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**Geological Survey**  
Suirbhéireacht Gheolaíochta  
Ireland | Éireann

# Geological Survey Ireland

**Establishment of Groundwater Zones of Contribution**

**Bullaun Group Water Scheme, Co. Galway**

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## Project description

Since the 1980s, 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 'Zone of Contribution' (ZOC) 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.

This report has been prepared for the Bullaun Group Water Scheme as part of the Rural Water Programme funding initiative of grants towards specific source protection works on Group Water Schemes (DECLG Circular L5/13 and Explanatory Memorandum).

The report has been prepared in the format developed during an earlier pilot project "Establishment of Zones of Contribution" which was undertaken by the Geological Survey of Ireland (GSI), in collaboration with the National Federation of Group Water Schemes (NFGWS), and with support from the National Rural Water Services Committee (NRWSC).

The methodology undertaken by the GSI included: liaising with the GWS and NFGWS to facilitate data collection, a desk study, a site visit to inspect the supply, the local area, and to record groundwater level(s). The data was then analysed and interpreted in order to delineate the ZOC.

The maps produced are based largely on the readily available information in the area, a field walkover survey, 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.

The report and maps are hosted on the GSI website ([www.gsi.ie](http://www.gsi.ie)). A glossary of acronyms and terms used in this report is included in the Appendices.



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## 1. Overview: Groundwater, groundwater protection and groundwater supplies

Groundwater is an important natural resource in Ireland. It originates from rainfall that soaks into the ground. If the ground is permeable, the rainfall will filter down until it reaches the main body of groundwater, which is usually within either the bedrock, or a sand/gravel deposit. If the bedrock or sand/gravel deposit can hold enough groundwater and allow enough flow to supply a useful abstraction, it is referred to as an aquifer.

In Irish bedrock aquifers, groundwater predominantly flows through interconnected fractures, fissures, joints and bedding planes, which can be envisaged as a 'pipe network', of various sizes, with varying degrees of interconnectivity. The speed of flow through this network is relatively fast, delivering groundwater, and a large proportion of the contaminants present in the groundwater, to its destination e.g. borehole, spring, river and sea.

In sand/gravel aquifers, the groundwater flows in the interconnected pore spaces between the sand/gravel grains. Generally, this is equivalent to a filter system that may physically filter out contaminants to varying degrees, depending on the nature of the spaces and grains. It also slows down the speed of flow giving more time for pathogens to die off before they reach their destination e.g., borehole, spring, river and sea.

Further filtration of contaminants may occur where the aquifers are protected by the overlying soil and subsoil; thick, impermeable clay soil and subsoil provide good protection while thin gravel will provide limited protection. Variation in subsoil type and thickness, is therefore, important when characterising the 'vulnerability' of groundwater to contamination.

The karst limestone aquifers provide significant and important groundwater supplies in Ireland. Karst landscapes develop in rocks that are readily dissolved by water e.g., limestone (composed of calcium carbonate). Consequently, conduit, fissure and cave systems develop underground.<sup>1</sup> Groundwater typically travels very fast in karst aquifers, which has a significant impact on the water quality; neither filtration nor pathogen die-off are associated with these aquifers.

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<sup>1</sup> Geological Survey of Ireland, 2000.



The interaction between abstraction and geology is shown in **Diagram 1**. In this scenario, a borehole is pumping groundwater from the bedrock aquifer. As the water is abstracted through the well, the original water table (a) is drawn down to level (b), where it induces a drawdown curve of the natural water table (c). The shape of this curve depends on the properties of the aquifer, for example, if the borehole is intersecting an aquifer with few fractures that are poorly interconnected, the groundwater from that system will soon be exhausted, and therefore the pumping will have to pull from deeper depths to maintain supply, which results in the steep, deep drawdown curve. Alternatively, if the borehole is intersecting an aquifer with a large number of well-connected groundwater-filled fractures, the abstraction will be met by pulling water from farther away, at a shallower depth, resulting in a shallow, wide drawdown curve.

