Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Scarriff Water Supply Scheme

Bow River Boreholes

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Prepared by:
Peter Conroy, TOBIN

With contributions from:
Coran Kelly, TOBIN; Taly Hunter-Williams, GSI; Dr. Robert Meehan, Consultant Geologist; Jenny Deakin, TCD;

And with assistance from:
Clare County Council

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.

The project "Establishment of Groundwater Source Protection Zones", led by the Environmental Protection Agency (EPA), represents a continuation of the GSI's work. A CDM/TOBIN/OCM project team has been retained by the EPA to establish Groundwater Source Protection Zones at monitoring points in the EPA's National Groundwater Quality Network.

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

COMPANY LOGOS

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1 INTRODUCTION

Groundwater Source Protection Zones are delineated for the Scarriff Bow River Borehole source 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 Source Protection Zone Delineation.

The Bow River Borehole site is one of three separate borehole sources for Scarriff. The boreholes contribute to the supply of the area surrounding Scarriff and Tuamgreaney, located along the western shore of Lough Derg.

The objectives of the report are as follows:

- To outline the principal hydrogeological characteristics of the Cappaghbaun Mountain and the townlands to the south of this where the borehole site is located.
- To delineate source protection zones for the Bow River Boreholes.
- To assist the Environmental Protection Agency and Clare County Council in protecting the water supply from contamination.

Groundwater protection zones are delineated to help prioritise the area around the source in terms of pollution risk to groundwater. This prioritisation is intended as a guide in evaluating the likely suitability of an area for a proposed activity prior to site investigations. The delineation and use of groundwater protection zones is further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999). The maps produced are based largely on the readily available information in the area, a field walkover and on mapping techniques which use inferences and judgements based on experience at other sites. As such, the maps cannot claim to 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.

2 LOCATION, SITE DESCRIPTION AND WELL HEAD PROTECTION

The Bow River Boreholes site (henceforth referred to as "the source") is located 4.3 km to the northeast of Scarriff in the townland of Cappabaunpark/Magherareagh as shown in Figure 1a. The source is accessed via a hardcore track off the local road which accesses the eastern side of the Cappabaunpark townland. The site originally abstracted surface water from the Bow River, utilizing a small pumping house and an impounding dam constructed on the river adjacent to the site. The pumping house is still in use and also houses the disinfection and treated water monitoring equipment. During the early 1990s, due to summer shortfalls in the surface water supply, a production well was drilled at the site. A second production well was added in 1995 and the site has been operated solely as a borehole groundwater source since that time.

The source therefore, is comprised of these two boreholes, aligned on a roughly north-south axis parallel to the river, 6.8 m apart and approximately 11 m west of the Bow River. In this report the southern borehole has been labeled PWSBH01, while the other has been labeled PWSBH02. The boreholes are operated alternately with the frequency of alternation managed manually by the site caretaker. A further trial borehole labeled PWSBH03 here, which proved to have a low yield, , was drilled onsite during the initial phase of drilling. This borehole is currently unused by the water supply scheme and is not considered part of the source, but was used as an observation borehole during this study. PWSBH03 is located on an axis running east from PWSBH01 towards the Bow River, such that

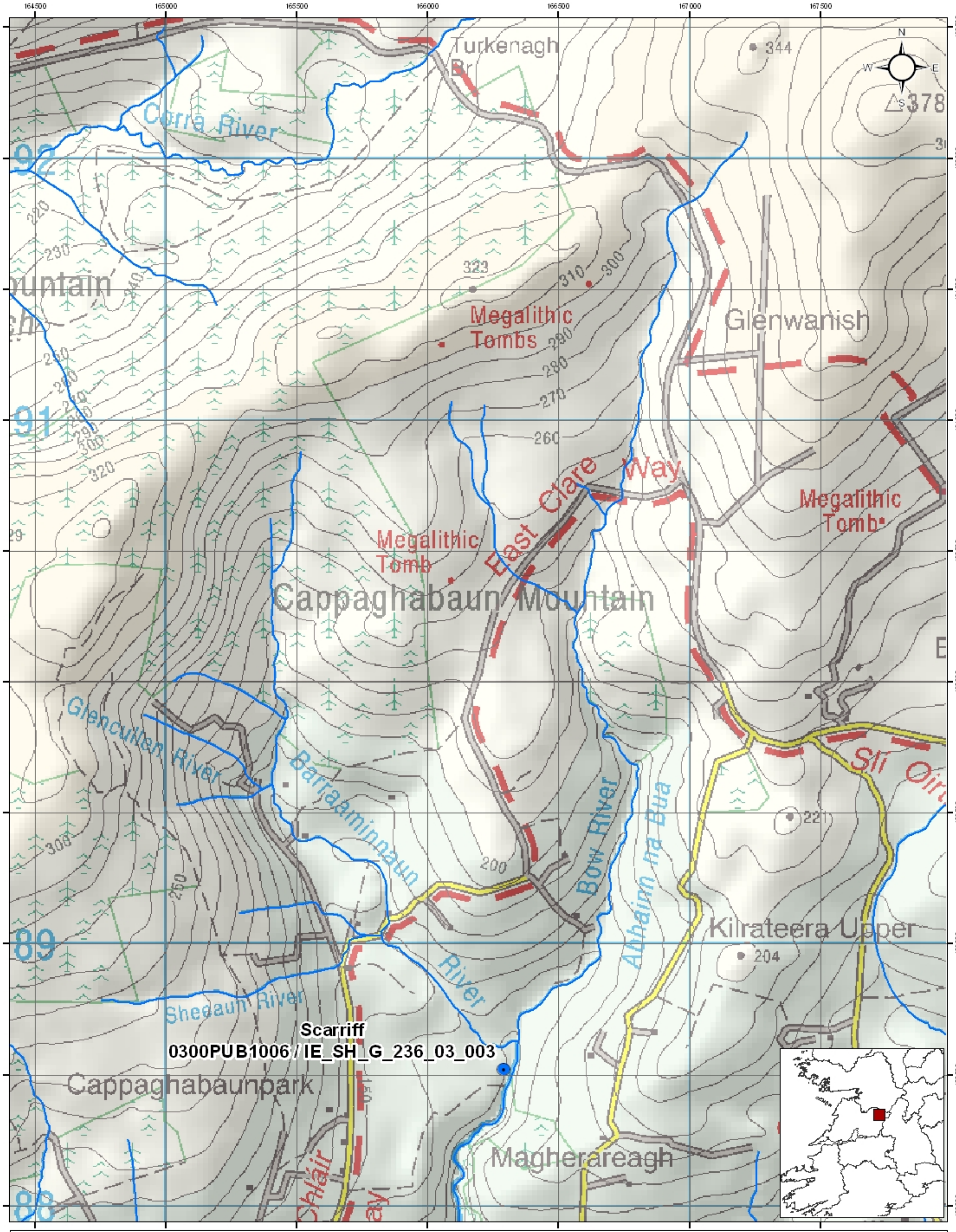


Figure 1a Scarriff PWS - Bow River Source SIte Location Map

PWS Abstraction

River

the three boreholes form a right angle around the western and southern sides of the pump house. PWSBH03 is located 6.65 m east of PWSBH01. The site layout is shown in Figure 1b.

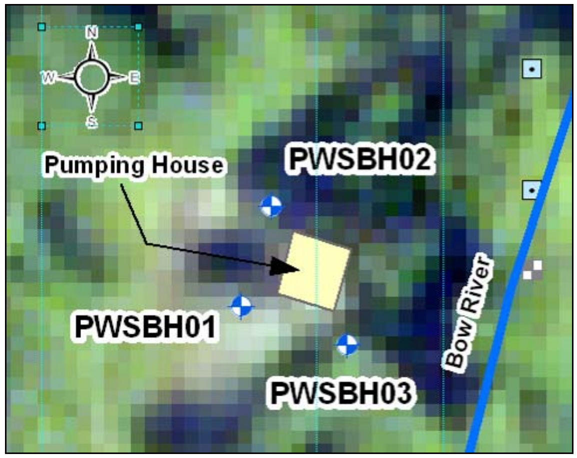


Figure 1b PWS Site Layout

Boreholes PWSBH01 and PWSBH02 have each been housed in an approximately 1.5 m by 1.5 m square, block built chamber with a large, hinged, lockable, steel lid. In each case the rim of the chamber is approximately 0.3 m above ground level, while the base of the chamber is approximately 0.35 m below ground level. The chambers are provided with drains to the adjacent river to prevent ponding within the chambers, however during the initial site visit the drain for PWSBH02 was blocked and the chamber was flooded by stagnant water above the level of the mouth of the borehole. It is likely that the ponded water was draining through the well cap into the borehole. This drain was subsequently fixed by Clare County Council. There is still some ponded water in the base of the chamber but it lies below the level of the top of the borehole casing. PWSBH03 has no sanitary well head protection. There are no records indicating that a grout seal was installed outside the steel casing at any of the boreholes.

3 SUMMARY OF WELL / SPRING DETAILS

Boreholes PWSBH01 and PWSBH03 were constructed by TJ Cross Water Well Drilling of Abbeyfeale, Co. Limerick. Borehole PWSBH02 was constructed by Liam Flannery of Mountshannon, Co. Clare. Basic information on total depth was obtained from TJ Cross' office records for boreholes PWSBH01 and PWSBH03. Clare County Council provided a summary driller's log from Liam Flannery for borehole PWSBH02. The data provided are summarised in Table 3-1.

The average abstraction from the source is currently 363 m^3/day (74,000 gallons per day (gpd)). Long term abstraction records for the source were not available although the caretaker informed us that there has been no shortage of supply from the site since groundwater abstraction was introduced in 1995.

4 METHODOLOGY

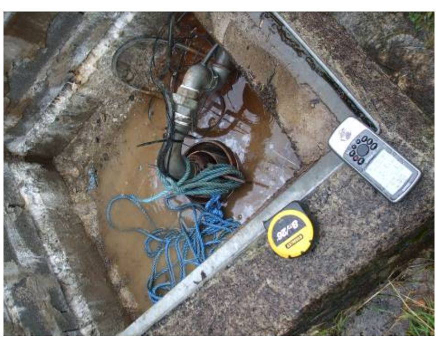
Site visits, site walk-overs and field mapping (including a well survey, groundwater level survey, mapping of drainage indicators, logging of bedrock outcrops and subsoil exposures and measuring the electrical conductivity and temperature of streams in the area) of the study area were conducted between 08/09/2009 and 17/09/2009. An interview with the source Caretaker was carried out on 08/09/2009.

A pumping test comprising a recovery phase and a constant discharge (CDT) phase, together with monitoring of field water quality parameters, was carried out on PWSBH01 between 06/10/2009 and 07/10/2009. The recovery phase (recovery from the drawdown caused by the ongoing water supply abstraction) was carried out prior to the CDT phase due to the operational requirements of the water supply scheme. The locations of all of the point features investigated during the site visits are shown in Figure 2. A summary table of the point data collected during the site visits and field mapping is provided in Appendix 1.

Table 4-1 Summary of Source Details

EU Reporting Code	IE_SH_G_236_03_003		
Borehole Name	PWSBH01	PWSBH02	PWSBH03
Grid reference	E166306 N188519	E166297 N188529	E166305 N188529
Townland	Cappaghbaun/ Magherareagh		
Source type	Borehole		
Drilled	TJ Cross	Liam Flanagan	TJ Cross
Owner	Clare Co. Council		
Elevation (Ground Level)	approx. 130 mAOD[1]		
Depth	83.8 m	48.768 m	188.98 m
Depth of casing	unknown	4.9 m	unknown
Diameter	200 mm reducing to 150 mm	200 mm	200 mm
Depth to rock	unknown	3.0 mbgl	unknown
Static water level[5]	8.6 m btc[2]	8.41 m btc[3]	8.9 m btc[4]
Pumping water level[6]	26.77 m btc[2]	26.31 m btc[3]	19.665 m btc[4,7]
Consumption (Co Co records)	363 m^3d		0

Note 1: mAOD = metres above ordnance datum; Note 2: 'mbtc' = metres below top of casing & tc = top of 6-inch steel casing; Note 3: tc = top dipper/cable hole in well cap; Note 4: tc = top of 8-inch steel casing; Note 5: water level measured on 07/10/2009 after 10 hour Recovery Test – Full recovery was not achieved; Note 6: Water level measured on 08/09/2009 after a wet summer. Note 7: Pumping water level for PWSBH03 is the level recorded in the borehole while PWSBH01 was being pumped.



Photograph 1 Borehole PWSBH01

Photograph 2 Borehole PWSBH02

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LANDUSE

The site is located immediately south of the confluence of the Bow and Barraminaun rivers, to the west of the main channel.

The land slopes from Cappaghbawn Mountain to the north and from high ground to the east and west towards each river (Figure 1). The highest point on Cappaghbaun Mountain is 4 km northeast of the source at 378 mAOD. The topographical gradient on the upper slopes of the flanking ridges typically varies between about from 0.08 and 0.2, but on the lower slopes closer to the source, the slope typically lessens to between 0.045 and 0.14. Immediately upstream of the river confluence there is a local, relatively flat alluvial plain, which slopes generally south at a gradient of 0.02. South of the confluence, the Bow River has incised a 10 m deep gorge into the valley floor.

Smaller tributary streams, including the Glencullen and the Sheeaun Rivers, drain into the Bow and Barraminaun Rivers up gradient of the source. South of the source, there are no mapped tributaries draining the valley, however site walkovers revealed frequent small streams and artificial drainage channels on both sides of the valley. The natural drainage density is therefore high and artificial drainage on the valley slopes is common.

Land use in the area is primarily agricultural, with lands used for livestock and bloodstock pasture and rough grazing. The nearest farmyard to the source is located approximately 300 m to the east, while a horse paddock and dog kennel business is located approximately 600 m to the northeast. A trout hatchery run by the Scarriff & Mountshannon Fishery Club is located adjacent to the Bow River approximately 650 m downstream of the source. A small bedrock quarry has been opened up on the lower slopes of Cappaghbaun Mountain, approximately 1 km north of the source (see bedrock outcrop OC04 on Figure 2) and is used by local farmers for maintaining hardcore tracks. Large tracts of conifer forestry have been planted in the upper slopes of the catchment while the remaining tracts of blanket bog on the upper slopes are used for rough grazing.

The population of the Cappaghbaunpark and Magherareagh townlands is low, with roughly 30 to 40 domestic residences and related farmyards in the study area. Some houses have recently been built on individual roadside plots in the Cappaghbaunpark area.

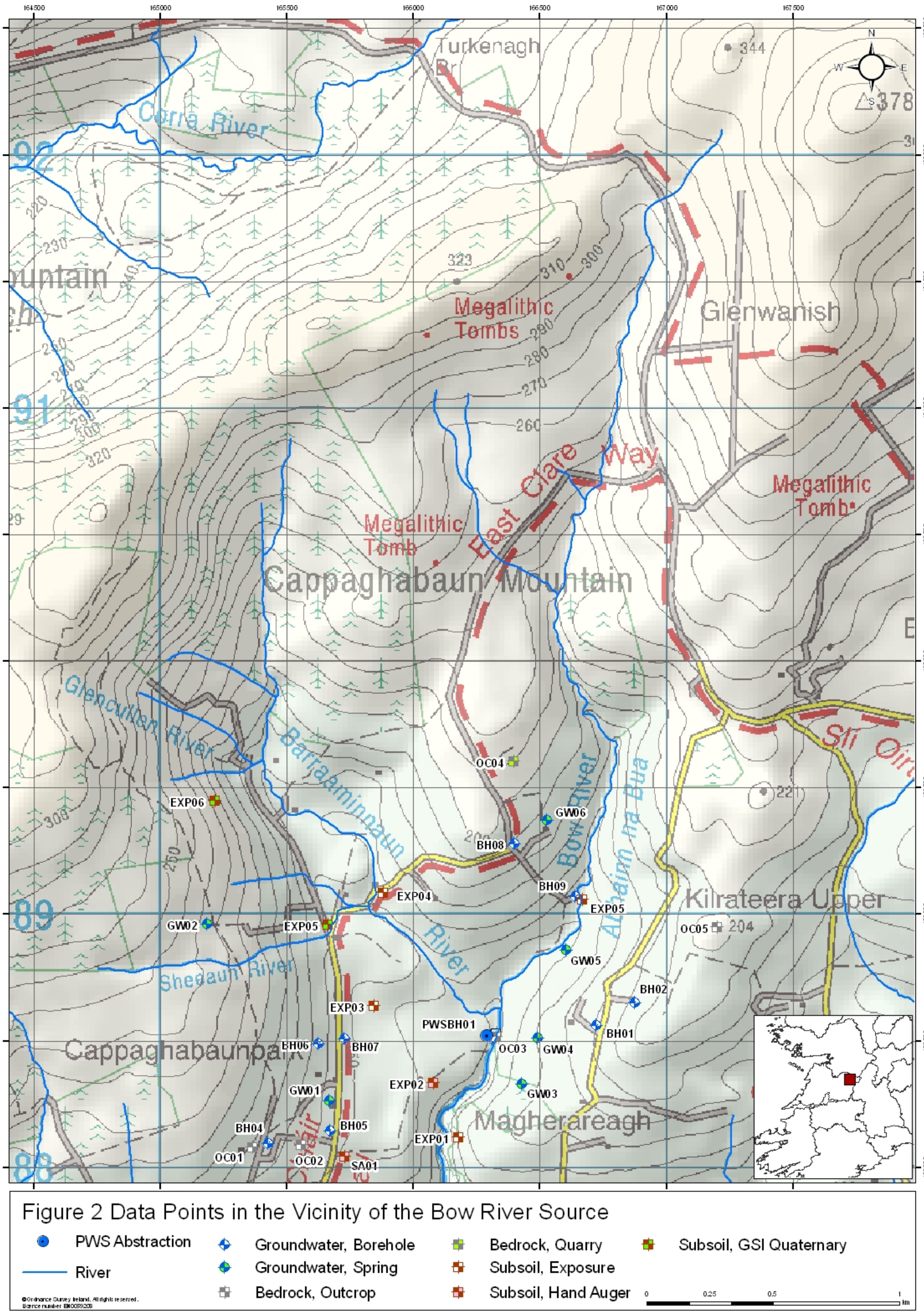


Figure 2 Data Points in the Vicinity of the Bow River Source

6 GEOLOGY

This section briefly describes the relevant characteristics of the geological materials that underlie the Bow River source. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections. The geological information is based on the bedrock geological map of Galway-Offaly, Sheet 15, 1:100,000 Series (Geological Survey of Ireland (GSI) 2005) and accompanying memoir (Gatley *et al* 2005), the GSI Well and Borehole Databases and on bedrock outcrop and subsoil exposures encountered during site visits.

