7/11 |
| RL06 | Silver River water level adjacent to GW04 | River Surface | 235983.6 | 228994.6 | 12:10 | 22-Jul | 65.255 | - | - | - | - | 65.26 | - | |
| RL07 | Silver River Invert level adjacent to GW04 | River Invert | 235983.6 | 228994.7 | 12:10 | 22-Jul | 64.955 | - | - | - | - | 64.96 | - | |
| GL01 | Main Gates of Durrow Abbey | Ground Level | 232566.5 | 230708.3 | 11:00 | 22-Jul | 62.355 | - | - | - | - | 62.36 | - | Centre of gates at rebar peg beneath cattle grid |

Table A1.4 - Gorundwater Quality Data

| Sample Location | | | | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Date** | | | | 13/10/1999 | 14/10/1999 | 15/10/1999 | 18/10/1999 | 12/07/05 | 21/08/06 | 11/09/06 | 09/10/06 |
| **Sample Time** | | | | - | - | - | - | - | 3:15 PM | 8:30 AM | 9:20 AM |
| **Sample Type** | | | | | | | | Groundwater | | | |
| **PARAMETER** | **UNITS** | **POTABLE M.A.C. (SI 278 of 2007)** | **Groundwater Threshold Value (Tests 1 - 4) (SI 9 of 2010)** | | | | | | | | |
| **PHYSICO-CHEMICAL PARAMETERS** | | | | | | | | | | | |
| pH | pH Units | 6.5-9.5 | | 7.4 | 7.5 | 7.5 | 7.3 | | | 7.3 | 7.4 |
| Conductivity @20C | uS/cm | 2500 | 800 - 1875 | 531 | 527 | 466 | 550 | | | 594 | 583 |
| TOC | mg/l | No abnormal change | | 0.7 | | | 0.6 | | | | |
| K:Na | | | | | | | | | | | |
| Total Hardness | mg/l Ca | | | | | | | | | | |
| Total Hardness | mg/l CaCO3 | | | 226 | 295 | 286 | | | 328.00 | 259.00 | 306.25 |
| Turbidity | N.T.U. | Acceptable to Consumer & no abnormal change | | | | | | | | 0.34 | 1.39 |
| Appearance | | | | | | | | | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Slightly Dull; slight/some SS |
| Colour, apparent | mg/l Pt Co | Acceptable to Consumer | | 189 | 246 | 22 | 24 | | | <5 | <5 |
| Odour No. dilution number | | Acceptable to Consumer & no abnormal change | | | | | | | None | None | None |
| Taste No. dilution number | | Acceptable to Consumer & no abnormal change | | | | | | | | | |
| **MICROBIOLOGICAL PARAMETERS** | | | | | | | | | | | |
| E coli (Filtration) | cfu/100ml | 0 | | 0 | 0 | 0 | | 0 | | 0 | 0 |
| Total Coliforms (Filtration) | cfu/100ml | 0 | | **4** | **1** | 0 | **2** | 0 | | **1** | 0 |
| Enterococci | cfu/100ml | 0 | | 0 | | | | | | | |
| Clostridium Perfringens in Water | cfu/100ml | 0 | | 0 | | | | 0 | | | |
| T.V.C. @ 22 (Pour Plate) | cfu/ml | No abnormal change | | >300 | | | >300 | | | | |
| **ANIONS** | | | | | | | | | | | |
| Alkalinity, total | mg/l CaCO3 | - | | 305 | 275 | 260 | | | | | |
| Chloride | mg/l | 250 | 24 - 187.5 | 19 | | | 20 | | | 21.6 | 21.5 |
| Sulphate | mg/l SO4 | 250 | 187.5 | 20 | | | 19 | | | | |
| Nitrate as NO3 | mg/l | 50 | 37.5 | 22 | 24 | 24 | 25 | | | 29.92 | 27.98 |
| Nitrite as NO2 | mg/l | 0.5 | 0.375 | <0.5 | <0.5 | <0.5 | <0.5 | | | <0.018 | <0.018 |
| Orthophosphate as P (filtered) | mg/l | | 0.035 | | | | | | | | |
| Bromate as BrO3 | ug/l | 10 | | <10 | | | <10 | | | | |
| Fluoride | mg/l | 1.5 | | 0.3 | | | 0.3 | | | | |
| Cyanide, total | ug/l | 50 | 37.5 | <50 | | | <50 | | | | |
| **CATIONS** | | | | | | | | | | | |
| Calcium, dissolved | mg/l Ca | 200 | | 101 | 110 | 95 | | | | | |
| Magnesium, dissolved | mg/l | 50 | | | | | | | | | |
| Sodium, dissolved | mg/l | 200 | 150 | 41 | | | 15 | | | | |
| Potassium, dissolved | mg/l | 12 | | | | | | | | | |
| Ammonium as NH4 | mg/l | 0.30 | 0.084 - 0.23 | <0.1 | <0.1 | <0.1 | <0.1 | | | <0.08 | <0.08 |
| **DISSOLVED METALS** | | | | | | | | | | | |
| Aluminium, dissolved | ug/l | 200 | 150 | | | | | | | | |
| Antimony, dissolved | ug/l | 5 | | | | | | | | | |
| Arsenic, dissolved | ug/l | 10 | 7.5 | | | | | | | | |