By knowing the rate of abstraction (output), how much rainfall there is (input), and by assessing the geological elements outlined above (nature of the bedrock fractures or sand/gravel deposit; how permeable the soil and subsoil are) to determine what happens in between input and output, the catchment area, or 'Zone of Contribution' (ZOC), to any groundwater water supply can be determined.

**Bullaun GWS (G050) is supplied by groundwater that flows to boreholes through the upper weathered zone and deeper fractures/fissures in a locally important pure unbedded limestone aquifer. The GWS abstracts an average of 138 m<sup>3</sup>/d.**



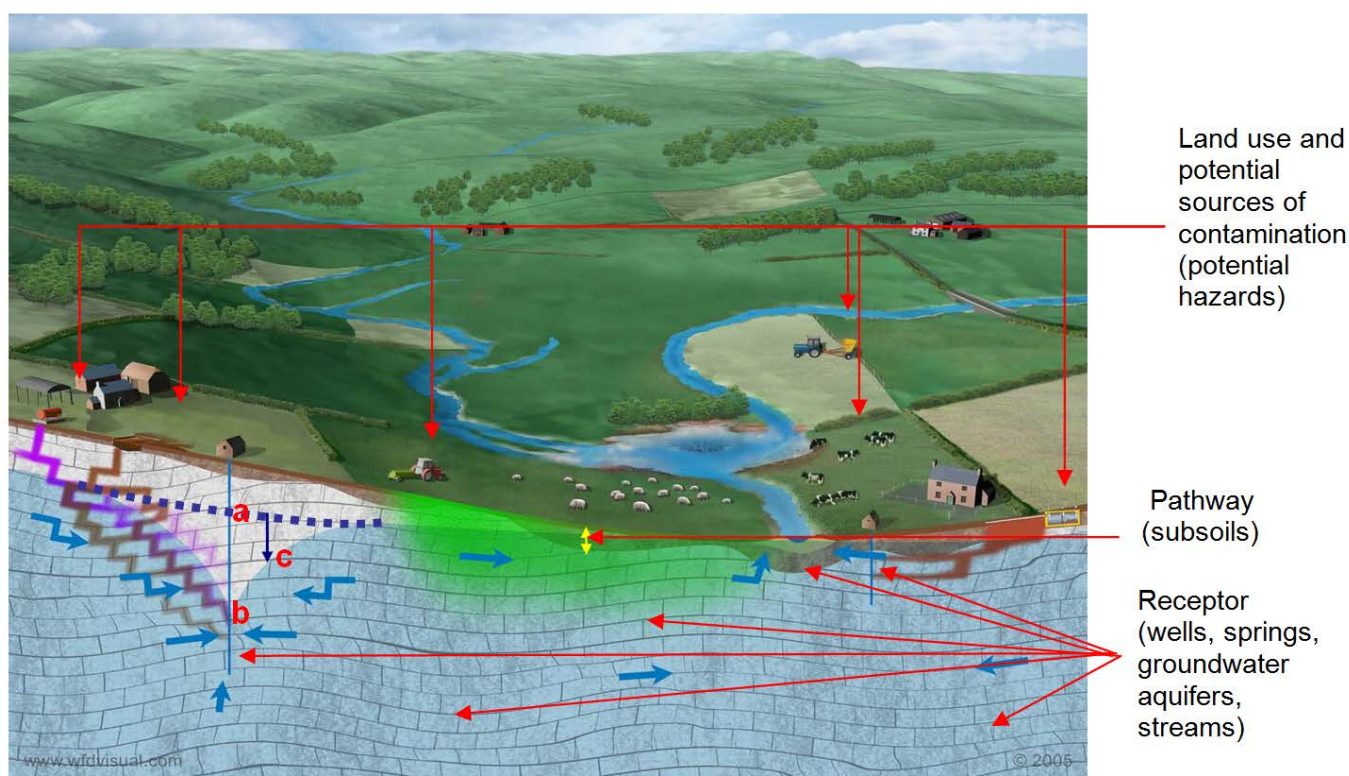


**Diagram 1. Rural Landscape highlighting the Interaction between Surface Water, Groundwater and Potential Hazards**

## 2. Location, Site Description, Supply Details and Wellhead Protection

The zone of contribution (ZOC) for the Bullaun Group Water Scheme (GWS) has been delineated according to the principles and methodologies set out in 'Groundwater Protection Schemes'<sup>2</sup> and in the GSI/EPA/IGI Training course on Groundwater SPZ Delineation.