6.1 BEDROCK GEOLOGY

The bedrock map indicates that the area around the source is underlain by medium to thickly bedded sandstones, siltstones, mudstones and volcanic rocks of the Silurian aged Kilanena Formation (KA). Outcrops of these rocks within the study area showed the beds were steeply dipping to the north and south and were very well fractured, particularly at the ground surface. The upper slopes of Cappaghbaun Mountain and some places along the ridges extending to the south on either side of the source are capped by Devonian Old Red Sandstones (ORS). The lower unit within the ORS is a carbonate rich cornstone < 3 m thick (Scalpnagowan Formation Maghera Cornstone Member (SGmc)) which has also penetrated downwards up to 8 m into the underlying Silurian rocks (Gatley *et al* 2005).

A major fault (Mountshannon Fault) is mapped running roughly east to west and veering south west across the mouth of the Bow River Valley. A second major parallel fault is also present in the area, together with a series of northwest and north-northwest trending cross faults. The bedrock geology of the area is shown in Figure 3. Figure 3 also shows the locations of two cross sections through the study area which are provided in Figure 4.

6.2 SOILS

The soils on the till areas are dominated by poorly drained soil types, typically deep, poorly drained, mineral soils (AminPD) derived from mainly non-calcareous parent materials (EPA website and An Foras Talúntais, 1980). These correspond to the surface water gley soils (Puckane and Gortaclareen series) of the Clare Soil Survey, which tend to be poorly drained and mottled, with the former liable to have perched water tables (An Foras Taluntais, 1980). An area of deep well drained mineral soils (AminDW) is mapped on the ridge in the Magherareagh area, however during site visits parts of this zone were found to be poorly or artificially drained. Soils on the crests of the ridges, particularly to the west and north of the source are mapped as blanket peat or poorly drained mineral soil with peaty topsoil (AminPDPT).

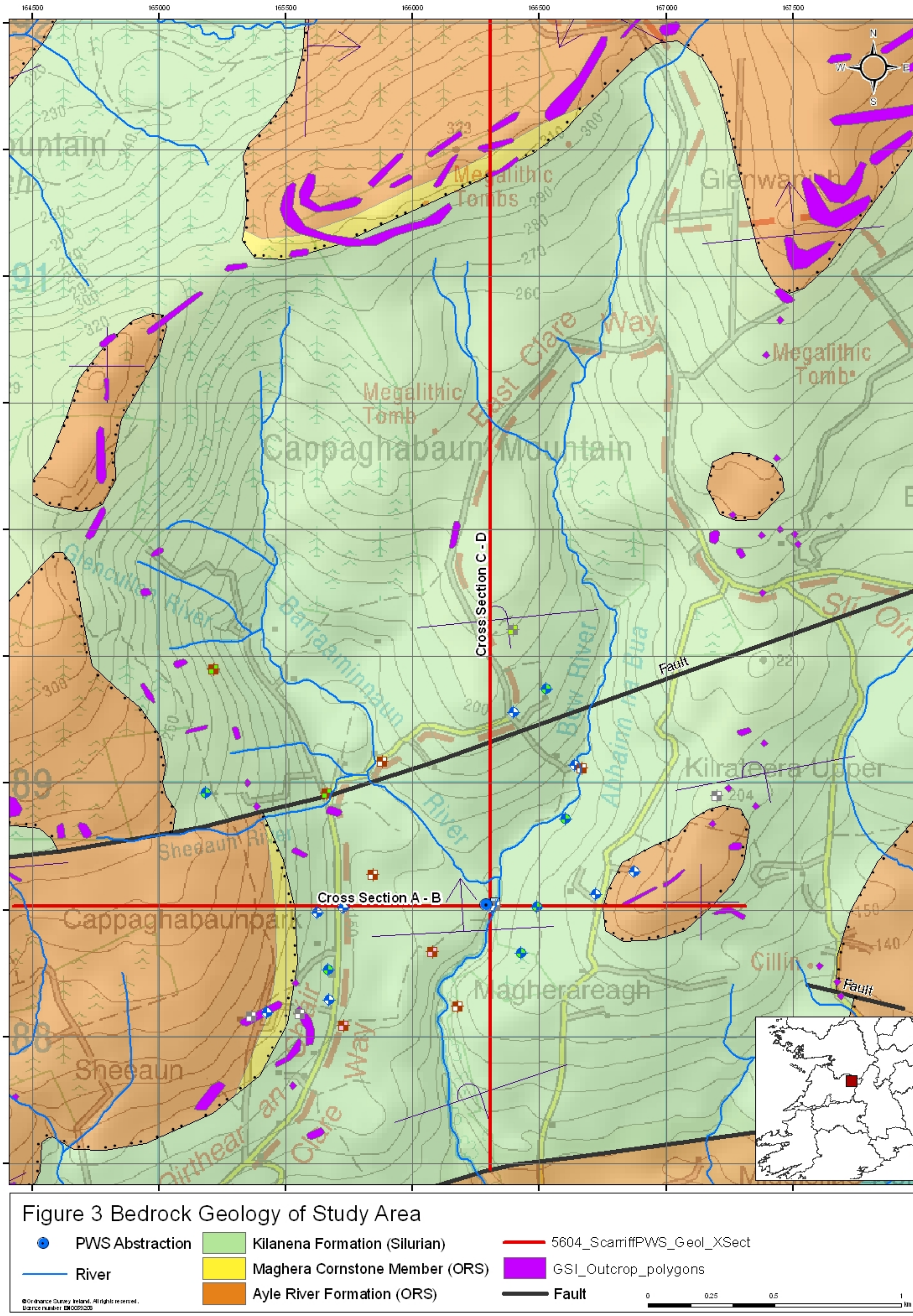


Figure 3 Bedrock Geology of Study Area

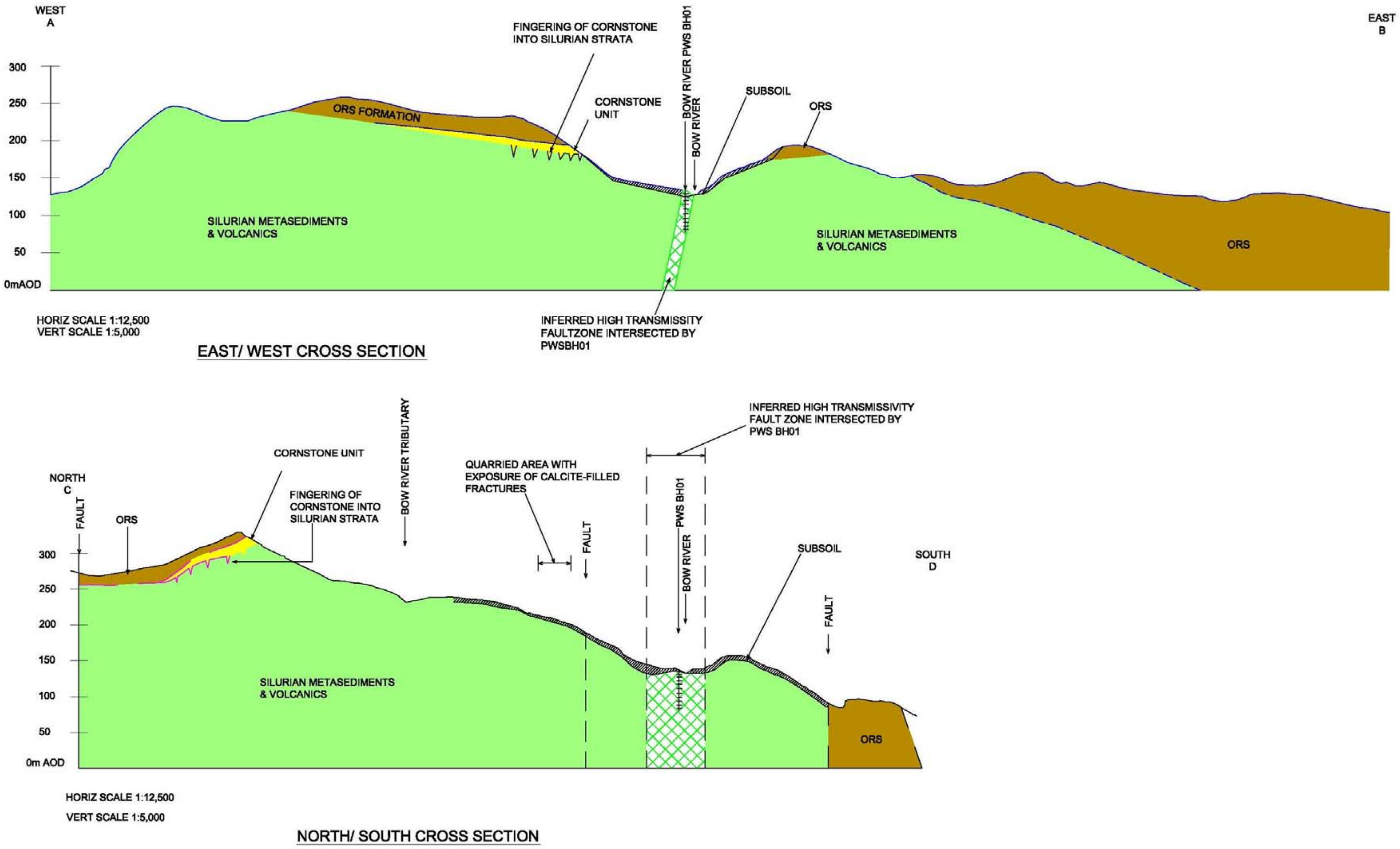


Figure 4 Geological Cross Sections

6.3 SUBSOILS GEOLOGY

According to GSI and EPA web mapping, the central part of the study area surrounding the source, and below approximately 150 mAOD, is underlain by tills derived from Lower Paleozoic sandstones and shales (TLPSsS). Tills derived from Devonian sandstones (TDSs), surround these and blanket the mid to upper flanks of the ridges surrounding the source. The uppermost sections of the ridges and Cappaghbaun Mountain are underlain by blanket peat deposits (BkPt). Pockets of alluvial subsoils are mapped along the courses of the Bow and Barraminaun Rivers, with a particularly extensive deposit flanking the Bow River in the area immediately upstream of the Source. The subsoil map of the area is shown in Figure 5.

During site visit, TDSs up to 1.5 m in thickness were observed underlying the peat deposits, in the flanks of drainage channels through the peat. The TDSs are thin or absent in places on the upper flanks of the ridge to the west of the source, with bedrock outcrop mapped at various localities in the Cappaghbaunpark area. Similar outcrops occur in places along the crests of the ridges to the east and west of the source.

Subsoil Permeability

The subsoils across County Clare have been classified according to British Standards 5930 (BS:5930) in the preparation of the Groundwater Vulnerability map for Clare County Council, by the Geological Survey of Ireland. The data were made available for the preparation of this report. The subsoil permeability of the till units in the study area has been classed as '***Low Permeability'***.

Within the study area, three small subsoil exposures in the shale and sandstone derived tills were logged in accordance with BS:5930 (EXP01, EXP02 and EXP03; Figure 2). The maximum depth of exposure of 2.5 m bgl was encountered at EXP01 at the site of a small landslide at the top of the incised channel of the Bow River. At locations EXP01 and EXP02, the subsoils were logged as SILT while at EXP03 the subsoil was logged as SILT/CLAY. Two further exposures, EXP04 and EXP05 were logged as highly permeable deposits of SAND or sandy GRAVEL. Anecdotal evidence from the drilling of borehole BH09, located 600 m north-northeast of the source indicates that low permeability material, presumably CLAY, was encountered at depth overlying the bedrock.

There is a widespread occurrence of poor drainage indicators such as rush, willow, alder, blanket peat across the ridges and the slopes of the valley.

Additional subsoil data from the GSI indicated that there was Silty Till at locations EXP06 and EXP07. While Silty Till is not a BS:5930 description, these data would suggest that the study area is dominated by '**moderately permeable**' subsoil. However, the surface water drainage density, presence of artificial drainage on the flanks of the ridges on either side of the source and the preponderance of vegetation indicators of poor drainage across the study area point to the presence of '**Low Permeability**' subsoils. As such, it may be that the subsoil exposures encountered may not be representative of the controlling subsoil permeability of the area and that the SILT and SILT/CLAY materials are underlain by low permeability CLAY. The anecdotal evidence of low permeability material at depth, from the drilling of borehole BH09, would appear to corroborate this. Overall, it is considered that the subsoil permeability of the area is '**Low**'.

Depth to bedrock

Depth to bedrock (DTB) has been interpreted across the study area based on bedrock outcrops mapped by the GSI, outcrops mapped during site visits, areas mapped as extreme groundwater vulnerability under the GSI Groundwater Protection Scheme (GWPS) (i.e. zones where DTB < 1 m bgl and where

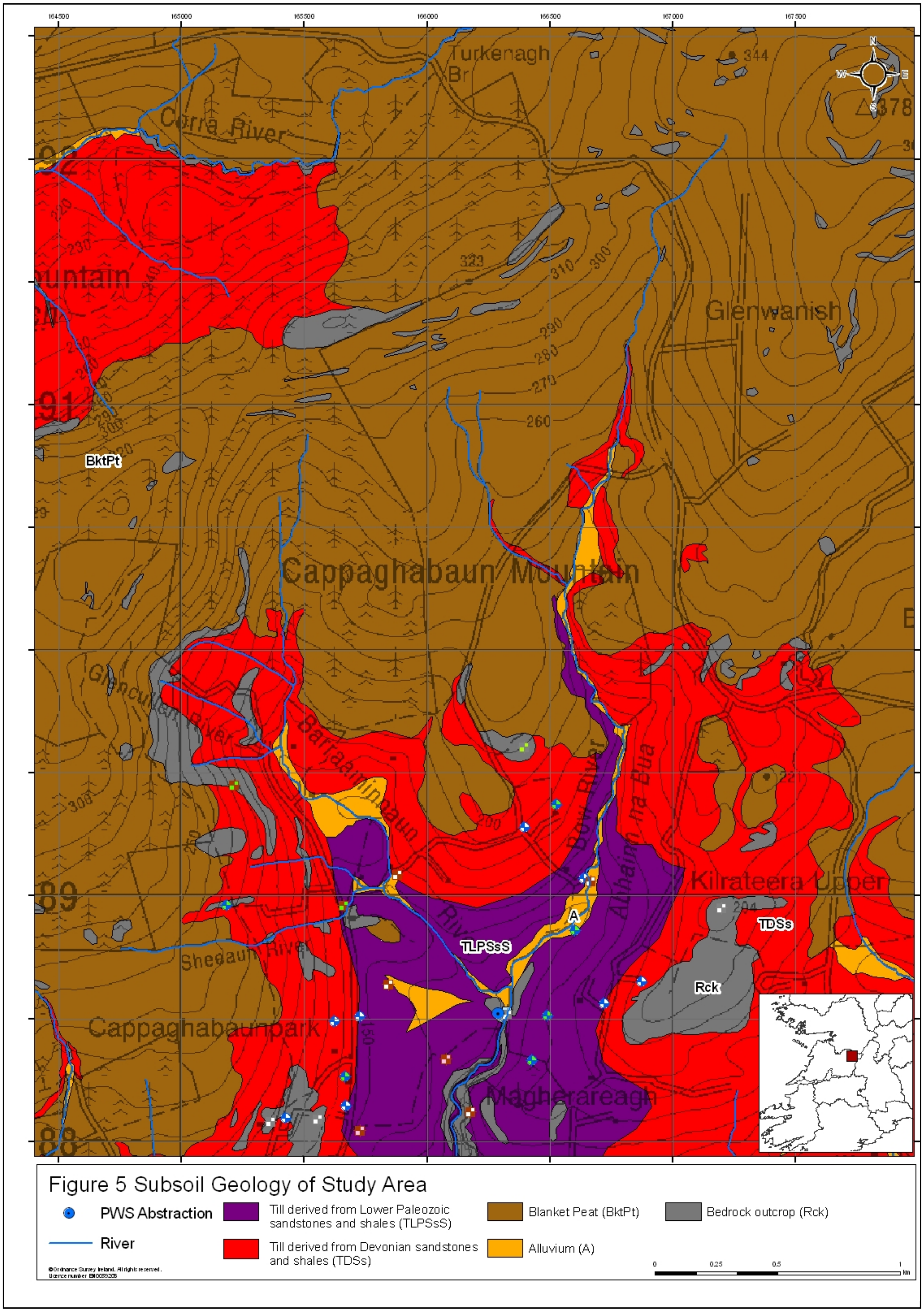


Figure 5 Subsoil Geology of Study Area

DTB is between 1 m and 3 m bgl) and logged and anecdotal evidence from drilling of boreholes across the study area.

From the GWPS mapping, DTB is mapped as less than 3 m across the upper slopes of the ridge through Cappaghbaunpark and onto Cappaghbaun Mountain. Pockets of shallow bedrock are also present on the ridge to the east of the source. A further, small pocket of shallow bedrock is mapped north of the source in the ridge separating the Barraminaun and Bow Rivers. During site visits this zone was found to extend further south towards the source as far as the bedrock outcrop in the quarry at OC04. A small pocket of outcrop (OC03) was also encountered in the Bow River riverbed adjacent to the source. Immediately adjacent to OC03 at PWSBH02, the DTB is recorded as 3 m, suggesting that the outcrop at OC03 is a very localised high point in the bedrock surface. The subsoil map of the area shows this outcrop extending south along the river, however no evidence of further outcrop was encountered on walking the riverbed during the site visits and the riverbed away from OC03 was found to be underlain by fluvial deposits.