| Barium, dissolved | ug/l | | | | | | | | | | |
| Boron, dissolved | ug/l | 1000 | 750 | | | | | | | | |
| Cadmium, dissolved | ug/l | 5 | 3.75 | | | | | | | | |
| Chromium, dissolved | ug/l | 50 | 37.5 | | | | | | | | |
| Copper, dissolved | ug/l | 2000 | 1500 | | | | | | | | |
| Iron, dissolved | ug/l | 200 | | | | | | | | | |
| Lead, dissolved | ug/l | 10 | 18.75 | | | | | | | | |
| Manganese, dissolved | ug/l | 50 | | | | | | | | | |
| Mercury, dissolved | ug/l | 1 | 0.75 | | | | | | | | |
| Nickel, dissolved | ug/l | 20 | 15 | | | | | | | | |
| Selenium, dissolved | ug/l | 10 | | | | | | | | | |
| Tin, dissolved | ug/l | | | | | | | | | | |
| Zinc, dissolved | ug/l | | | | | | | | | | |
| **TOTAL METALS** | | | | | | | | | | | |
| Calcium, total | mg/l | 200 | | | | | | | | | |
| Magnesium, total | mg/l | 50 | | | | | | | | | |
| Sodium, total | mg/l | 200 | | | | | | | | | |
| Potassium, total | mg/l | 12 | | | | | | | | | |
| Aluminium, Total | ug/l | 200 | 150 | <10 | <10 | <10 | <10 | | | <10 | 78 |
| Antimony, total | ug/l | 5 | | <10 | | | <10 | | | | |
| Arsenic, total | ug/l | 10 | 7.5 | <10 | | | <10 | | | | |
| Barium, total | ug/l | - | | | | | | | | | |
| Boron | ug/l | 1000 | 750 | 70 | | | 60 | | | | |
| Cadmium, total | ug/l | 5 | 3.75 | <5 | | | <5 | | | | |
| Chromium, total | ug/l | 50 | 37.5 | <10 | | | <10 | | | | |
| Copper, total | ug/l | 2000 | 1500 | <80 | <80 | <80 | <80 | | | <50 | <50 |
| Iron, total | ug/l | 200 | | 130 | **370** | 180 | <100 | | | <100 | 114 |
| Lead, total | ug/l | 10 | 18.75 | <10 | <10 | <10 | <10 | | | <5 | <5 |
| Manganese, total | ug/l | 50 | | <50 | <50 | <50 | <50 | | | <25 | <25 |
| Mercury | ug/l | 1 | 0.75 | <1 | | | <1 | | | | |
| Nickel, total | ug/l | 20 | 15 | <10 | | | <10 | | | | |
| Selenium, total | ug/l | 10 | | <10 | | | <10 | | | | |
| Tin, total | ug/l | - | | | | | | | | | |
| Zinc, total | ug/l | - | | 60 | 80 | 70 | | | | | |
| **PAHs** | | | | <1 | | | <2 | | | | |
| Fluoranthene | ng/l | | | | | | | | | | |
| Benzo(a)pyrene (DW) | ng/l | 10 | 7.5 | | | | | | | | |
| Benzo(b)fluoranthene | ng/l | | | | | | | | | | |
| Benzo(g,h,i)perylene | ng/l | | | | | | | | | | |
| Benzo(k)fluoranthene | ng/l | | | | | | | | | | |
| Indeno(1,2,3-cd)pyrene | ng/l | | | | | | | | | | |
| Polycyclic Aromatic Hydrocarbons, (DW sum of four) | ng/l | 100 | 75 | | | | | | | | |
| **VOCS** | | | | | | | | | | | |
| 1,2-Dichloroethane | ug/l | 3 | 2.25 | <1 | | | <1 | | | | |
| Benzene (0.05ug/l) | ug/l | 1 | 0.75 | <1 | | | <1 | | | | |
| Tetra- and Trichloroethene | ug/l | 10 | 7.5 | <1 | | | <1 | | | | |
| Trihalomethanes (low level) | ug/l | 100 | 75 | <1 | | | <1 | | | | |
| **PESTICIDES** | | | | | | | | | | | |
| 2,4-D | ug/l | 0.1 | 0.075 | | | | | | | | |
| 2,6-Dichlorobenzamide | ug/l | 0.1 | | | | | | | | | |
| Atrazine | ug/l | 0.1 | 0.075 | | | | | | | | |
| Bentazone | ug/l | 0.1 | 0.075 | | | | | | | | |
| Clopyralid | ug/l | 0.1 | | | | | | | | | |
| Cypermethrin | ug/l | 0.1 | 0.075 | | | | | | | | |
| Dichlobenil | ug/l | 0.1 | | | | | | | | | |
| Dichlorprop | ug/l | 0.1 | | | | | | | | | |
| Diuron | ug/l | 0.1 | 0.075 | | | | | | | | |
| Glyphosate | ug/l | 0.1 | 0.075 | | | | | | | | |
| Isoproturon | ug/l | 0.1 | 0.075 | | | | | | | | |
| Linuron | ug/l | 0.1 | | | | | | | | | |
| MCPA | ug/l | 0.1 | 0.075 | | | | | | | | |
| Mecoprop (MCPP) | ug/l | 0.1 | 0.075 | | | | | | | | |
| Metaldehyde | ug/l | 0.1 | | | | | | | | | |
| Propyzamide | ug/l | 0.1 | | | | | | | | | |
| Simazine | ug/l | 0.1 | 0.075 | | | | | | | | |
| Total Pesticides | ug/l | 0.5 | 0.375 | <0.05 | | | <0.05 | | | | |