Bullaun GWS is supplied from a borehole located in Kanargad townland, approximately 4 km north of Loughrea, Co. Galway (See **Figure 1**). The scheme comprises a supply (BH2) and a backup borehole (BH1), which are located within 10 m of the R350 road, on the east and west sides respectively (See **Diagram 2** and **Photos**, below) BH 1 is the original GWS borehole, which now serves as a backup. The supply is now taken from the newer BH 2, which has better raw water quality, due to better borehole construction. BH1 is in a locked, fenced, paved compound adjacent to the water treatment plant compound (See **Photos**, below). BH2 is in a partially below-ground chamber in the garden of a private house (See **Photos** below). There are security gates and fencing around this property.

<sup>2</sup> DELG/EPA/GSI, 1999

The scheme serves 204 connections. These connections comprise 135 house only, 56 house and business/land, 7 land only and 6 other (school, community etc.).

Average usage over the year in 2016-2017 was 138 m<sup>3</sup>/day. The abstraction rate is somewhat variable, at a minimum of 92 m<sup>3</sup>/day recorded in September 2016 and maximum of 188 m<sup>3</sup>/day recorded in April 2017 by the DBO Operator, Glan Agua Ltd.

During 2009 – 2010, 7.5 km of network was upgraded and in 2011 the network was metered under the DBO contractor. The metering resulted in detection and fixing of numerous leaks. The average annual usage has been consistent since early 2011. Before 2011, usage was approximately 50% greater.

BH2 is pumped at a rate of approximately 14 m<sup>3</sup>/hr for a period of 10 hours from midnight, through the water treatment system, to a treated water reservoir which is located beside the water treatment plant. Water level drawdown in BH 2 in response to pumping is significant, with a rapid decrease in water level of c. 75 m recorded within the first hour of pumping. Pumping water level stabilises at this level and rebounds almost immediately when the pump stops. The treatment system has a design flow of 480 m<sup>3</sup>/day. Flow from the treated water reservoir, in the network, is pumped.

The treatment system comprises a pre-chlorination, sand filter, ultra violet disinfection and residual chlorine disinfection.

Summary borehole details are presented in **Table 1**.