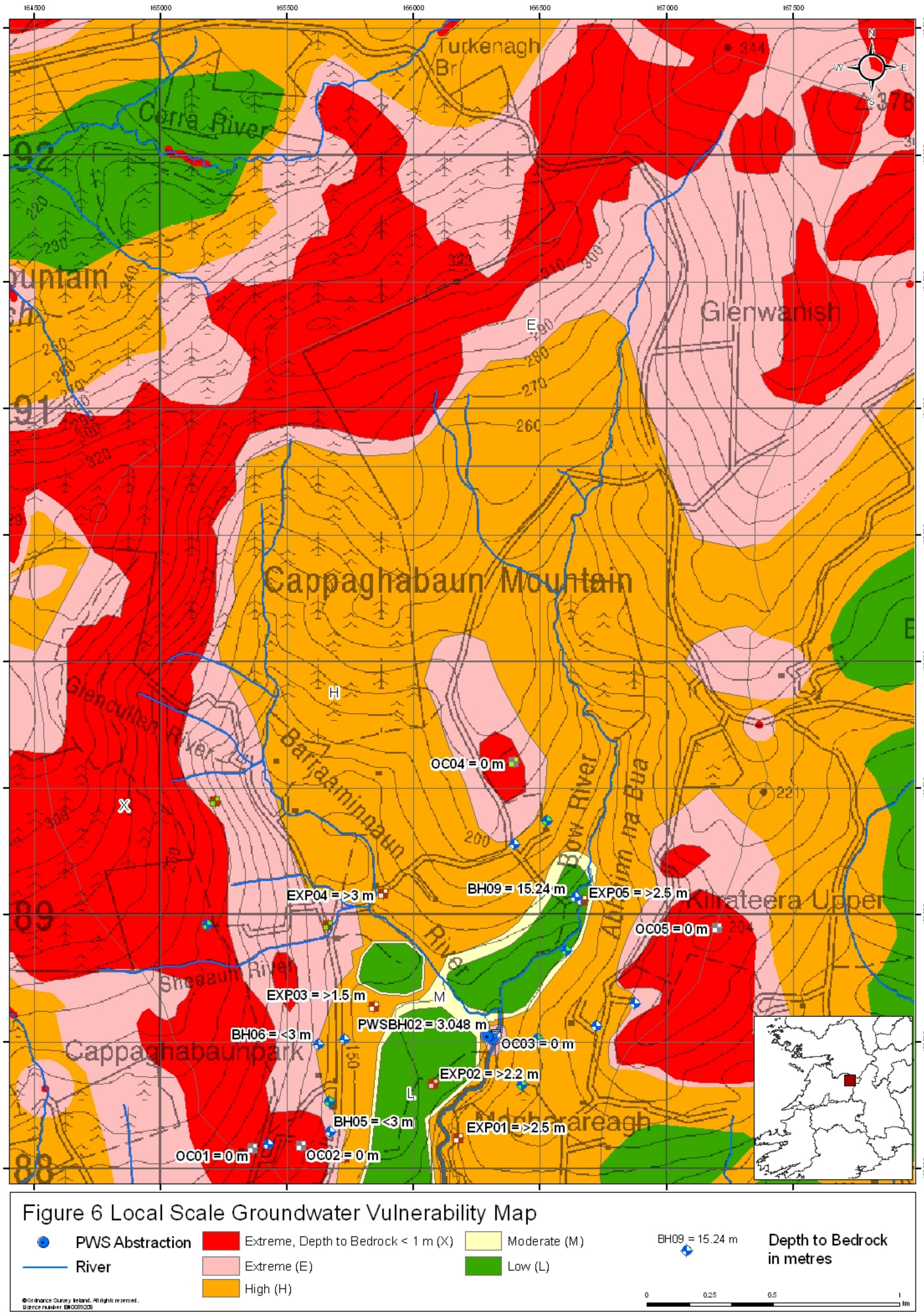
On the eastern side of the river in Magherareagh and to the north in Kilrateera Upper and Cappaghbaun Mountain, moving downslope from the ridges towards the rivers, the depth to bedrock is considered to increase gradually from 3 m to 5 m bgl (R. Meehan 2009, Pers. Comm.).

In the area upstream of the bedrock outcrop at OC03, where the subsoils are mapped as alluvium, the DTB is thought to increase to greater than 10 m along the courses of the Barraminaun and Bow Rivers. At borehole BH09, adjacent to the Bow River, approximately 1 km northeast of the source, the landowner reported that bedrock was encountered at approximately 15 m bgl during the drilling of the borehole in 1993. South of here and between the west side of the Bow River and the local road through the townland of Cappaghbaunpark, morphological indicators point to the presence of subglacial landforms where subsoils are likely to exceed 10 m in thickness (R. Meehan 2009, Pers. Comm.).

7 GROUNDWATER VULNERABILITY

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target'. In this area this means that 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).

A draft groundwater vulnerability map for the region, has been developed by the GSI. This regional scale map has been amended to take account of the local scale data collected during the desk study, site visits and field mapping stages of the project. The resulting map reveals areas of extreme vulnerability on the ridges to the west and east of the source. This grades into high vulnerability over much of the remainder of the study area moving down slope towards the Barraminaun and Bow Rivers in the north of the area and in the Magherareagh area. An area of moderate and low vulnerability is mapped in the area of alluvial subsoils to the north and west of the source. Finally, a small pocket of extreme vulnerability is mapped around the source itself, where bedrock outcrops in the riverbed adjacent to the source. The local scale groundwater vulnerability map is shown in Figure 6.


Turkenagh Br
Corra River
Glerwanish
Cappaghabaun Mountain
Glencullen River
Barjaaminnaun
Bow River
Abhainn na Bua
Kilrateera Upper
Sheaun River
Cappaghabaunpark
OC04 = 0 m
BH09 = 15.24 m
EXP05 = >2.5 m
EXP04 = >3 m
OC05 = 0 m
EXP03 = >1.5 m
PWSBH02 = 3.048 m
BH06 = <3 m
OC03 = 0 m
EXP02 = >2.2 m
BH05 = <3 m
EXP01 = >2.5 m
OC01 = 0 m
OC02 = 0 m
Figure 6 Local Scale Groundwater Vulnerability Map
PWS Abstraction
River
Extreme, Depth to Bedrock < 1 m (X)
Extreme (E)
High (H)
Moderate (M)
Low (L)
BH09 = 15.24 m
Depth to Bedrock in metres

8 HYDROGEOLOGY

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

- GSI Website and Databases
- County Council Staff
- EPA website and Groundwater Monitoring database
- Local Authority Drinking Water returns
- Whitegate Public Supply Groundwater Source Protection Zones (Cronin and Deakin, 1999)
- Groundwater Protection Scheme for Co. Clare (Deakin, 2000)
- Hydrogeological mapping by TOBIN Consulting Engineers and Robert Meehan September and October 2009.

8.1 GROUNDWATER BODY AND STATUS

The source and the surrounding area are located within the Tynagh groundwater body (GWB), close to the southwestern boundary of the body. The Tynagh GWB is of Good Status. The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the EPA website: www.epa.ie .

8.2 METEOROLOGY

Establishing groundwater source protection zones requires an understanding of general meteorological patterns across the area of interest. The data source is Met Eiréann.

Annual rainfall: 1,110 mm. The contoured data map of rainfall in Ireland (Met Éireann; 1961-1990 dataset) shows that the source is located approximately half way between the 1,000 mm and 1,200 mm average annual rainfall isohyets. The nearest station to the source during the period 1961 to 1990 was Scarriff garda station, which recorded an average annual rainfall of 1,110 mm (Fitzgerald and Forrestal, 1996).

Annual evapotranspiration losses: 516 mm. The closest synoptic weather station to the study area is Shannon Airport. Average potential evapotranspiration (P.E.) at the airport between 1961 and 1990 was 543.2 mm, based on Met Eireann data. Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits giving an Actual Evapotranspiration of 516 mm.

Annual Effective Rainfall: 594 mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall. Potential recharge is therefore equivalent to this, or 594 mm/year. See section on Recharge which estimates the proportion of effective rainfall that enters the aquifer.

8.3 GROUNDWATER LEVELS, FLOW DIRECTIONS AND GRADIENTS

Ground water levels were measured at the PWS boreholes and in private boreholes across the western and northern parts of the study area in September/October 2009. Full details of the water level data collected are provided in Table A1.1 in Appendix 1.

Depth to groundwater in the private boreholes varied across the area from >10 m below ground level (bgl) in the elevated areas with thin subsoils, to close to ground surface (1–3 m bgl) further down slope towards the lower areas where the thickness of the subsoils increases. Artesian conditions were present in some areas beneath the thicker subsoils, e.g. borehole BH09. In the public supply wells, the pumping water levels were >20 m bgl while water levels at the end of a short recovery test reached 8.9 m bgl. This level was still approximately 6 m below the level of the adjacent river. Information from the Clare GWPS indicates that the rest water level lies below the river level (Deakin, 2000). This suggests there is a resulting vertical gradient from the river to the boreholes.

Approximate groundwater contours based on the available, measured groundwater level data are shown in Figure 7. The contours indicate that the groundwater flow direction is generally down slope towards the rivers, with the groundwater piezometric level occasionally above ground level close to the Bow River. A number of springs were found in the area which are shown in Figure 2. Flow directions in the region are expected to approximately follow the local surface water catchments (GSI, 2004). Groundwater flow divides are therefore expected to coincide with topographic divides to the east and west of the source.

The average hydraulic gradient encountered across the area contoured ranges from 0.044 to 0.057. The Water Framework Directive summary for the Tynagh GWB indicates that groundwater gradients in the upland areas are likely to be steep (up to 0.1), while in low-lying areas, groundwater gradients of the order of 0.01 to 0.04 may be the norm (GSI, 2004).

8.4 HYDROCHEMISTRY AND WATER QUALITY

Samples of untreated groundwater are collected from the raw water tap in the source pump house. The collected water may come from either of boreholes PWSBH01 or PWSBH02, depending on which of the two is pumping when the sample is collected. Ten samples were collected and analysed by the EPA between July 2007 and December 2008. The resulting data are presented in Table A1.2 in Appendix 1. Field water quality data (pH, alkalinity, DO, conductivity and temperature) were collected from borehole PWSBH01 and from the Bow River adjacent to the source during the pumping test on 07/10/2009. The field water quality data are presented in Table A1.3 in Appendix 1. A summary of the available hardness, alkalinity, conductivity and pH data are provided in Table 8–1.

Table 8-1 Summary of pH, Electrical Conductivity, Alkalinity and Hardness Data

	PWSBH01				Bow River			
Parameter	**No. of Samples[1]**	**Minimum**	**Maximum**	**Average**	**No. of Samples[2]**	**Minimum**	**Maximum**	**Average**
pH[3]	23	6.46	7.99	7.03	4	5.82	7.28	6.73
EC (µS/cm)	23	349	535	459	4	165	184	175
Alkalinity (mg/l as $CaCO_3$)	14	218	270	233	2	61	69	65
Hardness (mg/l as $CaCO_3$)	9	226	259	245	0	-	-	-

Note 1: No of samples based on 9 No. EPA samples and 14 No. samples during pumping test on 07/10/2009. Only 5 No. Alkalinity samples and no hardness samples from pumping test on 07/10/2009.
Note 2: Based on 4 No. samples during pumping test on 07/10/2009. Only 2 No. Alkalinity samples and no hardness samples from pumping test on 07/10/2009
Note 3: Only field pH data were used in calculation of these statistics

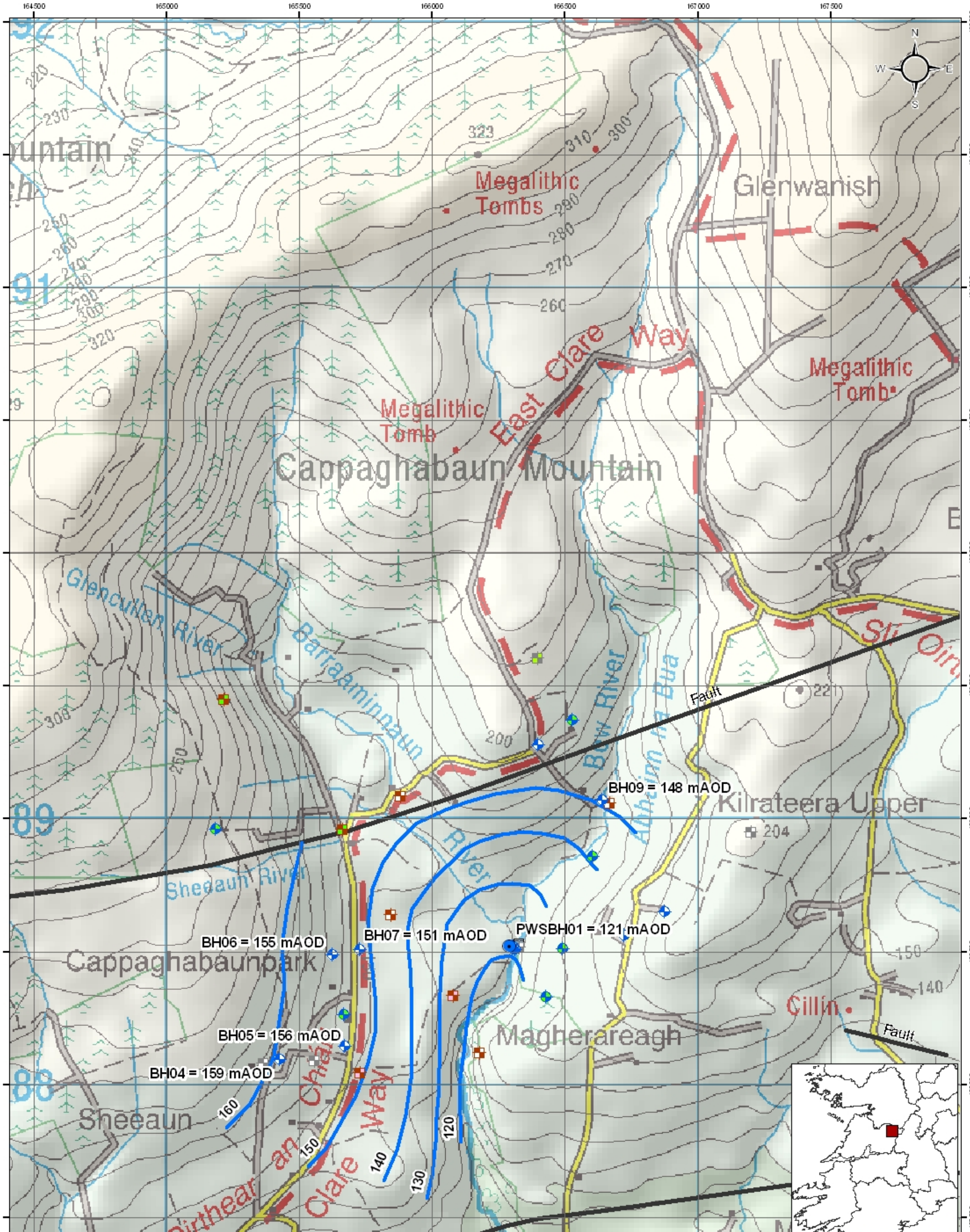


Figure 7 Groundwater Elevation Contours

PWS Abstraction
River
120 Estimated Bedrock Groundwater Elevation Contours (mAOD)
Bedrock Fault
BH07 = 151 mAOD Approximate Bedrock Groundwater Elevation in Borehole (mAOD) (Levels measured on 15 & 17/09/2009)
Note: PWSBH01 level measured on 07/10/2009 after 10 hour recovery test

Overall, the moderately hard condition of the water, the moderate alkalinity and conductivity and near neutral pH indicate a moderately mineralized groundwater, i.e. the groundwater contains a moderate amount of dissolved ions. This in turn indicates a moderate residence time for the groundwater and some contact with reactive material along its pathway from recharge to abstraction. The water is of calcium-bicarbonate type which indicates that the main interaction has been with calcite in the bedrock and subsoil.

The main source of bedrock calcite in the study area is the cornstone unit at the base of the ORS, which outcrops in the extremely vulnerable ridge top areas to the west and north of the source and is seen infilling fractures at OC02 and OC04. While calcite may be present in the subsoil across the remainder of the study area, it is considered that the confined bedrock groundwater pressure will result in leakage upwards into the subsoil rather than the reverse. As such, the extremely vulnerable calcite rich bedrock areas are considered to be the main recharge zones for the source and to be responsible for the strong calcium-bicarbonate signature of the groundwater.

The field data for the Bow River from 07/10/2009 indicate that the river water is significantly less mineralized than the groundwater with lower electrical conductivity and alkalinity. The surface water temperature was also at least 1.3^{O}C lower than the groundwater which remained relatively constant throughout the pumping test on 07/10/2009. A similar condition prevailed during a pumping test of the source prior to 2000 (Deakin, 2000). These data suggest that there is limited hydraulic connectivity between the surface water and the groundwater, and that any leakage resulting from the vertical gradient between the river and the boreholes under pumping conditions is of a magnitude which does not significantly affect the groundwater major ion hydrochemistry.

The data have also been assessed from a water quality perspective. The pollution indicators nitrate, chloride, ammonia, manganese, potassium and the potassium : sodium ratio were all well below their respective EPA threshold values and where relevant, their Maximum Admissible Concentrations (MAC) under the Drinking Water Regulations (S.I. 278 of 2007). Average nitrate was 5.2 mg/l as NO_3 with a maximum of 6.0 mg/l which is significantly less than the threshold value of 37.5 mg/l (see Figure 8a).