**Bold Red Text indicates exceeedance of MAC**

**Bold Orange Text indicates exceeedance of EPA Threshold (ammonium threshold = 0.175 mg/l as N)**

Table A1.4 - Gorundwater Quality Data

| PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 07/11/06 | 12/12/06 | 22/01/07 | 19/02/07 | 26/03/07 | 23/04/07 | 28/05/07 | 19/06/07 | 23/07/07 | 27/08/07 | 17/09/07 | 08/10/07 | 19/11/07 | 04/12/07 |
| 9:00 AM | 9:45 AM | 9:55 AM | 1:00 PM | - | 9:15 AM | 8:30 AM | 2:40 PM | 10:40 AM | 8:40 AM | 9:40 AM | 8:40 AM | 8:45 AM | 8:55 AM |
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| 7.4 | 7.4 | 7.5 | 7.4 | 7.4 | 7.4 | 7.4 | 7.3 | 7.4 | 7.4 | 7.4 | 7.4 | 7.3 | 7.3 |
| 582 | 567 | 559 | 583 | 569 | 606 | 612 | 542 | 616 | 557 | 576 | 613 | 627 | 623 |
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| | | | | | | | | | | | | | |
| | | 115.00 | - | 126.30 | 122.60 | 120.00 | 124.10 | 126.60 | 121.00 | 121.00 | 126.40 | 120.06 | 127.37 |
| 299.05 | 293.10 | 287.50 | - | 315.75 | 306.50 | 300.00 | 310.25 | 316.50 | 302.50 | 302.50 | 316.00 | 300.15 | 318.43 |
| 0.3 | 5.21 | 4.17 | 2.56 | 1.3 | 0.32 | 0.3 | 0.38 | 0.19 | 0.44 | 0.35 | 0.39 | 0.7 | 0.85 |
| Clear; Slight Sus Solids | Dull; Some Sus Solids | Dull; Large amount Sus Solids | Slightly Dull; Some Sus Solids | Slightly Dull; Some Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids |
| <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| None | None | None | None | None | None | None | None | None | None | None | None | None | None |
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| 0 | 0 | 0 | 0 | | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | | 1 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 2 |
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| 20.2 | 19.4 | 20.9 | 21.8 | 21.3 | 21.6 | 21.9 | 21.8 | 22.1 | 19.8 | 20.1 | 20.9 | 21.9 | 22.4 |
| | | | | | | | | | | | | | |
| 27 | 28.59 | 31.58 | 38.84 | 34.45 | 35.18 | 34.05 | 32.67 | 34.05 | 30.3 | 27.45 | 27.85 | 29.82 | 31.12 |
| <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.017 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 |
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| <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 |

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| 12 | | | 177 | 180 | <25 | <25 | 31 | <25 | <25 | <25 | <25 | 38 | 40 |
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| <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 |
| <100 | 253 | 191 | 144 | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 |
| <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 |
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| PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW01 (Arden BH No.1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21/01/08 | 18/02/08 | 11/03/08 | 22/04/08 | 26/05/08 | 10/06/08 | 21/07/08 | 26/08/08 | 22/09/08 | 21/10/08 | 17/11/08 | 07/12/08 | 22/02/10 | 30/08/10 |
| 9:40 AM | 5:05 PM | 11:40 AM | 9:30 AM | 8:35 AM | 8:30 AM | 8:15 AM | 9:30 AM | 8:55 AM | 10:45 AM | 10:00 AM | 1:40 PM | 10:55 AM | 9:25 AM |
| 7.5 | - | 7.4 | 7.3 | 7.3 | 7.4 | 7.2 | 7.3 | 7.3 | 7.3 | 7.4 | 7.4 | 7.4 | 7.3 |
| 585 | 566 | 584 | 579 | 614 | 609 | 609 | 595 | 600 | 610 | 576 | 606 | 579 | 586 |
| 126.40 | 118.90 | 122.80 | 83.90 | 130.00 | 87.90 | 121.90 | 127.80 | 85.60 | 127.70 | 128.90 | 92.10 | - | 119.60 |
| 316.00 | 297.25 | 307.00 | 209.75 | 325.00 | 219.75 | 304.75 | 319.50 | 214.00 | 319.25 | 322.25 | 230.25 | - | 299.00 |
| 0.41 | 0.12 | 0.19 | <0.5 | <0.5 | 0.66 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 1.24 | <0.5 |
| Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Slightly Dull; Some Sus Solids | Clear; Slight Sus Solids |
| <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| None | None | None | None | None | None | None | None | None | None | None | None | None | None |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 0 | 0 | 0 | 0 | 24 | 1 | 0 | 1 | 0 | 0 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20.2 | 19.9 | 20 | 22.5 | 20.5 | 20.2 | 20.4 | 19.5 | 20 | 19.6 | 19.3 | 18.9 | 21.8 | 22.4 |
| 27.24 | 27.9 | 27.44 | 28.78 | 29.24 | 28.64 | 27.43 | 30.45 | 25.1 | 27.31 | 24.5 | 24.51 | 24.45 | 21.99 |
| <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 |
|  |  |  | 0.21 |  |  |  |  |  | 0.21 |  |  | 0.27 | 0.5 |
| <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 |
| 62 | <25 | <25 | <25 | <25 | 27 | <25 | <25 | <25 | <25 | <25 | 25 | <25 | <25 |
| <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 |
| <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 | 168 | <100 |
| <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 |