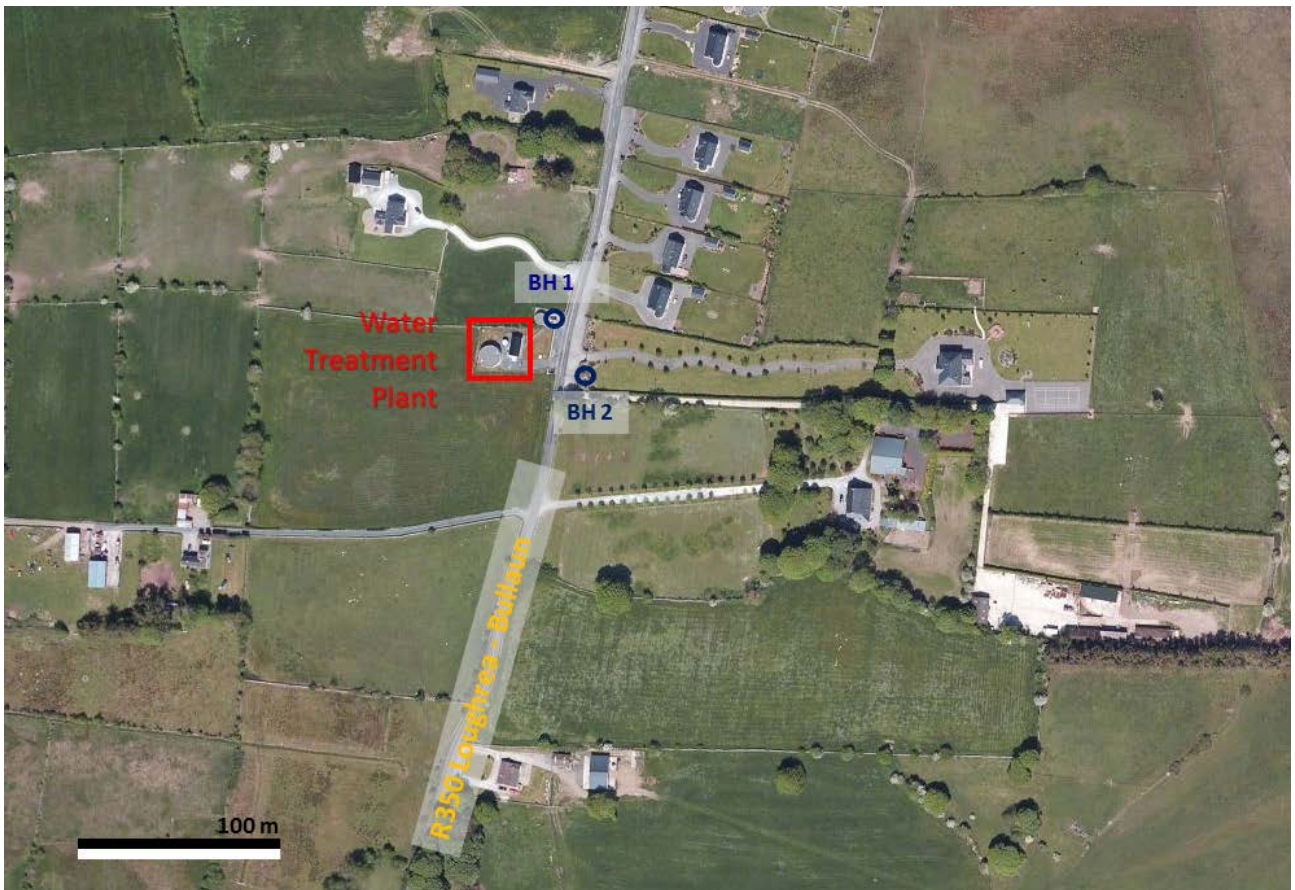


Diagram 2. Aerial Photo of Site



**Photo 1.** BH 1 pump chamber



**Photo 2.** BH 1 headworks in pump chamber



**Photo 3.** BH 2 pump chamber

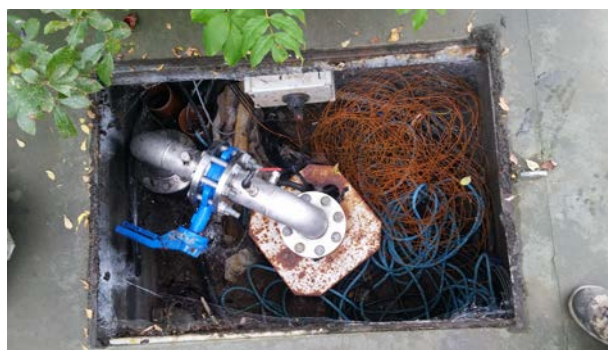


**Photo 4.** BH 2 headworks in pump chamber



**Photo 5.** BH 2 and adjacent houses.



**Photo 6.** Road and houses adjacent BH 2

**Table 1. Water Supply Details**

| NFGWS No. G050                                                            | BH 1 (Backup)                                                                                                                                                                                         | BH 2 (Supply)                                                                                                                                                                                                                                                                                                                                                                                                                           |
|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Grid reference                                                            | ITM: 562943, 720841                                                                                                                                                                                   | ITM: 562933, 720,878                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Townland                                                                  | Kanargad                                                                                                                                                                                              | Kanargad                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Source type                                                               | Borehole                                                                                                                                                                                              | Borehole                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Drilled                                                                   | 1983 (by Local Authority)                                                                                                                                                                             | c. 1980                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Drilling Contractor                                                       | Unknown                                                                                                                                                                                               | Unknown                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Owner                                                                     | Bullaun GWS.<br>Glan Agua Ltd. DBO Operator (2011-current)                                                                                                                                            | Bullaun GWS<br>Glan Agua Ltd. DBO Operator (2011-current)                                                                                                                                                                                                                                                                                                                                                                               |
| Elevation in metres above Ordnance Datum                                  | c. 70 (Estimated from OSI 1:2,000 Scale Map)                                                                                                                                                          | c. 70 (Estimated from OSI 1:2,000 Scale Map)                                                                                                                                                                                                                                                                                                                                                                                            |
| Total depth (m)                                                           | ~58 m (190 ft)                                                                                                                                                                                        | 109.7 m                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Construction details                                                      | <p>No borehole construction details available.</p> <p>Headworks enclosed in chamber 0.80 m a.g.l., with locked lid and watertight chamber.</p> <p>Top of casing at 0.03 m a.g.l.</p> <p>Dip tube.</p> | <p>300 mm outer steel casing installed to 6 m depth.</p> <p>200 mm inner liner and screen installed to 110 m.</p> <p>Borehole grouted and sealed from ground level to 57 m (Hydro-G, 2011 data compiled from Glan Agua Ltd.)</p> <p>Headworks enclosed in chamber 0.45 m a.g.l. and 0.47 m b.g.l. with locked chamber lid, chamber partially watertight.</p> <p>Top of casing at 0.24 m b.g.l.</p> <p>Dip tube (partially obscured)</p> |
| Depth to rock in metres below ground level                                | Unknown                                                                                                                                                                                               | Assumed c. 6 m to competent bedrock based on steel casing depth                                                                                                                                                                                                                                                                                                                                                                         |