Faecal and total coliforms were present at concentrations above their respective MAC and EPA thresholds (0 cfu/100 ml for each parameter for both MAC and EPA threshold) on 7 out of 8 monitoring events for total coliforms; and for 4 out of 8 events for faecal coliforms. This indicates a fairly constant source of organic waste related contamination impacting on the source. The maximum total and faecal coliform counts occurred on 13/08/2008 with concentrations of 66 cfu/100 ml and 26 cfu/100 ml respectively. These peaks coincide with a sub-threshold peak in the ammonia data on the same date (see Figure 8b).

The concentration of orthophosphate exceeded the EPA threshold for protection of surface water of 0.035 mg/l as P on one occasion up to January 2008 with non-detectable concentrations subsequently. The average concentration of PO_4^- in groundwater is less than the EPA threshold value (see Figure 8c). Concentrations of manganese, sodium and potassium were all well below their respective threshold levels (see Figure 8d).

The most likely bacteriological and phosphate contaminant source is leakage of stagnant ponded water into borehole PWSBH01 from the ponded water within the borehole chamber. This stagnant water was present prior to the fixing of the drain servicing the chamber in October 2009. The ponded water may have been contaminated with organic matter. Furthermore, there is no reference to grouting in the borehole log for borehole PWSBH02. As a result it is unlikely that the casing is properly sealed into the surrounding subsoil, such that contaminated overland flow may be able to leak down the side of the casing into the borehole. This is also likely to occur at the other two boreholes on the site.

Figure 8a EPA Chloride & Nitrate Groundwater Quality data for boreholes PWSBH01 & PWSBH02

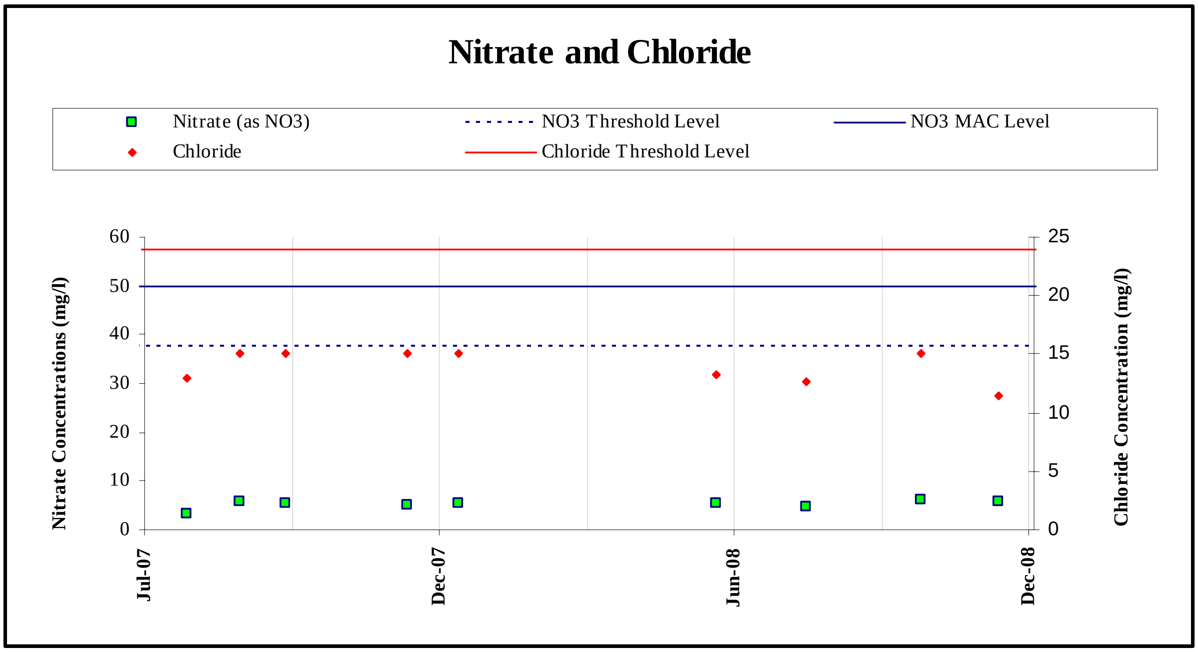
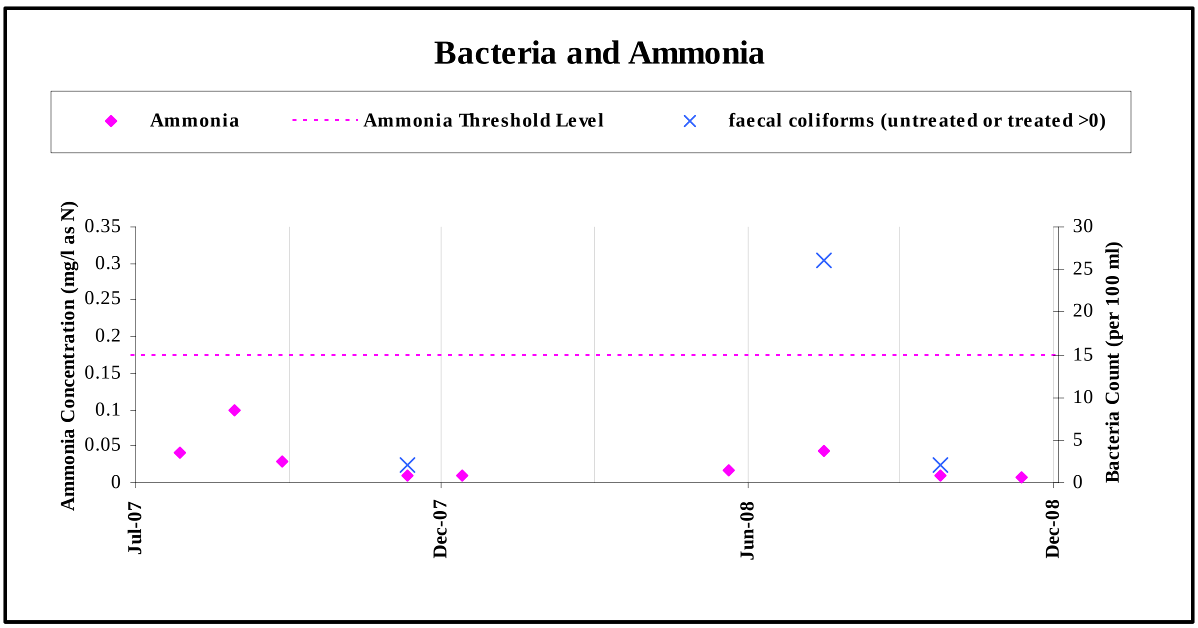


Figure 8b EPA Bacteria & Ammonia Groundwater Quality data for boreholes PWSBH01 & PWSBH02



An additional possible contaminant source for these exceedences could be leakage from the river to the PWS source, which although considered limited, could allow organic contaminants in the river to migrate into the PWS source in detectable concentrations. The most recent Water Quality Rating for the Bow River was 4 to 5 (unpolluted) from the year 2005. As such, the river is unlikely to be a significant source of contamination.

In summary, bacteriological exceedences, and occasional orthophosphate exceedences suggest contamination from an organic waste source. The most likely sources of the observed contamination are historical leakage into the borehole of ponded water inside the chamber housing borehole

PWSBH02 and ongoing leakage of overland flow down the outside of the casings of all three boreholes at the site.

Figure 8c EPA Phosphorous Groundwater Quality data for boreholes PWSBH01 & PWSBH02

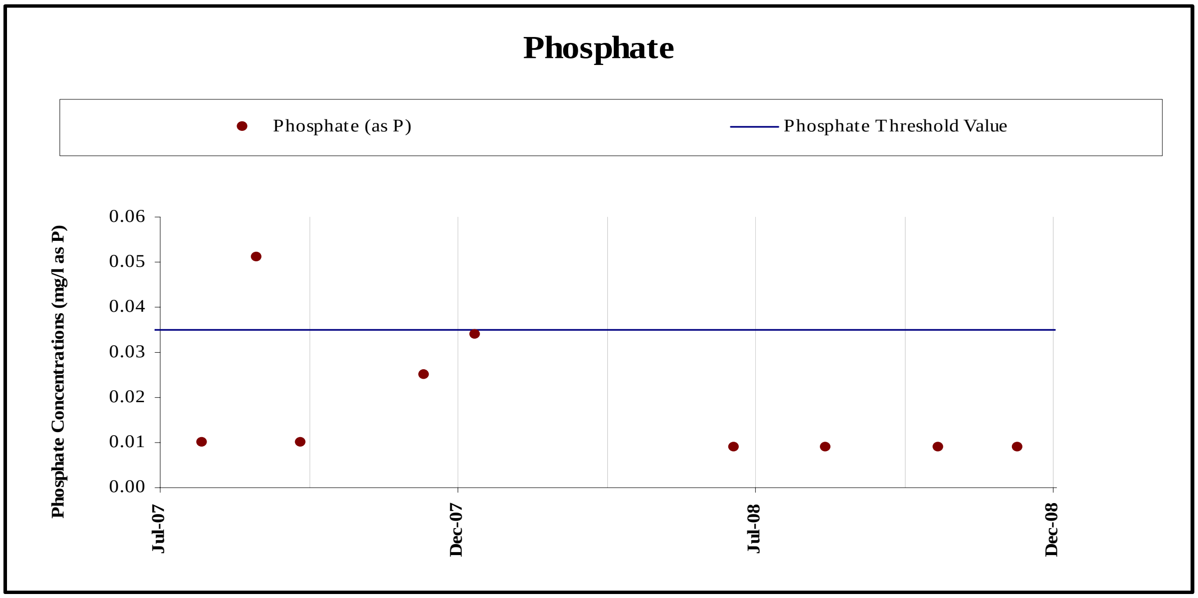
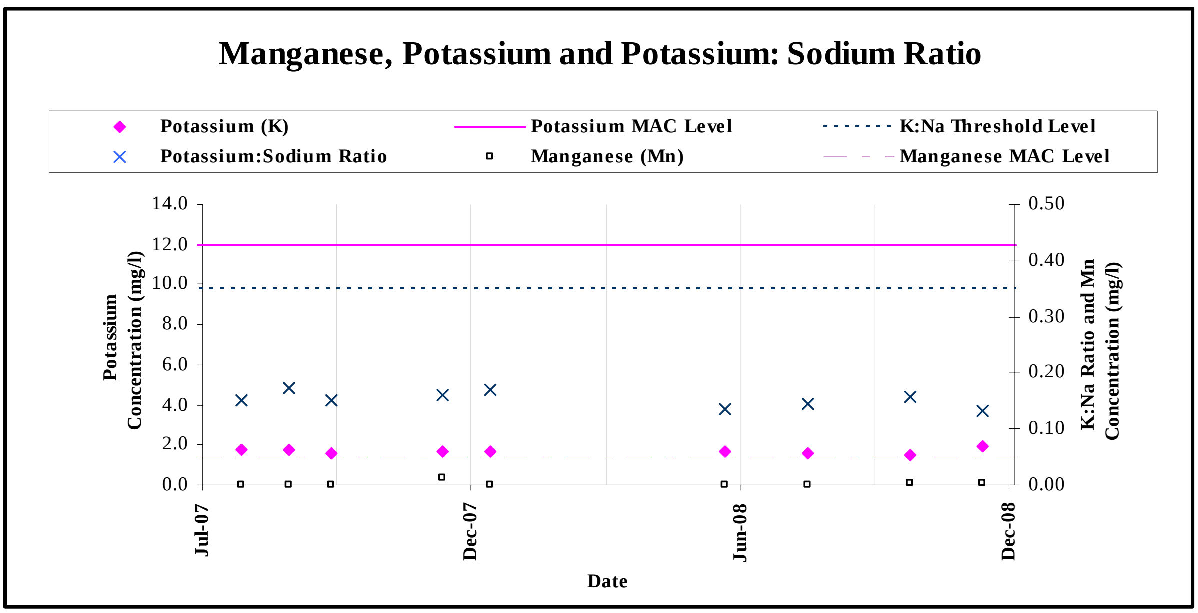


Figure 8d EPA Manganese, Sodium & Potassium Groundwater Quality data for boreholes PWSBH01 & PWSBH02



8.5 AQUIFER CHARACTERISTICS

The groundwater source is located in the Tynagh Groundwater Body. The GSI bedrock aquifer map of the area indicates that the Silurian Metasediments and Volcanics are classified as a *Poor Aquifer which is Generally Unproductive except for Local Zones (PI*). . The small outcrop of the cornstone bedrock to the west of the source is classified as a *Locally Important Aquifer which is Moderately Productive only in Local Zones (LI).* The bedrock aquifer map of the area is shown in Figure 9.

Typically the majority of bedrock groundwater flow takes place in the upper 15 m of the bedrock in a weathered zone a few metres thick and in a connected fracture zone below this (GSI, 2004). Isolated deeper inflows may occur where faults or significant fractures are intercepted by boreholes (GSI, 2004). Groundwater flow paths are typically short, with excess groundwater discharging to springs (e.g. springs GW01 to GW04 on Figure 2) or to the streams and rivers that traverse the aquifer (GSI, 2004).

The Groundwater Body report indicates aquifer permeabilities of typically 0.00036 m/d to 0.76 m/d in the top 30 m of rock (i.e. transmissivity of 0.01 to 22.8 m^2/d) could be expected in the Silurian bedrock strata, while zones of increased transmissivity up to 82 m^2/d have also been encountered. The Clare GWPS indicates that a transmissivity of 32 to 47 m^2/day was obtained from a 10 hour pumping test at 242 m^3/d of one of the source boreholes prior to 2000 (Deakin, 2000). The same test recorded a specific capacity of 43 $m^3/d/m$. A 10 hour pumping test of the source at 363 m^3/d on 07/10/2009 indicated a transmissivity of 11.6 m^2/day for the upper, weathered bedrock aquifer outside the proposed, transmissive fault zone, which is considered to preferentially channel water to the source (see below). An aquifer storativity of 1.14E-04 was calculated from the pumping test. The specific capacity from the pumping test was 19.9 $m^3/d/m$. The decrease in transmissivity and specific capacity between the two tests may indicate oxidation and partial blockage of fractures intersected by the site borehole due to introduction of air to the fractures during periods of large pumping-induced, water table drawdown. Alternatively the difference may be due to greater inefficiency of the well at the larger pumping rate of the second test. Full details of the 2009 pumping test are provided in Appendix 2.

Based on the estimated bedrock aquifer transmissivity and the aquifer hydraulic gradients, the advective groundwater flow velocity can be estimated based on the equation:

$$v = \frac{T \cdot i}{b \cdot n_e}$$

where:
- v = average groundwater velocity (m/day);
- T = aquifer transmissivity (m^2/day);
- n_e = effective porosity (dimensionless)
- i = hydraulic gradient; and,
- b =aquifer thickness.

The estimated groundwater velocity range in the bedrock aquifer, based on the available data is shown in Table 8-2.

Table 8-2 Estimated Groundwater Velocity Range

Parameter	Units	Minimum	Maximum	Data Source
T	m^2/d	11.6	47	Clare GWPS (Deakin, 2000), Pumping test of borehole PWSBH01 on 07/11/2009
i	[-]	0.044	0.057	Section 8.3
b	m	15	30	15 m based on typical thickness of weathered upper bedrock aquifer (GSI, 2004); 30 m based on depth at which highly productive zone (proposed fault zone) was encountered in borehole PWSBH02.
n_e	[-]	0.015	0.015	Assumed to be the same as in the overlying ORS strata in the area and given as 0.015 in the WFD Tynagh GWB summary (GSI, 2004).
v	m/d	1.13	11.9	Estimated

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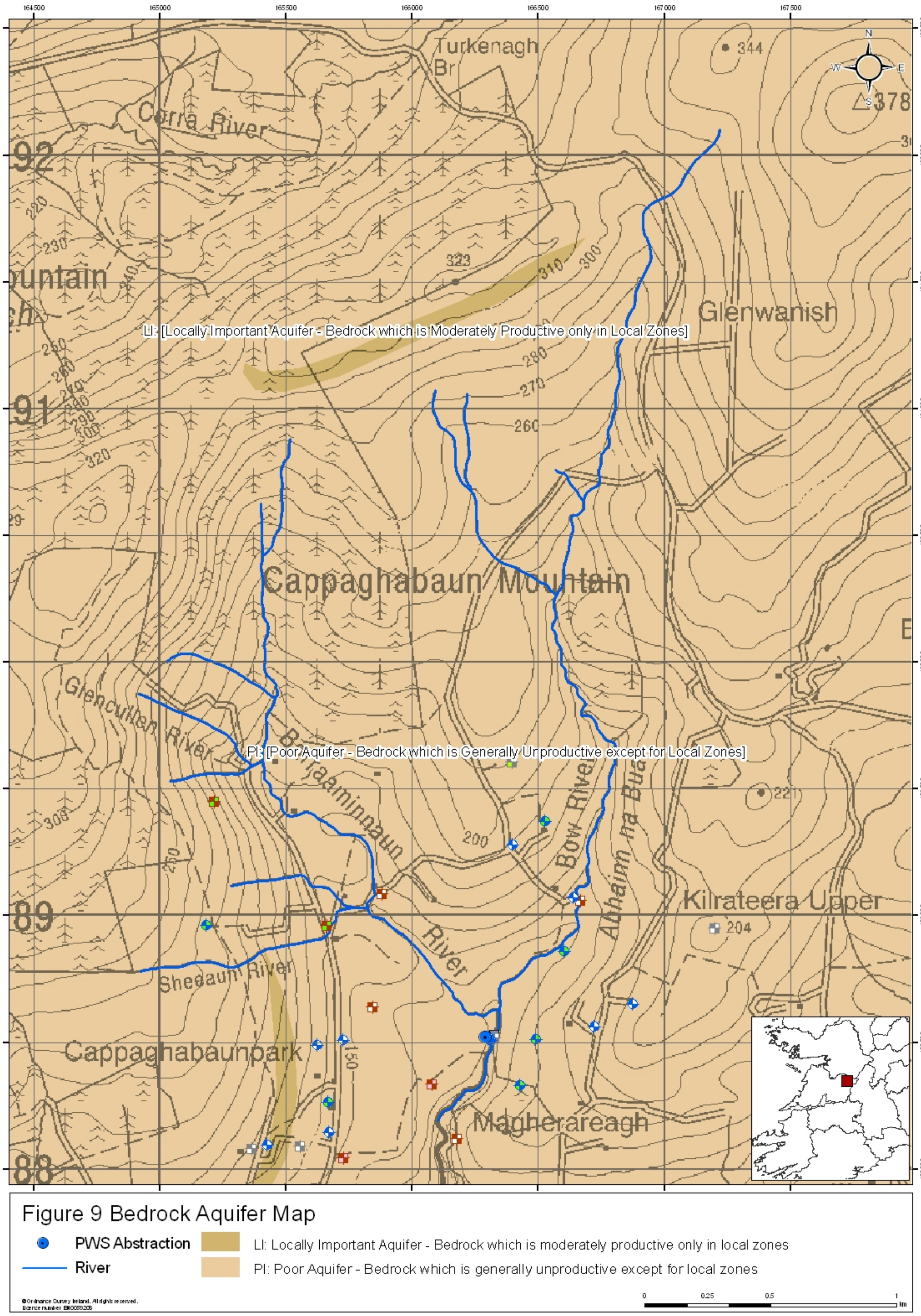

Figure 9 Bedrock Aquifer Map

Several strands of evidence point to the existence of a transmissive fault zone intersected by the PWS source. Morphologically the presence of a cross-fault could explain the change in direction of the Bow River between the two mapped faults north and south of the source. In this area the trend of the river is against the general southeasterly grain of the landscape (D. Drew,2009, Pers. Comm.).