Table A1.4 - Gorundwater Quality Data

| PW01 (Arden BH No.1) | PW01 (Arden BH No.1) | PW02 (Arden BH No.2) | PW02 (Arden BH No.2) | PW02 (Arden BH No.2) | PW02 (Arden BH No.2) | PW02 (Arden BH No.2) | PW02 (Arden BH No.2) | PW02 (Arden BH No.2) | PW02 (Arden BH No.2) | PW02 (Arden BH No.2) | PW02 (Arden BH No.2) | PW02 (Arden BH No.2) | PW02 (Arden BH No.2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06/12/10 | 13/12/10 | 12/07/05 | 21/08/06 | 11/09/06 | 09/10/06 | 07/11/06 | 12/12/06 | 22/01/07 | 19/02/07 | 26/03/07 | 23/04/07 | 28/05/07 | 19/06/07 |
| - | - | 12:40 PM | - | 8:45 AM | 2:30 PM | 9:15 AM | 9:50 AM | 10:05 AM | 1:10 PM | - | 9:20 AM | 8:35 AM | 2:45 PM |
| | | | | | | | | | | | | Filtered | |
| - | - | | | 7.2 | 7.3 | 7.3 | 7.3 | 7.4 | 7.4 | 7.4 | 7.3 | 7.3 | 7.3 |
| - | - | | | 659 | 640 | 645 | 633 | 628 | 643 | 638 | 659 | 663 | 587 |
| - | - | | | | | | | 126.30 | - | 132.20 | 144.30 | 128.60 | 130.40 |
| - | - | | 346.75 | 331.75 | 337.00 | 333.20 | 325.00 | 315.75 | - | 330.50 | 360.75 | 321.50 | 326.00 |
| - | - | | | 0.19 | 5.54 | 0.19 | 3.1 | 1.06 | 1.52 | 4.35 | 0.97 | 2.25 | 0.62 |
| - | - | | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Dull; Sus Solids | Clear; Slight Sus Solids | Dull; Sus Solids | Slightly Dull; Some Sus Solids | Slightly Dull; Some Sus Solids | Slightly Dull; Some Sus Solids | Clear; Slight Sus Solids | Dull; Some Sus Solids | Clear; Slight Sus Solids |
| - | - | | | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| - | - | | None | None | None | None | Chlorinous | None | None | None | None | Slightly vegatative | None |
| - | - | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 |
| - | - | 1 | | 0 | 62 | 2 | 0 | 0 | 0 | | 0 | 1 | 0 |
| - | - | 0 | | | | | | | | | 0 | 0 | 0 |
| - | - | | 23.9 | 23.9 | 23 | 21.7 | 22.9 | 22 | 23 | 22.1 | 22 | 22.3 | 22.6 |
| - | - | | | 40.8 | 37.44 | 33.34 | 38.06 | 46.41 | 51.64 | 50.11 | 46.87 | 47.18 | 45.13 |
| - | - | | | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 |
| - | - | | | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 |
| | | | | | | | | | | | | 168 | |
| | | | | | | | | | | | | <50 | |
| | | | | | | | | | | | | 439 | |
| | | | | | | | | | | | | <5 | |
| | | | | | | | | | | | | <25 | |
| - | - | | | <10 | 194 | <10 | | - | 214 | 304 | 194 | - | <25 |
| - | - | | | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 | - | <50 |
| - | - | | | <100 | 639 | <100 | 338 | <100 | 306 | 645 | <100 | - | <100 |
| - | - | | | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | - | <5 |
| - | - | | | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | - | <25 |
| 2 | <2 | | | | | | | | | | | | |
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| <1 | <1 | | | | | | | | | | | | |
| <2 | <2 | | | | | | | | | | | | |
| 2 | 0 | | | | | | | | | | | | |