| Inflow zones (water strikes) (m b.g.l.)                                   | Approximately 55                                                                                                                                                                                      | 55 and 85 (Bullaun GWS Committee)                                                                                                                                                                                                                                                                                                                                                                                                       |
| Static water level (SWL) (m bgl) (4/9/2017)                               | 4.55 m b.g.l (~62.45 m O.D.)                                                                                                                                                                          | 4.76 m b.g.l. (~63.24. O.D.)                                                                                                                                                                                                                                                                                                                                                                                                            |
| Pumping water level (PWL) (m bgl) (Hydro-G, 2011. See <b>Appendix 4</b> ) | Unknown                                                                                                                                                                                               | ~ 79 m b.g.l. (1- 17/11/2011)                                                                                                                                                                                                                                                                                                                                                                                                           |
| Pump intake depth (m bgl)                                                 | ~55 (180 ft)                                                                                                                                                                                          | 85 (1/11/2011). May subsequently have been lowered on Hydro-G (2011) advice.                                                                                                                                                                                                                                                                                                                                                            |
| Current abstraction rate (m <sup>3</sup> /day)                            | 0                                                                                                                                                                                                     | 138 (average June 2016-2017, recorded by DBO operator).                                                                                                                                                                                                                                                                                                                                                                                 |
| Number of Connections                                                     | N/A                                                                                                                                                                                                   | 204                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Reported yield (m <sup>3</sup> /d)                                        | 140 (Maximum abstraction achieved)                                                                                                                                                                    | 454 (Estimated by driller)                                                                                                                                                                                                                                                                                                                                                                                                              |
| Specific Capacity (m <sup>3</sup> /d/m)                                   | Not available                                                                                                                                                                                         | Not available                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Transmissivity (m <sup>2</sup> /d) (Estimated from constructed BH2- only) | Not available                                                                                                                                                                                         | 9                                                                                                                                                                                                                                                                                                                                                                                                                                       |



### 3. Physical Characteristics and Hydrogeological Considerations

#### 3.1 Physical characteristics of the area

An overview of the relevant information on rainfall, land use, topography, hydrology and geology for the area around the GWS is provided in **Table 2**.