Evidence from drilling records for borehole PWSBH02 and the pumping test of PWSBH01 (see Appendix 2) support the interpretation of a fault zone. During the drilling of PWSBH02 a low yield of 21 m^3/d typical of a poor aquifer was encountered in the weathered zone down to 15 m bgl. A large increase in yield of about 300 m^3/d was encountered at 29 m bgl with little further increase below 30 m bgl. The water strike at 29 m bgl is consistent with the intersection of a transmissive fault zone, which is the typical mechanism by which such large yields are obtained in poor aquifers. A similar high yield is obtained from borehole PWSBH01 and almost identical water levels were recorded in the two boreholes during monitoring of pumping and recovery scenarios at the two boreholes (See Appendix 2). The two boreholes are considered to intersect the same fault zone. Borehole PWSBH03 was drilled between the two boreholes and the river (see Figure 1b) and is unused due to low yields. The water level in borehole PWSBH03 was above that of the adjacent boreholes during pumping of borehole PWSBH01.

During recovery of the three boreholes after cessation of pumping at the source, water levels in borehole PWSBH03 synchronised with the other two boreholes above approximately 20 mbgl (See Appendix 2). This indicates that borehole PWSBH03 is likely to intersect the same fault zone but at a higher level, which becomes dewatered during pumping, such that the well is unable to maintain adequate yields for drawdown beyond 20 mbgl. This in turn indicates that the transmissivity of the aquifer outside the influence of the fault zone is low and incapable of maintaining high yields. This is typical of a poor aquifer.

Despite the morphological relationship between the Bow River and the fault zone, it is considered that within the study area there is relatively low hydraulic continuity between groundwater in the fault zone and the river surface water. Upgradient of the source, the river is considered to be perched above low permeability subsoils in the area mapped as low groundwater vulnerability. This would allow only minimal upwards leakage from the artesian aquifer to the river. In the vicinity of the source where the bedrock and fault zone outcrops in the riverbed it is considered that the shale component of the upper bedrock must be weathered and restricts leakage from the river to the borehole to a low magnitude. An indicator of this is that during the pumping and recovery testing of the PWS boreholes, there was a large hydraulic gradient from the river towards the borehole. Despite this, the groundwater major ion hydrochemistry during the test was not impacted by surface water (see Section 8.4) and the time drawdown curves from the test showed no indications of a recharge boundary/river influence (see Appendix 2).

The major, east northeast to west southwest oriented fault zone located approximately 600 m north of the source is interpreted to be transmissive and to allow preferential flow of groundwater along itself. The fault is considered to collect groundwater from the immediately adjacent bedrock aquifer to the north and south with nearby flow lines to the north and south of the fault converging on the fault. Groundwater flow in the fault is considered to follow the topographic gradient discharging to the Barraminaun River in the west and to the inferred fault zone in the east. The similarly trending Mountshannon Fault (located 1 km south of the source) was interpreted to be a barrier to flow in the Mountshannon/Whitegate Source Protection Zones Report (Cronin & Deakin, 1999). However, the same report notes that the fault could also act as a pathway in places along its length (Cronin & Deakin, 1999).

Overall therefore, it is considered that the aquifer is anisotropic with the interpreted fault zone acting as a high transmissivity linear-slot type sump within the generally low transmissivity aquifer. Groundwater in the upper weathered bedrock aquifer drains laterally from the body of the aquifer into the fault zone, from both sides, along the length of the fault zone. The inferred fault zone then channels the groundwater downgradient to the south with minimal hydraulic connectivity to the overlying river. It is likely that under natural conditions the fault zone discharges to the river further downgradient. Under pumping conditions at the PWS source, much of the flow in the inferred fault zone will be intercepted by the source, resulting in flow along the fault zone towards the source, from both ends of the fault. In the vicinity of the source the aquifer seems to be unconfined and may receive a negligible leakage input from the river.

8.6 RECHARGE

The term 'recharge' refers to the amount of water replenishing the groundwater flow system. The recharge rate is generally estimated on an annual basis, and is assumed to consist of the rainfall input (*i.e*. annual rainfall) minus water loss prior to entry into the groundwater system (*i.e*. annual evapotranspiration and runoff). The estimation of a realistic recharge rate is critical in source protection delineation, as this dictates the size of the zone of contribution to the source (*i.e*. the outer Source Protection Area).

At Scarriff, the main parameters involved in recharge rate estimation are: annual rainfall; annual evapotranspiration; and a recharge coefficient.

For poorly productive aquifers, such as the Silurian sandstones and shales, the Water Framework Directive Guidance Document No. GW5 (IWGG 2004) recommends applying a cap on groundwater recharge of 100 mm/yr. The very small outcrop of the locally important cornstone unit aquifer has been grouped with this category for the recharge calculation. This reflects the inability of these aquifers to accept all of the available recharge due to their low transmissivity and consequent inability to transmit the available recharge from the recharge zone to the discharge zone.

The lower lying area surrounding the source is mapped as low groundwater vulnerability to the north and west and high vulnerability to the east, with the PI aquifer overlain by low permeability subsoils. The aquifer is considered to be confined by the subsoils such that there is an upwards hydraulic gradient from the aquifer into the subsoil or else a minimal downwards gradient from subsoil to aquifer. The combination of low permeability subsoils and upwards/minimal-downwards hydraulic gradients will serve to minimise recharge of the bedrock aquifer across the lower lying areas. This effect will be enhanced in the areas of moderate and low vulnerability where the low permeability subsoils have greater thickness. Guidance Document GW5 recommends a recharge coefficient in the range of 10 to 40% for the high vulnerability areas decreasing to as low as 2% in the low vulnerability areas. Taking into account the upwards/minimal-downwards hydraulic gradient, it is considered that a low co-efficient should be used. A co-efficient of 12% has therefore been used to represent these lower lying areas with low permeability subsoils, indicating that overall the recharge is low.

The main bedrock recharge areas within the catchment are considered to be the extremely vulnerable areas on the ridges to the west, north and east of the source. Where the bedrock in these areas is close to the ground surface (<1 m bgl), it has been observed to be extremely fractured and broken, indicating that recharge could be accepted readily up to the PI aquifer cap limit of 100 mm/yr (17% of potential). The remainder of the extremely vulnerable areas are underlain by poorly drained soil and peat and low permeability subsoil up to 3 m thick, and which are given coefficient ranges of 15% to 50%. In these areas a co-efficient of 17% (i.e. the PI aquifer cap) has been used to reflect the poor aquifer type. The hydrochemical signature of the groundwater agrees with these areas being the main recharge zones, as discussed in Section 8.4 above.

Runoff losses are assumed to be 86% of potential recharge (effective rainfall). This value is based on an assumption of 83% runoff for 34% of the area (extreme vulnerability – PI aquifer) and 88% runoff over the remaining areas due to low subsoil permeability and upwards/minimal-downwards hydraulic gradient at the subsoil - bedrock aquifer interface.

The bulk ***recharge coefficient*** for the area is therefore estimated to be 0.14.

These calculations are summarised as follows:

Average annual rainfall (R)		1,110 mm
Estimated P.E.		543 mm
Estimated A.E. (95% of P.E.)		516 mm
Effective rainfall		594 mm
Potential recharge		594 mm
Recharge coefficient for extreme Vul rock at surface		
↳ Cap at 100 mm/yr (Pl)	17%	100 mm
Recharge coefficient for extreme Vul	17%	100 mm
Recharge coefficient for high, moderate and low Vul	12%	59 mm
Averaged runoff losses	86%	517 mm
Bulk recharge coefficient	14%	
Recharge		81 mm

8.7 CONCEPTUAL MODEL

The current understanding of the geological and hydrogeological setting is given as follows:

- The Scarriff wells are pumping an average of 363 m^3/day from Silurian sandstone and shale bedrock which is classified as a *Poor Aquifer which is moderately productive only in local zones (PI)*.

- Groundwater flow is in the upper weathered and shallow bedrock zones, primarily from the ridges down slope towards the river. Groundwater levels are deepest on the ridges (10–16.5 m bgl) where there is little subsoil cover, and rise close to ground level in the lower ground where flow is confined by generally low permeability subsoils which are more than 10 m thick. Further downgradient, adjacent to the Bow River, groundwater becomes artesian in places. Local hydraulic gradients range from 0.044 to 0.057. Groundwater divides coincide with the topographic divides to the east and west of the source.

- The groundwater level in boreholes PWSBH01, PWSBH02 and PWSBH03 is lower than in the adjacent Bow River level. Upgradient of the source at the artesian borehole BH09 the confined groundwater piezometric level is above the adjacent river level. Based on the hydrochemistry in the wells and the river, and the pumping test results, it appears that the Bow River is generally perched and is not in hydraulic connection with the groundwater. However, in the vicinity of the source there is bedrock outcrop in the base of the river, and there may be a small leakage input from the river to the groundwater below.

- An unmapped NNE-SSW trending fault zone has been inferred to be intersected by the source. This is based on the pumping test data and on the morphology of the Bow River in the area. The inferred fault zone acts as a high transmissivity linear-slot type sump within the generally low transmissivity aquifer. Groundwater in the upper weathered bedrock aquifer drains laterally from the body of the aquifer into the fault zone, from the west and east, along the length of the fault zone. There is also likely to be drainage into the fault zone from the north. The fault zone then channels the groundwater downgradient to the south with minimal hydraulic connectivity with the overlying river. It is likely that under natural conditions the fault zone discharges to the river further downgradient. Under pumping conditions at the PWS source, much of the flow in the fault zone will be intercepted by the source, resulting in flow along the fault zone towards the source, from both ends of the fault. This is supported by the decrease in borehole yield in summer. A regional scale mapped east northeast to west southwest trending fault 600 m to the north of the source is also interpreted to be transmissive and would collect groundwater from the immediately adjacent bedrock aquifer to the north and south. Groundwater flow in this fault is considered to follow the topographic gradient discharging to the Barraminaun River in the west and to the inferred fault zone in the east.

- Local scale groundwater vulnerability mapping for the study area shows that the ridges with their thin subsoil cover are classified as extremely vulnerable, while low and moderate vulnerability areas are present to the west and north of the source where the subsoils are more than 10 m thick. The remainder of the area is classified as high vulnerability.

- The groundwater is of calcium–bicarbonate type. This is considered to be due to the influence of the cornstone bedrock in the upland areas where groundwater vulnerability is Extreme. This suggests that these upland areas may be the main source of the relatively small amount of recharge (81 mm/annum) to the aquifer.

- Water quality data for the source showed consistent breaches of the drinking water MAC for faecal and total coliforms, and a single breach of the EPA threshold limit for orthophosphate. These data indicate possible contamination of the groundwater by a local source of organic contaminants. The most likely sources of the observed contamination are historical leakage into the borehole of ponded water inside the chamber housing borehole PWSBH02 and ongoing leakage of overland flow down the outside of the casings of all three boreholes at the site.

- A schematic representation of the conceptual model is shown in Figure 10.

- The limitations of the conceptual model are mainly related to a lack of information with respect to the following:

  ⇨ The presence of the inferred fault zone needs to be confirmed. The existence of the fault is a key element of the conceptual model. Knowledge of the orientation, dip, width and length of the fault zone would allow the Zone of Contribution to the source to be delineated with greater certainty. Geophysical investigations should be carried out in the vicinity of the source to determine these parameters; and,

  ⇨ The pumping test is considered to have been too short in both the recovery and CDT phases. This was due to the operational requirements of the PWS scheme. It would be useful to arrange a larger scale test during the summer at some point in the future, in order to test whether the well is inducing flow in from the river.

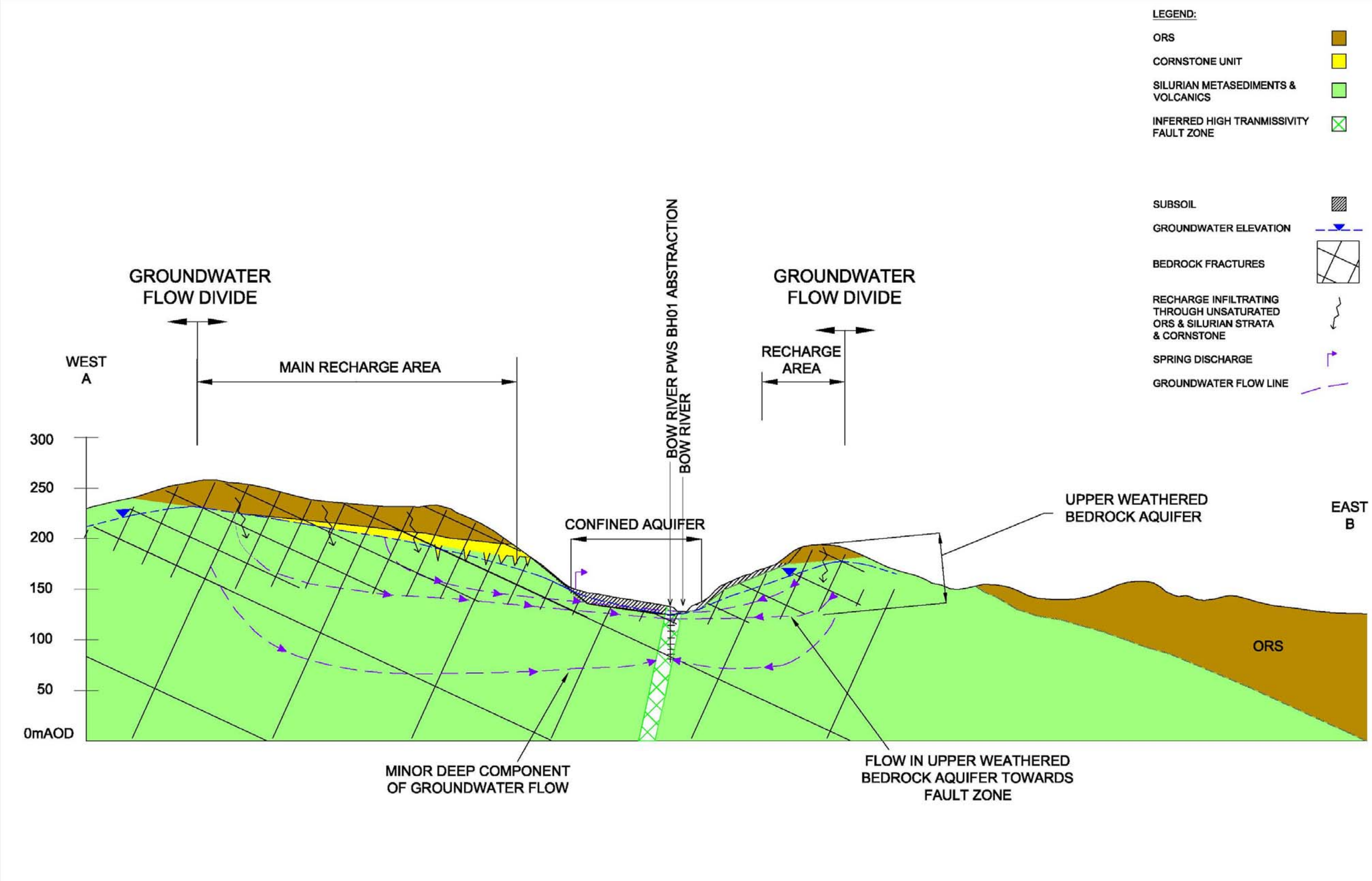

FIGURE 10 SCHEMATIC GROUNDWATER CROSS SECTION

9 DELINEATION OF SOURCE PROTECTION AREAS

This section describes the delineation of the areas around the source that are believed to contribute groundwater to it, and that therefore require protection. The areas are delineated based on the hydrogeological conceptual model, as described in Section 8.7 and presented in Figure 11.

Two source areas are delineated:

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

9.1 OUTER PROTECTION AREA

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, i.e. **the zone of contribution (ZOC)**, which is defined as the area required to support an abstraction from long-term recharge. 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. The shape and boundaries of the ZOC were determined using hydrogeological mapping, water balance estimations, and conceptual understanding of groundwater flow. The boundaries are described below along with associated uncertainties and limitations.