Table A1.4 - Gorundwater Quality Data

| **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23/07/07 | 27/08/07 | 17/09/07 | 08/10/07 | 19/11/07 | 04/12/07 | 21/01/08 | 18/02/08 | 11/03/08 | 22/04/08 | 26/05/08 | 10/06/08 | 21/07/08 | 26/08/08 |
| 10:50 AM | 8:45 AM | 9:50 AM | 8:50 AM | 8:45 AM | 9:00 AM | 9:45 AM | 5:10 PM | 11:50 AM | 9:35 AM | 8:45 AM | 8:35 AM | 8:30 AM | 9:40 AM |
| | Filtered | | | | | | | | | | | Filtered | Filtered |
| 7.3 | 7.3 | 7.3 | 7.3 | 7.2 | 7.2 | 7.3 | - | 7.2 | 7.2 | 7.2 | 7.3 | 7.2 | 7.3 |
| 649 | 592 | 623 | 651 | 661 | 647 | 634 | 616 | 645 | 652 | 662 | 657 | 639 | 531 |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| 135.00 | 131.70 | 133.70 | 136.80 | 132.16 | 136.50 | 138.10 | 129.50 | 146.30 | 96.90 | >140 | 104.90 | 136.50 | 130.20 |
| 337.50 | 329.25 | 334.25 | 342.00 | 330.40 | 341.25 | 345.25 | 323.75 | 365.75 | 242.25 | >350 | 262.25 | 341.25 | 325.50 |
| 0.89 | 1.46 | 0.46 | 0.31 | 0.29 | 0.23 | 0.14 | 0.34 | 0.13 | <0.5 | 0.57 | <0.5 | 2.38 | 1.1 |
| Clear; Slight Sus Solids | Slightly Dull; Some Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Slightly Dull; Some Sus Solids | Clear; Slight Sus Solids |
| <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| None | None | None | None | None | None | None | Slightly stale | None | None | None | None | None | None |
| | | | | | | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | **2** | 0 | 0 | 0 | **3** | 0 | **1** | 0 | 0 | **7** | 0 |
| | | | | | | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | | | | | | | | |
| 22.8 | 20.7 | 20.7 | 21 | 22 | 22.4 | 20.6 | 19.7 | 19.6 | 22.1 | 20.5 | 20.7 | 20.5 | 18.8 |
| | | | | | | | | | | | | | |
| **44.67** | 34.29 | 33.55 | 34.43 | 35.62 | 35.58 | 31.65 | 32.56 | 34.03 | 35.59 | 34.42 | 34.83 | 32.06 | 29.82 |
| <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 |
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| | 0.106 | | | | | | | | 0.1 | | | | |
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| <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 |
| | 97 | | | | | | | | | | | 45 | 56 |
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| | <50 | | | | | | | | | | | <50 | <50 |
| | 120 | | | | | | | | | | | **579** | 152 |
| | <5 | | | | | | | | | | | <5 | <5 |
| | <25 | | | | | | | | | | | <25 | <25 |
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| <25 | - | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | - | - |
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| <100 | - | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 | <100 | - | - |
| <5 | - | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | - | - |
| <25 | - | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | - | - |
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| **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **PW02 (Arden BH No.2)** | **BH07 (Arden Chip Depot)** | **BH07 (Arden Chip Depot)** | **BH07 (Arden Chip Depot)** | **BH12 (TW7, Ballyduff BH)** | **BH12 (TW7, Ballyduff BH)** | **BH12 (TW7, Ballyduff BH)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22/09/08 | 21/10/08 | 17/11/08 | 07/12/08 | 22/02/10 | 30/08/10 | 06/12/10 | 13/12/10 | 26/06/08 | 09/03/10 | 10/03/10 | 06/06/08 | 12/06/08 | 27/06/08 |
| 9:10 AM | 10:40 AM | 10:10 AM | 1:50 PM | 11:00 AM | 9:30 AM | - | - | - | 11:50 AM | 2:05 PM | - | - | - |
| 7.2 | 7.2 | 7.3 | 7.3 | 7.2 | 7.3 | - | - | 7.4 | 7.5 | 7.3 | 7.6 | 7.2 | |
| 609 | 656 | 637 | 655 | 649 | 678 | - | - | 572 | 590 | 596 | 706 | 691 | |
| | | | | | | | | 1.6 | | | 3 | 2 | |
| | | | | | | | | | | | | | |
| 87.30 | 138.50 | 131.90 | 92.20 | - | 140.30 | - | - | | - | - | | | |
| 218.25 | 346.25 | 329.75 | 230.50 | - | 350.75 | - | - | | - | - | | | |
| 0.95 | 0.75 | 0.68 | <0.5 | 0.86 | 4.02 | - | - | <2 | <0.5 | <0.5 | 31 | 6 | |
| Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | Clear; Slight Sus Solids | - | - | | Clear; Slight Sus Solids | Clear; Slight Sus Solids | | | |
| <5 | <5 | <5 | <5 | <5 | <5 | - | - | <2 | <5 | <5 | 85 | 4 | |
| None | None | None | None | None | None | - | - | None | None | None | | | |
| | | | | | | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | - | - | 0 | 0 | 0 | | | 0 |
| 0 | 0 | **2** | 0 | 0 | **3** | - | - | 0 | 0 | 0 | | | **6** |
| | | | | | | | | 0 | | | | | **11** |
| 0 | 0 | 0 | 0 | 0 | 0 | - | - | 0 | | 0 | | | 0 |
| | | | | | | | | 5 | | | | | 214 |
| | | | | | | | | | | | | | |
| 18.7 | 18.8 | 18.2 | 17.7 | 18.1 | 21.7 | - | - | 18 | 21.4 | 18.1 | **48** | **39** | |
| | | | | | | | | 16 | | | 19 | 21 | |
| 24.5 | 32.11 | 28.01 | 28.36 | 23.37 | 24.92 | - | - | 16 | 17.59 | 15.24 | - | **40** | |
| <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | <0.018 | - | - | <0.2 | 0.066 | <0.018 | - | <0.2 | |
| | | | | | | | | | | | | | |
| | | | | | | | | <0.6 | | | | | |
| | 0.11 | | | 0.09 | 0.09 | | | 0.12 | 0.09 | | - | <0.1 | |
| | | | | | | | | <0.01 | | | | | |
| | | | | | | | | | | | | | |
| <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | <0.08 | - | - | <0.1 | 0.08 | <0.08 | <0.1 | <0.1 | |
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| | | | | | | | | 12 | | | 21 | 18 | |
| | | | | | | | | | | | | | |
| <25 | <25 | <25 | <25 | <25 | <25 | - | - | 56 | <25 | <25 | 0.2 | 0.024 | |
| | | | | | | | | <0.12 | | | | | |
| | | | | | | | | <0.2 | | | - | 0.0004 | |
| | | | | | | | | | | | - | - | |
| | | | | | | | | <30 | | | - | <0.03 | |
| | | | | | | | | <0.2 | | | - | 0.00022 | |
| | | | | | | | | <2 | | | - | <0.01 | |
| <50 | <50 | <50 | <50 | <50 | <50 | - | - | <0.05 | <50 | <50 | - | <0.05 | |
| <100 | <100 | <100 | <100 | <100 | **1136** | - | - | <0.05 | <100 | <100 | 0.13 | 0.07 | |
| <5 | <5 | <5 | <5 | <5 | 2 | - | - | <2 | <5 | <5 | - | <0.002 | |
| <25 | <25 | <25 | <25 | <25 | 23 | - | - | <0.03 | <25 | <25 | <0.03 | <0.03 | |
| | | | | | | | | <0.02 | | | | | |
| | | | | | | | | 0.9 | | | - | <0.0005 | |
| | | | | | | | | <0.5 | | | - | 0.0014 | |
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| | | | <2 | | | <2 | <2 | | | | | | |
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| | | | <1 | | | <1 | <1 | | | | | | |
| | | | <2 | | | <2 | <2 | | | | | | |
| | | | | | | 0 | 0 | | | | | | |
| | | | <1 | | | | | | | | | | |
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| | | | <1 | | | | | | | | | | |
| | | | <1 | | | | | | | | | | |
| | | | None Detected | | | | | | | | | | |