**Table 2. Physical Characteristics of the Area of Interest**

|                                                                                                                   | GWS Well                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Description/Comments                                                                                                                                                                                                                                                                                                                                                                                  |
|-------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Topography<br>(Figure 1 & Figure 2)                                                                               | The borehole is located in a lowland area, at a height of c.70 m. The land rises southwards towards a local high of 80 m 1 km to the south. Uplands with a maximum height of 130 m occur approximately 5 km to the south and south east.                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                       |
| Land use                                                                                                          | The land use is predominantly cattle grazing, with associated silage cutting. There is significant ribbon development along the R350 road and its side roads, comprising un-sewered one-off dwellings and also farmyards.                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                       |
| Surface Hydrology<br>(Figure 1 & Figure 2)                                                                        | The boreholes are in the catchment of the Craughwell river, which drains westwards into the Dunkellin river, discharging to the sea Galway bay. They are located 500 m south of the closest tributary of the Craughwell- river. A number of springs occur in the area and are sources of drains and permanent watercourses which drain towards that tributary.                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                       |
| Topsoil<br><a href="http://gis.epa.ie/envision">http://gis.epa.ie/envision</a>                                    | The soils surrounding, to the west and immediate north west of the borehole are well drained. They surround pockets of shallow well drained soils, adjacent to where rock is at surface. To the east and south there are poorly drained soils.                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                       |
| Subsoil (Figure 3)<br><a href="http://www.gsi.ie/mapping">www.gsi.ie/mapping</a>                                  | The subsoils are dominated by moderately permeable glacial till (boulder clay) derived chiefly from limestone, surrounding small areas of bedrock exposed at the surface. The till transitions to low permeability peat in the lowest parts of the landscape farther east.                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                       |
| Groundwater Vulnerability<br>(Figure 4)<br><a href="http://www.gsi.ie/mapping">www.gsi.ie/mapping</a>             | Vulnerability is predominantly high, surrounding small areas of extreme (E) and extreme – rock near surface (X). Moderate and low vulnerability occur further to the east (See <b>Appendix 1</b> ).                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                       |
| Geology (Figure 5)<br><a href="http://www.gsi.ie/mapping">www.gsi.ie/mapping</a><br>(Gatley <i>et al</i> , 2005). | The bedrock surrounding the boreholes is Waulsortian massive unbedded lime mudstone. c. 500 m north, this is overlain by/interfingers with the Lucan formation dark limestone and shales, which are classified as the Dinantian Upper Impure Limestone rock unit group. The exact location of the bedrock boundaries in this area is uncertain. Approx. 1 km east of the boreholes, the Lucan formation is brought into contact with the Waulsortian by faulting of the bedrock, along which bedrock movement has occurred. |                                                                                                                                                                                                                                                                                                                                                                                                       |
| Aquifer Classification<br>(Figure 6)<br><a href="http://www.gsi.ie/mapping">www.gsi.ie/mapping</a>                | Both bedrock types are classified as Locally Important Aquifer – Bedrock which is Moderately Productive only in Local Zones (LI)                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                       |
| Groundwater Body (GWB)<br><a href="http://www.wfdireland.ie/maps">www.wfdireland.ie/maps</a>                      | The borehole is located in the GWDTE-Rahasane Turlough (SAC000322) GWB. The part of the waterbody surrounding the boreholes is categorised as ‘strongly expected to achieve good status’. Areas at risk of not achieving ‘good’ surround this.                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                       |
| Recharge Coefficient (%)<br>(Appendix 2)                                                                          | 22.5% – 60% (85% in small pockets)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Low recharge amounts (mm/yr) occur due to the presence of wet soils and due to limited recharge acceptance capacity caused by the LI bedrock aquifer.<br><br>Recharge amounts are highest on pockets of X and E vulnerability. Recharge acceptance capacity of the bedrock aquifer may be increased above 200 mm in a zone around the fault, increasing recharge amounts where soils are dry or thin. |
| Recharge (mm/yr)<br><a href="http://www.gsi.ie/mapping">www.gsi.ie/mapping</a>                                    | 163 - 200 mm/yr                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                       |



### 3.2 Hydrochemistry and water quality

GWS rural monitoring data (November 2000 – November 2001), DBO Operator check monitoring results (June 2016 – May 2017) and a full suite of groundwater analysis (24/7/2017) were used to assess the raw water hydrochemistry and water quality for Bullaun GWS. These water quality data are presented in **Appendix 3**.