Water balance calculations based on the average recharge for the area of 81 mm/yr and the average abstraction of 363 m3/day, indicate that a recharge area of 1.63 km2 would be required to sustain the supply. At the Bow River PWS source, given the large drawdown experienced under the average PWS abstraction and the associated dewatering of borehole PWSBH03, it is likely that the average abstraction is close to the maximum sustainable abstraction for the hydrogeological setting and that increased abstraction rates would not be viable. The ZOC footprint is often increased by 50% as a margin of safety against increases in abstraction, however in this case significant increases in abstraction are not likely to be viable. As such, no additional area has been added to the ZOC footprint.

The northern boundary of the ZOC is split into northeastern and northwestern components. The northeastern component intersects the northernmost extent of the inferred northeast to southwest trending fault. The boundary extends roughly west and east from this point following groundwater flowlines up the topographic slope to the crests of the Cappaghbaun and Kilrateera Upper ridges respectively. Groundwater flow is expected to drain to the Bow River to the north of the boundary and to the inferred fault zone and ZOC to the south. The mapped east - west trending fault encompassed by this section of the ZOC is expected to be transmissive, with groundwater flow draining in the direction of the topographic slope and into the inferred fault zone.

The northwestern component of the boundary runs southwest initially, roughly following the topographic divide between the Bow and Barraminaun rivers, from the crest of the Cappaghbaun Mountain ridge. The boundary intersects the Barraminaun River upgradient of the confluence of the rivers where subsoil thickness starts to increase and the river is likely to become perched above the bedrock aquifer. From here the boundary turns west following the direction of groundwater flow lines off the Cappabaunpark ridge. To the north of the boundary groundwater flow, including flow along the east to west trending fault zone, discharges to the Barraminaun River. To the south groundwater flow is considered to discharge to the inferred northeast to southwest trending fault zone.

The eastern and western boundaries are taken as the groundwater divides to the east and west of the source, to the south of the mapped fault. This accounts for groundwater discharge to the inferred fault zone from the east and west of the fault.

The **southern** boundary follows groundwater flow lines from topographic divides on the Cappaghbaunpark and Kilrateera Upper ridges to the west and east of the source respectively. These flowlines intersect at the inferred northeast to southwest fault zone at a point approximately 90 m downgradient of the source. This is considered to be a conservative estimate of the downgradient extent of groundwater flow direction reversal within the fault zone, due to pumping at the source.

This delineation gives a ZOC area of 1.67 km2, which is slightly greater than the are required by the water balance calculations above.

9.2 INNER PROTECTION AREA

The Inner Source Protection Area (SI) is the area defined by the horizontal 100 day time of travel from any point below the watertable to the source (DoELG, EPA, GSI, 1999). The 100-day horizontal time of travel to the source is calculated from the velocity of groundwater flow in the bedrock. The velocity multiplied by the 100 day time period gives the distance travelled by the groundwater during the TOT. This distance gives the lateral extent of the buffer which must be applied around the source to form the SI.

In the case of the Bow River PWS, travel time along the inferred fault zone is assumed to be negligible. As a result the buffer has been delineated as an offset distance along either side of the inferred fault zone. The offset distance is calculated based on the groundwater flow velocity in the upper, weathered section of the bedrock aquifer, which discharges into the fault zone. The groundwater velocity range in this unit was calculated between 1.13 and 11.9 m/d in Section 8.5. This gives a range in 100 day travel time distance of 113 m to 1.2 km. Conceptually, a continuous flow line of 1.2 km is considered unlikely in the upper, weathered section of a poor aquifer. Flow lines are typically short in these conditions (GSI, 2004). As such, the distance has been set at the lower end of the range plus a 50% margin of safety giving a distance of 170 m.

The remainder of the ZOC is classified as the Outer Source Protection Area (SO).

10 GROUNDWATER PROTECTION ZONES

Groundwater protection zones are shown in Figure 12, and are based on an overlay of the source protection areas on the groundwater vulnerability. Therefore the inner groundwater protection zones are SI/X, SI/E, SI/H, SI/M and SI/L. The outer groundwater protection zones are SO/X, SO/E, SO/H, SO/M and SO/L. The main recharge areas for the source are designated as SO/X and SO/E.

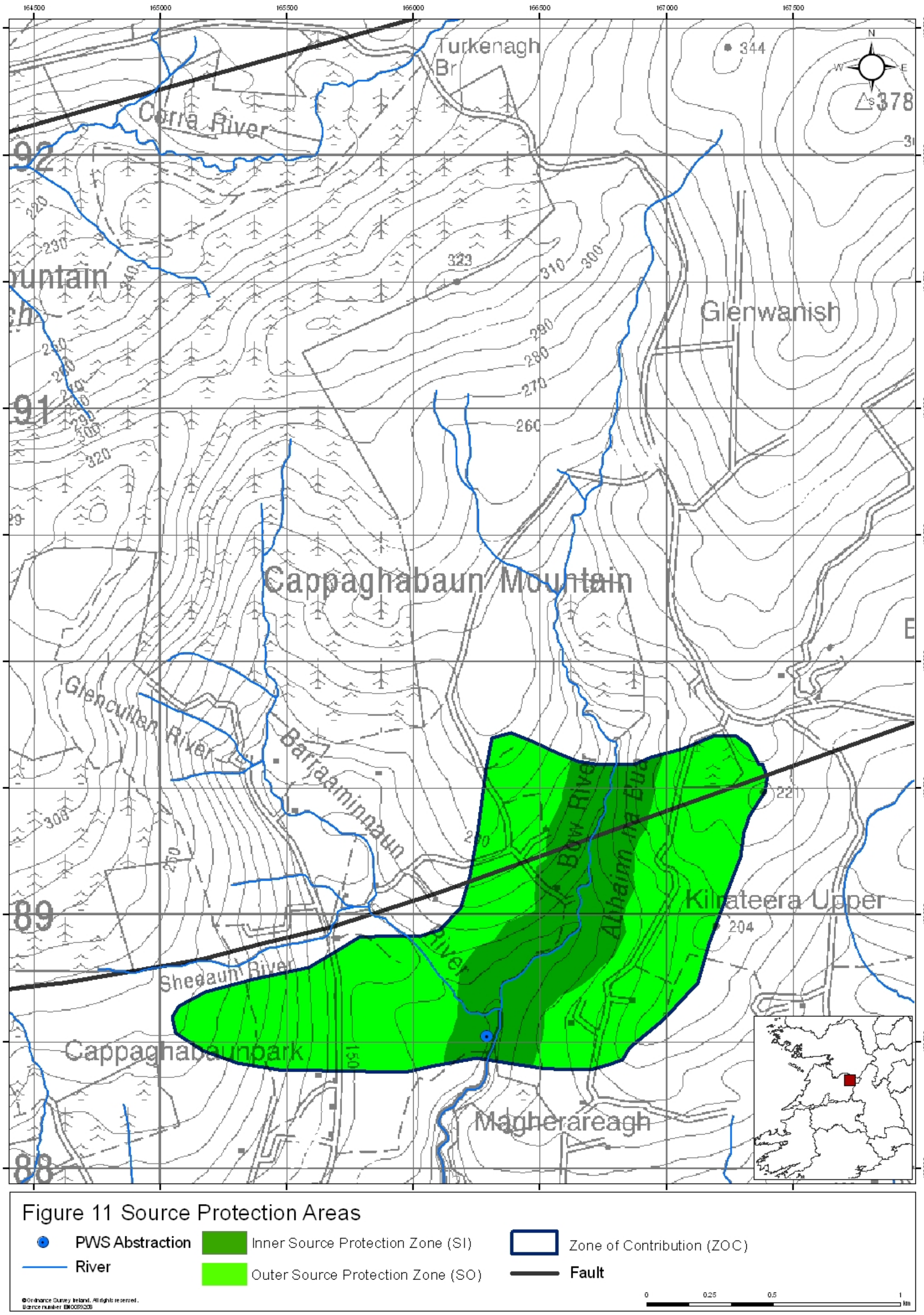

Figure 11 Source Protection Areas

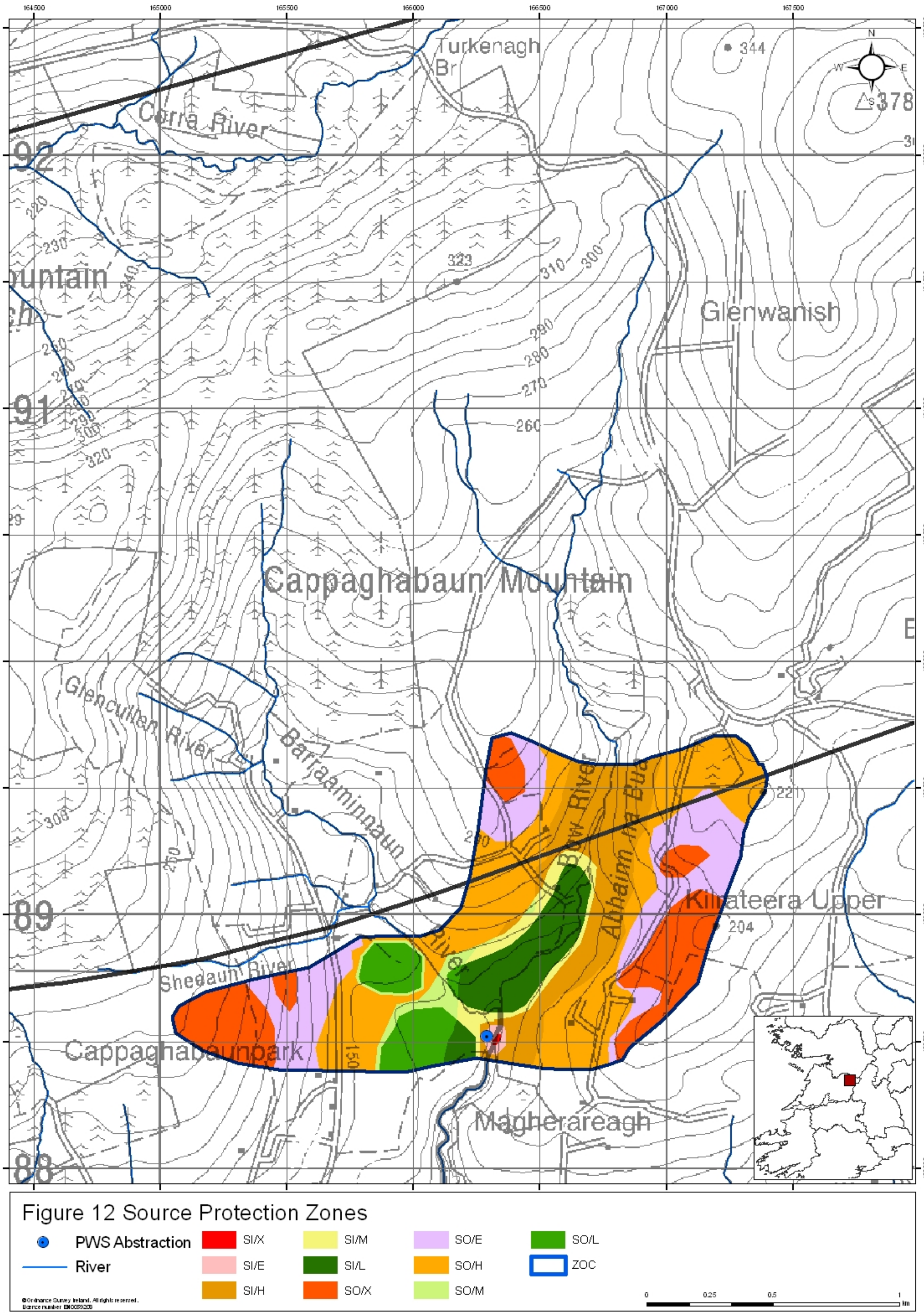

Figure 12 Source Protection Zones

11 POTENTIAL POLLUTION SOURCES

The main potential sources of contamination within the ZOC are:

- Direct microbial contamination of the source by animals and birds and by ponded water inside the borehole housing chambers. The main potential contaminants from these sources are faecal bacteria, viruses and cryptosporidium.
- All private residences within the ZOC are serviced by septic tanks or similar wastewater treatment discharging percolation areas. The main potential contaminants from this source are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, faecal bacteria, viruses and cryptosporidium.
- The majority of land within the zone of contribution is agricultural land, primarily rough grazing. A number of farming operations are located within the ZOC. The main potential contaminants from these sources are ammonia, nitrates, phosphates, chloride, potassium, BOD, COD, TOC, pesticides, faecal bacteria, viruses and cryptosporidium.
- Many private home heating fuel tanks are located within the catchment area. The main potential contaminants from this source are hydrocarbons.
- Roadways are present within the ZOC. The main potential contaminants from this source are hydrocarbons and metals.

12 CONCLUSIONS

The untreated groundwater is currently impacted by microbial contamination and phosphate. Likely sources of the contamination are historical leakage into the borehole of ponded water inside the chamber housing borehole PWSBH02 and ongoing leakage of overland flow down the outside of the casings of all three boreholes at the site.

Due to the potentially high groundwater velocity within the inferred fault zone all of the inferred fault zone within the ZOC is included in the SI and groundwater entering the fault zone is assumed to reach the source very rapidly. A 170 m wide buffer has been delineated on either side of the inferred fault zone and delineated as SI to ensure that the overall travel time within the SI from the bedrock aquifer to the source via the inferred fault zone is greater than 100 days. The protection zones delineated in this report are SI/E, SI/H, SI/M, SI/L, SO/X, SO/E, SO/H, SO/M and SO/L.

The conclusions and recommendations of the report are based on current understanding of groundwater conditions and bedrock geology as inferred from the available data. The report should not be used as the sole basis for site-specific decisions.

Particular care should be taken when assessing the location of any activities or developments that might cause contamination of the Bow River Source, particularly within the inner source protection zone (SI). Reference should be made to the guidelines contained within the DELG/EPA/GSI “Groundwater Protection Scheme” publication regarding the siting of certain activities, such as septic tanks and landspreading of organic wastes, within source protection areas.

13 RECOMMENDATIONS

Further investigations might usefully include:

- A larger scale pumping test, which may provide additional information on aquifer hydraulics and on the interconnectedness of the boreholes with the stream and the inferred fault zone; and,
- The extent of the fault zone should be assessed using geophysics.

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APPENDIX 1

POINT DATA & WATER QUALITY DATA

Table A1.1 – Point Data from hydrogeological Mapping
Table A1.2 – EPA WaterQuality Data For Scarriff PWS Source

Table A1.1 - Point data from hydrogeological mapping - Scarriff PWS, Bow River Source

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	Recovery Test GWL mbtc	Total Depth (m)	tc magl	GL mAOD	GWL mAOD	DTB	Exp Interval	Subsoil K
						8/9/09	15/9/09	17/9/09	7/10/09							
PWSBH01	Groundwater	Borehole	166306	188519	Production Well at Bow River Site. Used alternately with PWSBH02. Driller Tommy Cross. TC = top of 6" steel casing	26.77			8.6	84	-0.28	130	121.12	-	-	-
PWSBH02	Groundwater	Borehole	166297	188529	Production Well at Bow River Site. Used alternately with PWSBH01. Driller Liam Flannery. Drillers log gave: Clay(to 3mbgl)/Soft Shale (3 to15.2mbgl)/Shale (15.2 to 29.3mbgl)/Soft Shale (29.3 to 30.5mbgl)/Shale (30.5 to 48.7mbgl). Casing to 4.9mbgl; liner to full depth. Yield = 21.6m3/d at 15.2m; approx 300m3/day at 29.3m. TC = top of dipper/cable hole in well cap	26.31			8.41	49	-0.31	130	121.28	3.05	-	CLAY
PWSBH03	Groundwater	Borehole	166305	188520	Observation well at Bow River site. Failed trial well. Driller Tommy Cross. TC = top of 8" steel casing	19.665			8.9	189	0.075	130	121.18	-	-	-
SW01	Surface Water	Bow River	166326	188521	River Level Adjacent to Pump House, downstream of dam. Estimated at approx 2.65m below ground level at pump house							127.35				
SW02	Surface Water	Bow River	166326	188530	River Level Adjacent to Pump House, upstream of dam. Estimated at approx 1.4m below ground level at pump house							128.6				
BH01	Groundwater	Borehole	166723	188560	Private borehole in pump house in a field. Couldn't access BH mouth											
BH02	Groundwater	Borehole	166874	188651	Private borehole adjacent to a house. BH buried under overgrown slab - couldn't access BH mouth											
BH03	Groundwater	Borehole	166244	186795	Private borehole in front of new house. Drilled Jul 2008 by Liam Flannery. Artesian - Overflow approx 194 m3/day TC = top of 8" steel casing		0.03			52	0.885	59.9	60.755			
BH04	Groundwater	Borehole	165427	188096	Private borehole in pumphouse in field adjacent to a house. Bored approx 1990. Base of casing possibly at 8 mbgl based on ledge encountered by dipper at this depth. TD based on estimate using dipper. TC = top of 6" steel casing		16.465			31	0.12	175	158.66	-		
BH05	Groundwater	Borehole	165671	188145	Private borehole in field behind old farmhouse. Bored by Liam Flannery in approx 1993. Possibly GSI Well Dbase GSINAME 1417NEW076. TC = top of 6" steel casing. Bedrock spring supplies common along ridge at this elevation according to borehole owner. Neighbouring property supplied by such a spring.			1.12		55	0	157	155.88	0		
OC01	Bedrock	Outcrop	165363	188080	Outcrop of Sandstone bedrock confirmed.									0		

Table A1.1 - Point data from hydrogeological mapping - Scarriff PWS, Bow River Source