| Silver River BH (BH09?) | PW01 | PW01 | PW01 | PW02 | PW02 | PW02 |
|---|---|---|---|---|---|---|
| 13/06/08 | Max | Min | Mean | Max | Min | Mean |
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| 7.4 | 7.5 | 7.2 | 7.37 | 7.4 | 7.2 | 7.28 |
| 593 | 627 | 466 | 582 | 678 | 531 | 638 |
| 3.5 | 0.7 | 0.6 | 0.65 | | | |
| | | | | | | |
| | 130.00 | 83.90 | 118 | 146.30 | 87.30 | 128 |
| | 328.00 | 209.75 | 292 | 365.75 | 218.25 | 322 |
| | 5.21 | 0.12 | 1.04 | 5.54 | 0.13 | 1.31 |
| | | | | | | |
| 42 | 246 | 22 | 120 | | | |
| None | | | | | | |
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| 0 | 1 | 0 | 0 | | | |
| 1 | 24 | 0 | 1 | 62 | 0 | 3 |
| 0 | 0 | 0 | 0 | | | |
| 0 | 0 | 0 | 0 | | | |
| 0 | | | | | | |
| | | | | | | |
| | 305 | 260 | 280 | | | |
| 17 | 22.5 | 18.9 | 20.73 | 23.9 | 17.7 | 21.1 |
| 19 | 20 | 19 | 19.50 | | | |
| 3 | 38.84 | 21.99 | 28.55 | 51.64 | 23.37 | 36.0 |
| <0.2 | | | | | | |
| | | | | | | |
| <0.6 | | | | | | |
| <0.1 | 0.5 | 0.173 | 0.28 | 0.11 | 0.09 | 0 |
| <0.01 | | | | | | |
| | | | | | | |
| | 110 | 95 | 102.0 | | | |
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| | 41 | 15 | 28.0 | | | |
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| <10 | 180 | 12 | 67 | 304 | 194 | 227 |
| <0.12 | | | | | | |
| 7.9 | | | | | | |
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| <0.03 | 70 | 60 | 65 | | | |
| 0.45 | | | | | | |
| <1.0 | | | | | | |
| <0.05 | | | | | | |
| 0.44 | 370 | 114 | 194 | 1136 | 306 | 613 |
| <2.0 | | | | 2 | 2 | 2 |
| 0.26 | | | | 23 | 23 | 23 |
| <0.2 | | | | | | |
| 6.2 | | | | | | |
| <5.0 | | | | | | |
| | | | | | | |
| | 80 | 60 | 70 | | | |
| | | | | | | |
| <1.0 | | | | | | |
| 1 | | | | | | |
| <1.0 | | | | | | |
| <1.0 | | | | | | |
| <2.0 | | | | | | |
| 1 | | | | | | |
| None detected | | | | | | |
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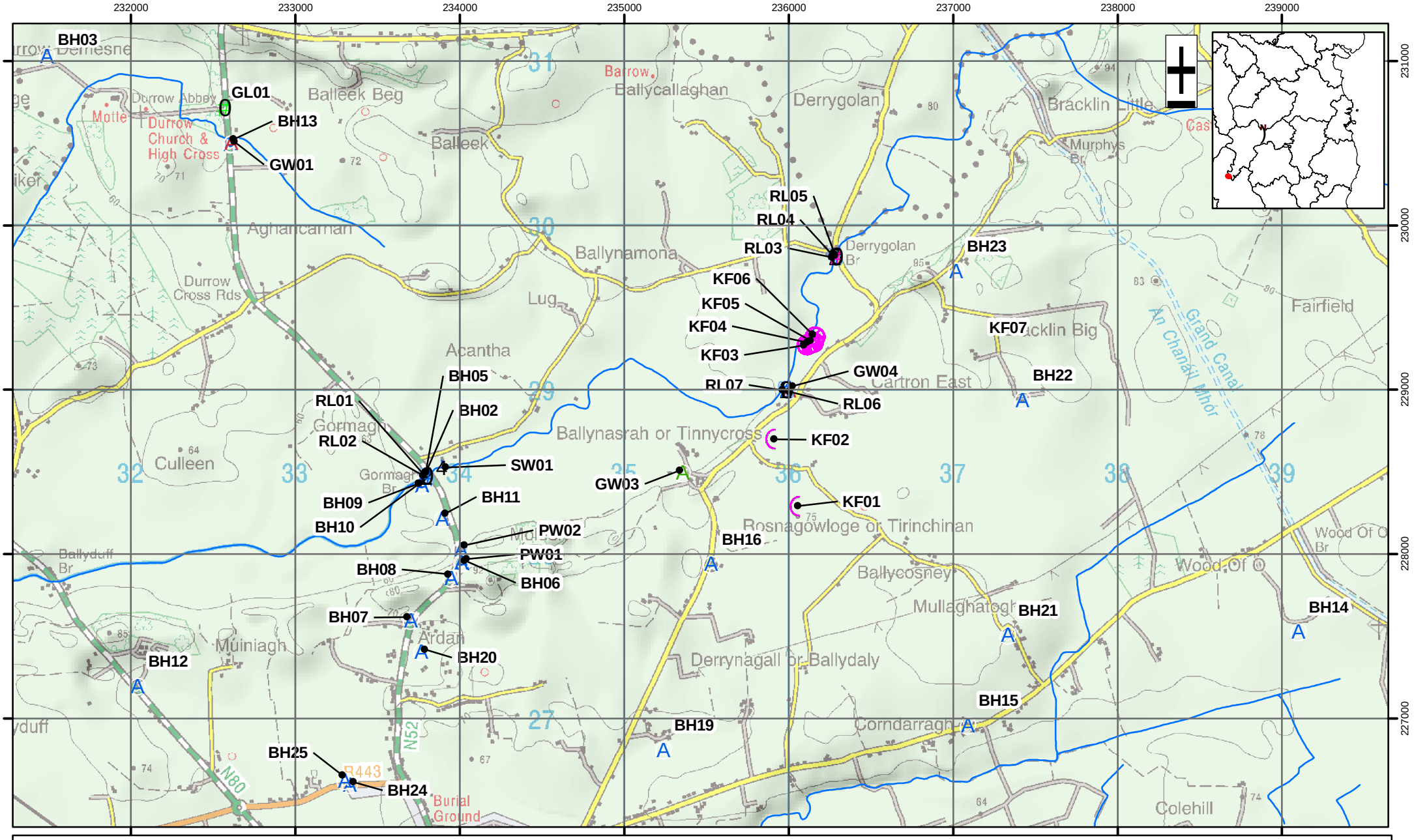
**Table A1.5 Recharge coefficients for the diffuse recharge component of the ZOC area**

| Vulnerability | Location in Study Area | Additional Factors | % Area | Recharge Coefficient Guidance | | Chosen Recharge Coefficient | Recharge per m2 | LI Recharge Cap Applied? |
|---|---|---|---|---|---|---|---|---|
| | | | | Inner Range | Outer Range | | (mm/yr) | (mm/yr) |
| Low | Cut Peat in east of ZOC | Low slope | 0.30 | 0 - 10% | 3 - 5% | 0.05 | 21 | |
| | Cut Peat in east of ZOC | Low slope. LI Aquifer but actual recharge < Recharge Cap | 3.0 | 0 - 10% | 3 - 5% | 0.05 | 21 | Natural recharge < recharge cap |
| Moderate | Moderate permeability alluvium (Tinnycross) subsoils overlain by poorly drained soil | Low slope | 0.25 | 20 - 40% | 10 - 50% | 0.45 | 185 | |
| | Moderate permeability till (adjacent to bog in Cartron East) subsoils overlain by poorly drained soil | Low slope. LI Aquifer but actual recharge < Recharge Cap | 0.42 | 20 - 40% | 10 - 50% | 0.45 | 185 | Natural recharge < recharge cap |
| | Pockets of moderate permeability till subsoils across ZOC overlain by well drained soil | Low drainage density; No indicators of poor drainage. Low slope | 0.57 | 30 - 40% | 25 - 60% | 0.55 | 226 | |
| | Pockets of moderate permeability till subsoils across ZOC overlain by well drained soil | Low drainage density; No indicators of poor drainage. Low slope. Recharge Cap - LI Aquifer | 1.62 | 30 - 40% | 25 - 60% | 0.487 | 200 | Yes |
| | Cut Peat in east of ZOC | Low slope | 6.66 | 0 - 10% | 3 - 5% | 0.08 | 33 | |
| | Cut Peat in east of ZOC | Low slope. LI Aquifer but actual recharge < Recharge Cap | 3.69 | 0 - 10% | 3 - 5% | 0.08 | 33 | Natural recharge < recharge cap |