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	Recovery Test GWL mbtc	Total Depth (m)	tc magl	GL mAOD	GWL mAOD	DTB	Exp Interval	Subsoil K
						8/9/09	15/9/09	17/9/09	7/10/09							
OC02	Bedrock	Outcrop	165556	188089	Outcrop of grey-green shale to slate with slight metallic lustre. Fine grained with fine cross bedding. Heavily weathered. Cleavage (bedding?) runs SSW to NNE at approx 80 degrees from horizontal. Frequent fractures, < 2mm aperture, infilled with quartz/calcite. Bedding (?) orthogoal to cleavage & dips roughly 20 to 30 degrees to NW. Rock close to surface in surrounding area.									0		
OC03	Bedrock	Outcrop	166326	188515	Outcrop in riverbed at Bow River PWS pump house. Siltltstone/Shale/Slate bedrock, thickly bedded (beds apporz 0.01m thick), interbedded with grey sandstone beds approx 0.2 to 0.3 m thick. Cross bedded. Frac set trending SE, spacing approx 4 to 5 fracs per metre, aperture < 1mm, vertical to sub-vertical. Occasional joints along bedding planes. Dip is 70 degrees to the SE.									0		
BH06	Groundwater	Borehole	165625	188490	Private borehole under manhole in rear driveway of house, in front of garage. Bored 2004 by Crystal Water of Cappamore. Rock close to surface at site (house founded on rock. TC = top of 6-inch steel casing = 0.23 mbgl			10.08		50	-0.23	165	154.69	<3		
BH07	Groundwater	Borehole	165726	188509	Private borehole under manhole in rockery in centre of a lawned area adjacent to owners house. Drilled in 2003 by Liam Flannery. TC = top of 6-inch steel casing (note - this is the same elevation as the top of the 5-ich blue platic liner).			3.39		52	0.17	154	150.78			
EXP03	Subsoil	Exposure	165842	188638	Small subsoil exposure in stream bank incised approx 1.5m below surrounding ground level. Surrounding ground is Poorly drained & rushy; Slope 5 to 10 degrees towards Bow River (East), the stream enters Bow River immediately north of the PWS pump house. No sign of rock outcrop in the area									>1.5	0 to 1.5mbgl	Lightly sandy, gravelly SILT/ CLAY

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	Recovery Test GWL mbtc	Total Depth (m)	tc magl	GL mAOD	GWL mAOD	DTB	Exp Interval	Subsoil K
						8/9/09	15/9/09	17/9/09	7/10/09							
EXP04	Subsoil	Exposre	165879	189084	Sand & Gravel ridge running adjacent to Barraminaun River. Exposure is a former small scale sand/gravel pit, now very overgrown & quarried out. Pit is approx 5m deepalong ridge & approx 20m across & crescent shaped. No outcrop at stream adjacent to pit. Gravels are angular to subangular Sandstone and some quartz.									>3	1 to 3mbgl	Slightly silty, gravelly SAND.
BH08	Groundwater	Borehole	166398	189280	Private borehole in rear driveway of house. Borehole inaccessible - buried under driveway hardcore.					29						
BH09	Groundwater	Borehole	166641	189071	Private borehole in grassy verge of driveway, adjacent to house. Drilled in approximately 1995 by Liam Flannery. Borehole is artesian. On drilling artesian yield was approx 500gpd (2.25 m3/d), with casing at 1.8 magl. BH is now capped (with minor leakage at cap) and piped under artesian pressure to a storage tank with inflow invert approx 1.0m above ground level at the borehole. Current overflow from tank is approx 0.15 l/s (12.9m3/d). Owner recalled approx 50 ft of subsoil over bedrock. Borehole was immediately artesian on entering bedrock. TC = top of 6-ich steel casing. Est RWL at 1.8 magl.			-2.12		30	-0.32	146	147.8	15.2		

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	Recovery Test GWL mbtc	Total Depth (m)	tc magl	GL mAOD	GWL mAOD	DTB	Exp Interval	Subsoil K
						8/9/09	15/9/09	17/9/09	7/10/09							
EXP05	Subsoil	Exposure	166665	189058	Sand & Gravel exposure on eastern bank of Bow River adjacent to BH09. Rounded Sandstone Cobble & Boulder in a sand and gravel matrix. 2.5 m exposed thickness.									>2.5	0 to 2.5 mbgl	SAND/ GRAVEL / COBBLE/ BOULDER
OC04	Bedrock	Quarry	166394	189603	Rock is grey, fine SANDSTONE with slump bedding. Beds 0.1 to 0.3 m thick. Interbedded with shale beds every 0.5 to 1m. Shale is thinly bedded. Sandstone is cross bedded in places. Dip is approximately 70 to 80 degrees SSE to SE. Fractures: NW to NNW trending sub-vertical set, spacing approx 2 per metre. Evidence of a sub-horizontal set dipping W to NW at 15 to 20 degrees. Rock is generally quite broken with permeability along bedding, joints & fractures. Fracture apertures generally look < 1mm. Frequent calcite infilling of joints and fractures - possible from Scalpnagown Cornstone infill of the weathered upper Silurian surface.									0		
OC05	Bedrock	Outcrop	167200	188950	Outcrop confirmed									0		
SA01	Subsoil	Hand Auger	165728	188041	Mottled brown, pink & grey.					1						sandy, slightly gravelly CLAY
EXP01	Subsoil	Exposure	166178	188120	Subsoil exposure at site of small landslide on east bank of Bow River, slightly downstream of PWS pump house. Material is fairly uniform latteraly and vertically across the exposure. Vegetation is bog & rush on plateau east of exposure with pasture beyond at top of rise; Below slip is birch scrub and rush/moss down slope to river. There is a horizontal gravel layer running along the base of the visible part of the exposure @ approx 2mbgl. Fingering of grey mottling from below topsoil down into the subsoil in many places. Material is mottled grey-pink-brown-orange, firm to stiff, sandy gravelly SILT.									>2.5	0 to 2.5 mbgl	sandy, gravelly SILT

Table A1.1 - Point data from hydrogeological mapping - Scarriff PWS, Bow River Source

Name	Type	Sub-type	X	Y	Description	GWL mbtc	GWL mbtc	GWL mbtc	Recovery Test GWL mbtc	Total Depth (m)	tc magl	GL mAOD	GWL mAOD	DTB	Exp Interval	Subsoil K
						8/9/09	15/9/09	17/9/09	7/10/09							
EXP02	Subsoil	Hand Auger	166077	188335	Hand auger at base of 1.2m deep drain. Vegetation is rushy pasture, with artificial boundary drains. Wall of drain exposed susbsoil down to 1.2 mbgl, with same material encountered with hand auger down to 2.2mbgl. Saturatedbelow 1.2mbgl. Material is mottled pink-brown/orange/grey, firm slightly sandy, gravelly SILT.									>2.2	0 to 2.2mbgl	slightly sandy, gravelly, SILT
EXP05	Subsoil	GSI Quaternary	165661	188960	GSI Quaternary point data - Silty Till, approx co-ords					1						
EXP06	Subsoil	GSI Quaternary	165213	189447	GSI Quaternary point data - Silty Till, approx co-ords					1						
GW01	Groundwater	Spring	165667	188265	OSI 25-inch:1 mile map. Indicates spring. Approx Co-ords.											
GW02	Groundwater	Spring	165184	188961	OSI 25-inch:1 mile map. Indicates spring. Approx Co-ords.											
GW03	Groundwater	Spring	166428	188330	OSI 25-inch:1 mile map. Indicates spring. Approx Co-ords.											
GW04	Groundwater	Spring	166491	188511	OSI 25-inch:1 mile map. Indicates spring. Approx Co-ords.											
GW05	Groundwater	Spring	166602	188859	OSI 25-inch:1 mile map. Indicates spring. Approx Co-ords.											
GW06	Groundwater	Spring	166529	189373	OSI 25-inch:1 mile map. Indicates spring. Approx Co-ords.											

		mg/l	mg/l Ca	mg/l Mg	mg/l K	mg/l Na	mg/l Cl	mg/l	mg/l SO4	mg/l CaCO3	µg/l Sr	ug/l Zn	ug/l Sb
GSI Name	Date	NO3	Ca	Mg	K	Na	Cl	NO2	SO4	Alk	Sr	Zn	Ant
mg/l	Jan-82	25			4		30						
mg/l	Jan-82	50	200	50	12	150	250	0.1	250		5000	1	0.01
GSI Name	Date	NO3	Ca	Mg	K	Na	Cl	NO2	SO4	Alk	Sr	Zn	Ant
Scarriff	27/07/2007	3.3	79	11.9	1.8	12	13.0	0.050	5	238	191	0.007	0.001
Scarriff	29/08/2007	5.8	81	12.2	1.8	11	15.0	0.050	6	270	202	0.001	0.001
Scarriff	26/09/2007	5.5	75	11.6	1.6	11	15.0	0.050	7	240	191	0.001	0.001
Scarriff	10/12/2007	5.1	80	11.4	1.7	11	15.0	0.050	6	260	185	0.089	0.001
Scarriff	11/01/2008	5.3	82	12.0	1.7	10	15.0	0.050	6	270	185	0.007	0.001
Scarriff	18/06/2008	5.5	78	13.9	1.7	12	13.2	0.043	4	232	181	0.006	0.000
Scarriff	13/08/2008	4.7	78	13.2	1.6	11	12.7	0.043	4	242	187	0.005	0.000
Scarriff	22/10/2008	6.0	77	11.0	1.5	10	15.0	0.043	3	231	178	0.002	0.000
Scarriff	09/12/2008	5.7	73	10.6	1.9	14	11.5	0.043	5	230	178	0.022	0.000
Scarriff	Arithmetic Mean	5.21	78.12	11.97	1.70	11.20	13.93	0.05	5.07	245.89	186.51	0.02	0.00

		mg/l CaCO3	uS/cm	ug/l Al	ug/l Fe	ug/l Mn	mg/l N	No./100ml	No./100ml	ug/l Ba	mg/l P	µg/l Se	µg/l Ag
GSI Name	Date	Hard	Cond	Al	Fe	Mn	NH4	TC	F. coli	Ba	P	Se	Ag
mg/l	Jan-82						0.15	0	0				
mg/l	Jan-82		1500	0.2	0.2	0.05	0.3	0	0	0.5	5000	0.01	0.01
GSI Name	Date	Hard	Cond	Al	Fe	Mn	NH4	TC	F. coli	Ba	P	Se	Ag
Scarriff	27/07/2007	245	438	0.002	0.022	0.001	0.040	-	-	0.0440	-	-	0.002
Scarriff	29/08/2007	259	408	0.002	0.030	0.001	0.100	1	1	0.0450	-	-	0.002
Scarriff	26/09/2007	254	349	0.002	0.037	0.001	0.030	20	1	0.0420	-	-	0.002
Scarriff	10/12/2007	-	486	0.002	0.021	0.013	0.010	13	2	0.0650	-	-	0.002
Scarriff	11/01/2008	240	535	0.008	0.002	0.001	0.010	1	1	0.0390	-	-	0.002
Scarriff	18/06/2008	253	411	0.005	0.005	0.001	0.016	4	1	0.0399	0.040	-	0.001
Scarriff	13/08/2008	249	481	0.005	0.005	0.001	0.043	66	26	0.0414	0.130	-	0.001
Scarriff	22/10/2008	238	464	0.005	0.005	0.002	0.010	11	2	0.0392	0.030	-	0.001
Scarriff	09/12/2008	226	436	0.005	0.014	0.003	0.007	2	1	0.0406	0.110	-	0.001
Scarriff	Arithmetic Mean	245.45	445.33	0.00	0.02	0.00	0.03	14.75	4.38	0.04	0.08	-	0.00

		ug/l B	ug/l Cd	ug/l Cr	ug/l Cu	mg/l F-	ug/l Pb	ug/l Hg	ug/l Ni	mg/l P	ug/l Ni	mg/l P	oC
GSI Name	Date	B	Cd	Cr	Cu	F	Pb	Hg	Ni	PO4	Ni	PO4	Temperatur
mg/l	Jan-82									0.02		0.02	
mg/l	Jan-82	2	0.005	0.05	0.5	1	0.05	0.001	0.05	5	0.05	5	
GSI Name	Date	B	Cd	Cr	Cu	F	Pb	Hg	Ni	PO4	Ni	PO4	
Scarriff	27/07/2007	0.0120	0.0004	0.0050	0.001	0.1	0.0010	0.0001	0.0010	0.010	0.0010	0.010	13.2
Scarriff	29/08/2007	0.0030	0.0004	0.0100	0.001	0.1	0.0010	0.0001	0.0010	0.051	0.0010	0.051	16.4
Scarriff	26/09/2007	0.0130	0.0004	0.0020	0.001	0.2	0.0010	0.0001	0.0010	0.010	0.0010	0.010	11.2
Scarriff	10/12/2007	0.0050	0.0010	0.0100	0.006	0.1	0.0010	0.0001	0.0030	0.025	0.0030	0.025	9.8
Scarriff	11/01/2008	0.0030	0.0004	0.0010	0.001	0.2	0.0010	0.0001	0.0010	0.034	0.0010	0.034	8.5
Scarriff	18/06/2008	0.0200	0.0001	0.0010	0.003	0.1	0.0003	0.0000	0.0005	0.009	0.0005	0.009	12.7
Scarriff	13/08/2008	0.0200	0.0001	0.0010	0.003	0.1	0.0003	0.0000	0.0006	0.009	0.0006	0.009	13.0
Scarriff	22/10/2008	0.0200	0.0001	0.0013	0.007	0.1	0.0006	0.0000	0.0005	0.009	0.0005	0.009	10.8
Scarriff	09/12/2008	0.0200	0.0001	0.0010	0.008	0.1	0.0003	0.0000	0.0016	0.009	0.0016	0.009	8.5
Scarriff	Arithmetic Mean	0.01	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.02	0.00	0.02	

		mg/l P	µg/l Se	ug/l B	ug/l Cd	ug/l Cr	ug/l Cu	mg/l F-	ug/l Pb	ug/l Hg	ug/l As		
GSI Name	Date	P	Se	B	Cd	Cr	Cu	F	Pb	Hg	As	Ratio (using mg)	
mg/l	Jan-82											0.35	
mg/l	Jan-82	5000	0.01	2	0.005	0.05	0.5	1	0.05	0.001	0.05		
GSI Name	Date	P	Se	B	Cd	Cr	Cu	F	Pb	Hg	As	K/Na Ratio	
Scarriff	27/07/2007	-	-	0.0120	0.0004	0.0050	0.001	0.1	0.0010	0.0001	0.001	0.15	0.09
Scarriff	29/08/2007	-	-	0.0030	0.0004	0.0100	0.001	0.1	0.0010	0.0001	0.001	0.17	0.10
Scarriff	26/09/2007	-	-	0.0130	0.0004	0.0020	0.001	0.2	0.0010	0.0001	0.001	0.15	0.09
Scarriff	10/12/2007	-	-	0.0050	0.0010	0.0100	0.006	0.1	0.0010	0.0001	0.001	0.16	0.10
Scarriff	11/01/2008	-	-	0.0030	0.0004	0.0010	0.001	0.2	0.0010	0.0001	0.001	0.17	0.10
Scarriff	18/06/2008	0.040	-	0.0200	0.0001	0.0010	0.003	0.1	0.0003	0.0000	0.000	0.14	0.08
Scarriff	13/08/2008	0.130	-	0.0200	0.0001	0.0010	0.003	0.1	0.0003	0.0000	0.000	0.15	0.09
Scarriff	22/10/2008	0.030	-	0.0200	0.0001	0.0013	0.007	0.1	0.0006	0.0000	0.000	0.16	0.09
Scarriff	09/12/2008	0.110	-	0.0200	0.0001	0.0010	0.008	0.1	0.0003	0.0000	0.000	0.13	0.08
Scarriff	Arithmetic Mean	0.08	-	0.01	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.15	0.09

Red colour denotes result in excess of MAC
Orange Colour denotes result in excess of EPA Threshold
Blue Colour Denotes result was less than the Detection Limit (DL), where DL is equal to the numeric value shown

APPENDIX 2

PUMPING TEST DATA

Borehole PWSBH01 Pumping TEst Analysis
Table A2.1 – Borehole PWSBH01 Pumping TEst Data

Pumping test of borehole PWSBH01

Borehole PWSBH01 was subjected to a short pumping test between 06/10/2009 and 07/10/2009. As the borehole was being pumped for public water supply, the test regime comprised an initial recovery phase following shut down of the public abstraction. The recovery was monitored between 18.15 and 22.15 on 06/10/2009 and again between 08.30 and 09.00 on 07/10/2009. A constant discharge test (CDT) at 363 m^3/day was subsequently carried out on the source using borehole PWSBH01 as the pumping well. The CDT commenced at 09.25 on 07/10/2009 and was monitored until 19.25 on 07/10/2009. Groundwater levels were monitored in boreholes PWSBH01, PWSBH02 and PWSBH03 throughout the test. The monitoring data collected are provided in Table A2.1. Graphs of drawdown versus time for the recovery test and CDT are shown in Figures A2.1a and A2.1b.

The time-drawdown curves for the CDT phase do not show any early flattening off in drawdown which might indicate the presence of a recharge boundary (i.e. the Bow River) interacting with the fault zone.

The time-drawdown graphs for both the CDT and recovery phases show the close coincidence of the drawdown in boreholes PWSBH01 and PWSBH02. This indicates that the two boreholes are responding instantaneously to the pumping stress times. This in turn indicates a minimal hydraulic gradient within the fault zone and conversely, a very high transmissivity.

During the recovery phase, the drawdown from borehole PWSBH03 synchronised with that of the other two boreholes for drawdown of less than approximately 13 m (i.e. approximately 21.9 m bgl). This indicates that the borehole intersects the fault zone above this level, as discussed in Section 8.3. The drawdown in borehole PWSBH03 during the CDT phase lagged behind that of the other two boreholes.