**Table A1.5 Recharge coefficients for the diffuse recharge component of the ZOC area (Continued)**

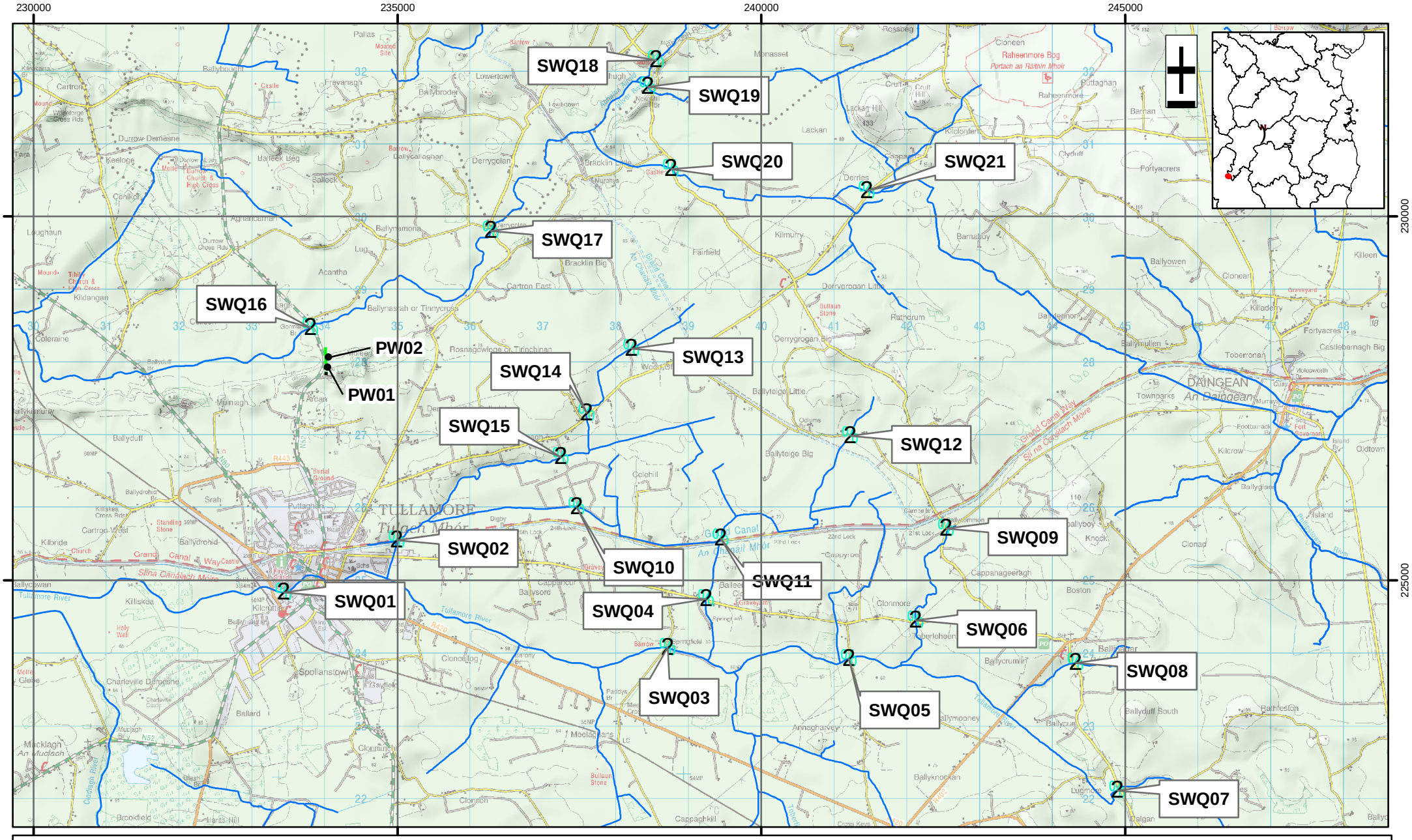
| Vulnerability | Location in Study Area | Additional Factors | % Area | Recharge Coefficient Guidance | | Chosen Recharge Coefficient | Recharge per m2 | LI Recharge Cap Applied? |
|---|---|---|---|---|---|---|---|---|
| | | | | Inner Range | Outer Range | | (mm/yr) | (mm/yr) |
| High | Gravels subsoils with poorly drained soils amid peat deposits in Cartron East | In the midst of cut peat. Low slope. | 1.56 | 80 - 90% | 60 - 100% | 0.9 | 370 | |
| | Moderate permeability alluvium (adjacent to Silver River) subsoils overlain by poorly drained soil | Low slope | 0.45 | 20 - 40% | 10 - 50% | 0.45 | 185 | |
| | Gravels subsoils with well drained soils across ZOC | Low drainage density; No indicators of poor drainage | 62.18 | 80 - 90% | 60 - 100% | 0.95 | 390 | |
| | Gravels subsoils with well drained soils in east of ZOC | Low drainage density; No indicators of poor drainage; Recharge Cap - LI Aquifer | 2.96 | 80 - 90% | 60 - 100% | 0.49 | 200 | Yes |
| | Moderate permeability till and alluvial subsoils between the Silver River and esker, with poorly drained soils | Groundwater possibly close to surface. Low slope | 2.40 | 25 - 40% | 15 - 50% | 0.5 | 206 | |
| | Moderate permeability till with well drained soils between the esker and Silver River | Low drainage density; No indicators of poor drainage. Low slope | 3.03 | 35 - 80% | 50 - 70% | 0.75 | 308 | |
| Extreme (E) | Till and Alluvial subsoils overlain by poorly drained soils between the Silver River and esker | Low drainage density; No indicators of poor drainage. Low slope | 4.58 | 25 - 40% | 15 - 50% | 0.4 | 164 | |
| | Till overlain by well drained soils close to the Silver River | Low drainage density; No indicators of poor drainage. Low slope | 0.41 | 50 - 70% | 45 - 80% | 0.7 | | |
| Extreme (X) | Newly mapped X Vulnerability along Silver River | Low drainage density. Low slope | 3.90 | 80 – 90% | 60 – 100% | 0.95 | 390 | |
| | Newly mapped X Vulnerability along Silver River | Low drainage density. Low slope. Recharge Cap - LI aquifer | 2.03 | 80 – 90% | 60 – 100% | 0.49 | 200 | Yes |




# Figure A1.1 Data Point Locations

| | | | | |
|---|---|---|---|---|
| ! PWS Abstraction | A Borehole | Enclosed Depression | 4 Surface Water Abstraction | Weir Invert |
| Stream | A Dug Well | Swallow Hole | River Surface | |
| | A Spring | Ground Level | River Inver | |

0 0.25 0.5 0.75 1 km




## Figure A1.2 Surface Water Quality Point Locations

! PWS Abstraction

Stream

A Borehole

A Dug Well

A Spring

Enclosed Depression

Swallow Hole

Ground Level

4 Surface Water Abstraction

2 River Surface

River Inver

Weir Invert



0 0.25 0.5 0.75 km