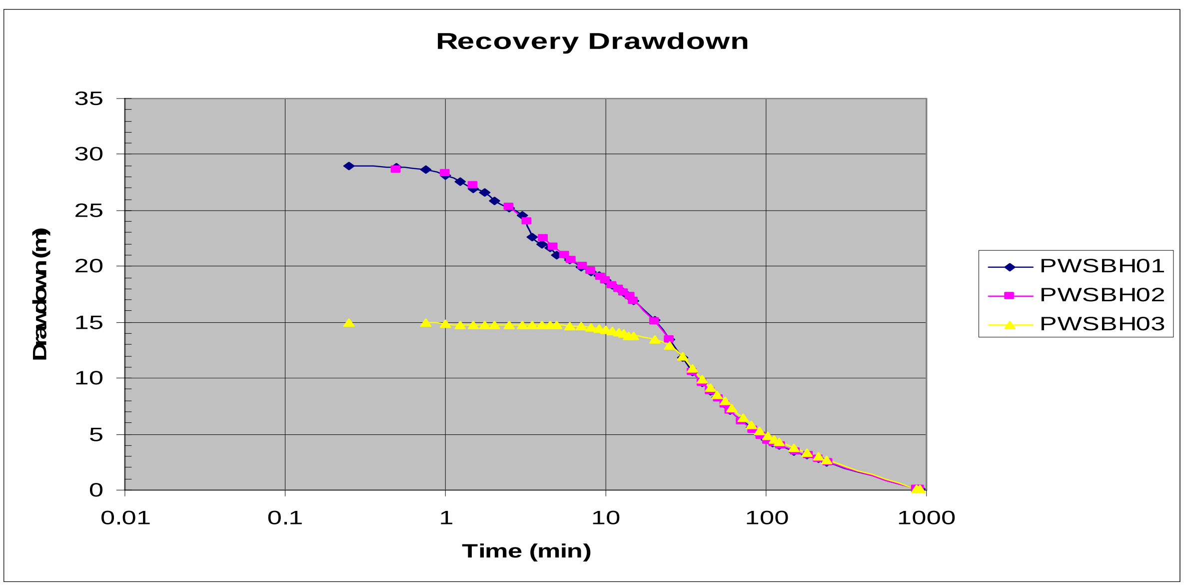

Figure A2.1a Graph of Recovery Test Drawdown versus Time

The pump test data were analysed using the Ramey and Gringarten curve matching procedure for determining transmissivity of an aquifer intersected by a plane vertical fracture of finite length, infinite transmissivity and with a monitoring point located outside the fracture in the body of the aquifer. The analysis was executed for a scenario with the pumping well at the fracture midpoint and the observation well on a perpendicular from the mid-point of the fracture / pumping well. As discussed above, the observation well PWSBH03 was not fully independent of the fault zone. As such, the analysis is likely to overestimate the transmissivity of the aquifer. The procedure also provides an estimate of the length of the fracture, however in practice the results are found to significantly underestimate the real length of the fractures / fault zones tested (Kruseman & DeRidder, 1990). The curve matching procedure was carried out manually and estimated the aquifer transmissivity and storativity at 11.6 m^2/day and 1.14E-04 respectively. The length of the fault zone was estimated at 32 m, which is considered to be a significant underestimate.

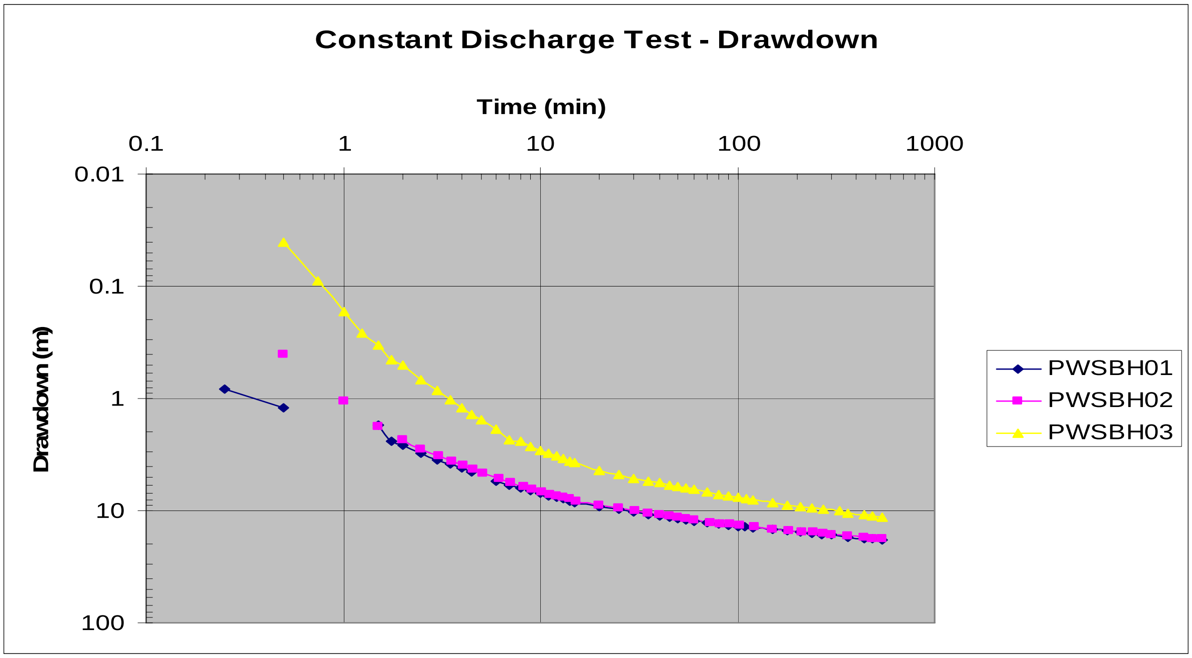

Figure A2.1b Graph of Constant Discharge Test Drawdown versus Time

Scarriff PWS - Borehole PWSBH01 Constant Discharge Test Data

	Water Level								Drawdown			Discharge						
Time	mb datum	Time				mb datum	Time		m			Time	Flow Meter					
min	**PWSBH01**	min	sec		min	**PWSBH02**	min	**PWSBH03**	**PWSBH01**	**PWSBH02**	**PWSBH03**	min	Gallons	Litres	Volume (l)	**rate (l/s)**	sec/10 gal	**l/sec**
0	8.58	0			0.00	8.39	0	8.88	0	0	0	1	6764940	30442230			10.2	4.4
0.25	9.4	0.25			0.25		0.25	8.88	0.82		0	2	6765020	30442590	360	6.0	10.2	4.4
0.5	9.8	0.5			0.50	8.8	0.5	8.92	1.22	0.41	0.04	3	6765080	30442860	270	4.5	9.8	4.6
0.75		0.75			0.75		0.75	8.97			0.09	4	6765140	30443130	270	4.5	10.8	4.2
1		1			1.00	9.44	1	9.05		1.05	0.17	5	6765190	30443355	225	3.8	10.5	4.3
1.25		1.25			1.25		1.25	9.14			0.26	6	6765240	30443580	225	3.8	10.6	4.2
1.5	10.3	1.5			1.50	10.15	1.5	9.21	1.72	1.76	0.33	7	6765300	30443850	270	4.5	10.6	4.2
1.75	10.97	1.75			1.75		1.75	9.33	2.39		0.45	8	6765360	30444120	270	4.5	10.6	4.2
2	11.2	2			2.00	10.7	2	9.39	2.62	2.31	0.51	9	6765410	30444345	225	3.8	10.4	4.3
2.5	11.65	2.5			2.50	11.22	2.5	9.57	3.07	2.83	0.69	10	6765470	30444615	270	4.5	10.3	4.4
3	12.1	3	4	0.06667	3.07	11.67	3	9.735	3.52	3.28	0.855	11	6765520	30444840	225	3.8	10.8	4.2
3.5	12.45	3	34	0.56667	3.57	12	3.5	9.92	3.87	3.61	1.04	12	6765580	30445110	270	4.5	10.7	4.2
4	12.72	4	5	0.08333	4.08	12.36	4	10.1	4.14	3.97	1.22	13	6765640	30445380	270	4.5	10.8	4.2
4.5	13.11	4	35	0.58333	4.58	12.66	4.5	10.26	4.53	4.27	1.38	14	6765690	30445605	225	3.8	10.7	4.2
5		5	6	0.1	5.10	12.99	5	10.44		4.6	1.56	15	6765750	30445875	270	4.5	10.7	4.2
6	14.01	6	11	0.18333	6.18	13.58	6	10.74	5.43	5.19	1.86	20	6766030	30447135	1260	4.2	10.9	4.1
7	14.46	7	6	0.1	7.10	13.99	7	11.2	5.88	5.6	2.32	25	6766300	30448350	1215	4.1	11	4.1
8	14.9	8	11	0.18333	8.18	14.49	8	11.3	6.32	6.1	2.42	30	6766570	30449565	1215	4.1	11.1	4.1
9	15.29	9	9	0.15	9.15	14.88	9	11.54	6.71	6.49	2.66	35	6766840	30450780	1215	4.1	11	4.1
10	15.63	10	9	0.15	10.15	15.21	10	11.76	7.05	6.82	2.88	40	6767120	30452040	1260	4.2	11.1	4.1
11	15.94	11	19	0.31667	11.32	15.57	11	11.97	7.36	7.18	3.09	46	6767420	30453390	1350	4.1	11	4.1
12	16.22	12	12	0.2	12.20	15.82	12	12.165	7.64	7.43	3.285	50	6767660	30454470	1080	4.0	11	4.1
13	16.49	13	7	0.11667	13.12	16.06	13	12.315	7.91	7.67	3.435	55	6767950	30455775	1305	4.4	10.9	4.1
14	16.75	14	8	0.13333	14.13	16.31	14	12.48	8.17	7.92	3.6	60	6768220	30456990	1215	4.1	11	4.1
15	16.96	15	8	0.13333	15.13	16.54	15	12.625	8.38	8.15	3.745	83	6769508	30462786	5796	4.2	10.71	4.2
20	17.83	20	5	0.08333	20.08	17.4	20	13.27	9.25	9.01	4.39	114	6771215	30470467.5	7682	4.2	10.84	4.2
25	18.42	25	5	0.08333	25.08	17.98	25	13.705	9.84	9.59	4.825	125	6771859	30473365.5	2898	4.3	10.78	4.2
30	18.96	30	13	0.21667	30.22	18.5	30	14.03	10.38	10.11	5.15	153	6773375	30480187.5	6822	4.1	11.01	4.1
35	19.36	35	2	0.03333	35.03	18.92	35	14.305	10.78	10.53	5.425	184	6775508	30489786	9599	5.1	10.89	4.1
40	19.74	40	5	0.08333	40.08	19.3	40	14.55	11.16	10.91	5.67	213	6776699	30495145.5	5360	3.1	11.01	4.1
45.5	20.12	45	40	0.66667	45.67	19.67	45.5	14.78	11.54	11.28	5.9	243	6778343	30502543.5	7398	4.1	10.96	4.1
50	20.39	50	12	0.2	50.20	19.95	50	14.985	11.81	11.56	6.105	273	6780001	30510004.5	7461	4.1	10.8	4.2
55	20.69	55	1	0.01667	55.02	20.23	55	15.205	12.11	11.84	6.325	303	6781649	30517420.5	7416	4.1	10.98	4.1
60	20.99	60	3	0.05	60.05	20.53	60	15.395	12.41	12.14	6.515	363	6784930	30532185	14765	4.1	11.01	4.1
70.1167	21.47	72	38	0.63333	72.63	21.12	70.41667	15.78	12.89	12.73	6.9	445	6789397	30552286.5	20102	4.1	10.9	4.1
80	21.87	81	45	0.75	81.75	21.43	80.75	16.04	13.29	13.04	7.16	483	6791500	30561750	9464	4.1	11	4.1
90	22.12	91	25	0.41667	91.42	21.7	90.5	16.255	13.54	13.31	7.375	545	6794881	30576964.5	15215	4.1	10.97	4.1
100.75	22.39	102	15	0.25	102.25	21.98	101.3333	16.47	13.81	13.59	7.59	603	6798021	30591094.5	14130	4.1	11.01	4.1
110	22.595	110		0	110.00		110.8333	16.66	14.015		7.78					**4.2**	**l/s**	**4.2**
120	22.8	121	30	0.5	121.50	22.38	120.5	16.83	14.22	13.99	7.95					**363.3**	**m3/day**	
150.167	23.36	151	39	0.65	151.65	22.93	150.75	17.365	14.78	14.54	8.485							
180	23.79	181	40	0.66667	181.67	23.36	180.5	17.845	15.21	14.97	8.965							
210	24.155	211	55	0.91667	211.92	23.72	210.6667	18.17	15.575	15.33	9.29							
240	24.38	241	55	0.91667	241.92	23.96	240.6667	18.41	15.8	15.57	9.53							
270	24.835	272	0	0	272.00	24.41	270.9167	18.65	16.255	16.02	9.77							
300	25.16	301	45	0.75	301.75	24.73	330.8333	18.91	16.58	16.34	10.03							
360	25.655	361	45	0.75	361.75	25.22	360.75	19.31	17.075	16.83	10.43							
440.25	26.3	443	15	0.25	443.25	25.855	441.25	19.795	17.72	17.465	10.915							
480	26.5	481	45	0.75	481.75	26.05	480.75	19.99	17.92	17.66	11.11							
540	26.82	541	55	0.91667	541.92	26.37	540.6667	20.3	18.24	17.98	11.42							
600		600					600											

	Water Level								Drawdown			Discharge						
Time	mb datum	Time				mb datum	Time		m			Time	Flow Meter					
min	**PWSBH01**	min	sec		min	**PWSBH02**	min	**PWSBH03**	**PWSBH01**	**PWSBH02**	**PWSBH03**	min	Gallons	Litres	Volume (l)	**rate (l/s)**	sec/10 gal	**l/sec**
0	37.87	0			0.00	37.06	0	23.7	29.27	28.65	14.8							
0.25	37.6	0.25			0.25		0.25	23.86	29		14.96							
0.5	37.5	0.5			0.50	37.01	0.5		28.9	28.6								
0.75	37.2	0.75			0.75		0.75	23.86	28.6		14.96							
1	36.7	1			1.00	36.69	1	23.78	28.1	28.28	14.88							
1.25	36.2	1.25			1.25		1.25	23.7	27.6		14.8							
1.5	35.5	1.5			1.50	35.68	1.5	23.69	26.9	27.27	14.79							
1.75	35.2	1.75			1.75		1.75	23.64	26.6		14.74							
2	34.5	2			2.00		2	23.68	25.9		14.78							
2.5	33.8	2.5			2.50	33.71	2.5	23.68	25.2	25.3	14.78							
3	33.1	3	15	0.25	3.25	32.39	3	23.68	24.5	23.98	14.78							
3.5	31.2	3	30	0.5	3.50		3.5	23.67	22.6		14.77							
4	30.6	4	6	0.1	4.10	30.89	4	23.66	22	22.48	14.76							
4.5	30.2	4	45	0.75	4.75	30.13	4.5	23.65	21.6	21.72	14.75							
5	29.6	5	30	0.5	5.50	29.38	5	23.63	21	20.97	14.73							
6	29.2	6	5	0.08333	6.08	28.95	6	23.59	20.6	20.54	14.69							
7	28.55	7	8	0.13333	7.13	28.41	7	23.53	19.95	20	14.63							
8	28.1	8	5	0.08333	8.08	28	8	23.46	19.5	19.59	14.56							
9	27.74	9	15	0.25	9.25	27.48	9	23.38	19.14	19.07	14.48							
10	27.3	10	5	0.08333	10.08	27.12	10	23.27	18.7	18.71	14.37							
11	26.89	11	6	0.1	11.10	26.69	11	23.15	18.29	18.28	14.25							
12	26.58	12	4	0.06667	12.07	26.42	12	23.02	17.98	18.01	14.12							
13	26.27	13	5	0.08333	13.08	26.08	13	22.875	17.67	17.67	13.975							
14	25.94	14	7	0.11667	14.12	25.77	14	22.735	17.34	17.36	13.835							
15	25.56	15	5	0.08333	15.08	25.37	15	22.635	16.96	16.96	13.735							
20	23.78	20	20	0.33333	20.33	23.51	20	22.335	15.18	15.1	13.435							
25	22.05	25	5	0.08333	25.08	21.83	25	21.875	13.45	13.42	12.975							
30	20.4	30		0	30.00		30	20.85	11.8		11.95							
35	19.13	35	4	0.06667	35.07	18.94	35	19.78	10.53	10.53	10.88							
40	18.2	40	8	0.13333	40.13	17.98	40	18.78	9.6	9.57	9.88							
45.5	17.47	45	0	0	45.00	17.29	45.5	18.09	8.87	8.88	9.19							
50	16.84	50	4	0.06667	50.07	16.63	50	17.445	8.24	8.22	8.545							
55	16.24	55	11	0.18333	55.18	16.04	55	16.87	7.64	7.63	7.97							
60	15.76	60	15	0.25	60.25	15.55	61.11667	16.27	7.16	7.14	7.37							
70	14.84	70	33	0.55	70.55	14.6	72	15.335	6.24	6.19	6.435							
80	14.15	82	45	0.75	82.75	13.79	80.667	14.745	5.55	5.38	5.845							
90	13.55	92	15	0.25	92.25	13.26	90.91667	14.125	4.95	4.85	5.225							
100.167	13.14	102	40	0.66667	102.67	12.85	101.333	13.7	4.54	4.44	4.8							
110.417	12.84	112	30	0.5	112.50	12.61	111.25	13.43	4.24	4.2	4.53							
120.167	12.6	122	40	0.66667	122.67	12.35	121.25	13.18	4	3.94	4.28							
150	12.08	152	20	0.33333	152.33	11.85	150.8333	12.68	3.48	3.44	3.78							
180	11.7	182	20	0.33333	182.33	11.48	180.8333	12.28	3.1	3.07	3.38							
210	11.38	211	50	0.83333	211.83	11.16	210.8333	11.9	2.78	2.75	3							
240	11.115	242	0	0	242.00	10.92	240.75	11.62	2.515	2.51	2.72							
874	8.67	876			876.00	8.49	873	8.99	0.07	0.08	0.09							
900	8.6	900			900.00	8.41	900	8.9	0.1	0.1	0.1							