The data for untreated (raw) water samples are summarised in **Table 3** and **Table 4**, where they have been compared to the drinking water limits (DWL) from the Drinking Water Regulations (S.I. No. 122 of 2014) and/or threshold values (TV) from the European Communities Environmental Objectives (Groundwater) Regulations 2010 (S.I. No. 9 of 2010). The treated water compliance with required parameter values was identified from Monthly Status Reports produced by the DBO operator.

**Table 3. BH 1 (Backup)<sup>3</sup> Key Hydrochemistry and Water Quality values in untreated water samples**

| Parameter                                        | No. of samples | Min                                                                                      | Max         | Average                                                    | Drinking Water Limit (DWL) or Threshold Value (TV) |
|--------------------------------------------------|----------------|------------------------------------------------------------------------------------------|-------------|------------------------------------------------------------|----------------------------------------------------|
| Total Hardness (mg/l as CaCO <sub>3</sub> )      | 1              | 407                                                                                      | 407         | n/a                                                        | [-]                                                |
| Electrical Conductivity (µS/cm) (laboratory)     | 11             | 644                                                                                      | <b>802</b>  | 723                                                        | 800 (TV), 2,500 (DWL)                              |
| Total Coliforms (MPN/100 ml)                     | 11             | 0                                                                                        | <b>38</b>   | 5 exceedances (<100 counts)<br>0 exceedances (>100 counts) | 0 (DWL)                                            |
| Faecal Coliforms ( <i>E. Coli</i> ) (MPN/100 ml) | 11             | 0                                                                                        | <1          | 0 exceedances (<100 counts)<br>0 exceedances (>100 counts) | 0 (DWL)                                            |
| Clostridium Perfringens (cfu/100 ml)             | 1              | Data acquired for this study (2017) were not reliable and are not included in the table. |             |                                                            | 0 (DWL)                                            |
| Nitrate (mg/l NO <sub>3</sub> )                  | 11             | 0.44                                                                                     | 4.87        | 2.45                                                       | 50 (DWL), 37.5 (TV)                                |
| Chloride (mg/l)                                  | 1              | <b>24.5</b>                                                                              | <b>24.5</b> | n/a                                                        | 250 (DWL), 24 (TV)                                 |
| Ammonium (mg/l NH <sub>4</sub> )                 | 11             | 0.12                                                                                     | <b>2.44</b> | <b>0.45</b>                                                | 0.3 (DWL), 0.225 (TV)                              |
| Iron (µg/l)                                      | 11             | 30                                                                                       | 112         | 60                                                         | 200 (DWL)                                          |
| Manganese (µg/l)                                 | 11             | <6                                                                                       | 45          | 21                                                         | 50 (DWL)                                           |
| Potassium:sodium ratio                           | 1              | 0.1                                                                                      | 0.1         | n/a                                                        | 0.4 (indicator)                                    |

<sup>3</sup> Pers comm from committee: data are raw water samples from the BH at the treatment plant (i.e. BH1)



**Table 4. BH 2 (Supply) Key Hydrochemistry and Water Quality values in untreated water samples**

| Parameter                                        | No. of samples | Min                                                                                      | Max           | Average | Drinking Water Limit (DWL) or Threshold Value (TV) |
|--------------------------------------------------|----------------|------------------------------------------------------------------------------------------|---------------|---------|----------------------------------------------------|
| Total Hardness (mg/l as CaCO <sub>3</sub> )      | 1              | 410                                                                                      | 410           | n/a     | [-]                                                |
| Electrical Conductivity (µS/cm) (laboratory)     | 1              | 707                                                                                      | 707           | n/a     | 800 (TV), 2,500 (DWL)                              |
| Total Coliforms (MPN <sup>4</sup> /100 ml)       | 1              | Data acquired for this study (2017) were not reliable and are not included in the table. |               |         | 0 (DWL)                                            |
| Faecal Coliforms ( <i>E. Coli</i> ) (MPN/100 ml) | 1              |                                                                                          |               |         | 0 (DWL)                                            |
| Clostridium Perfringens (cfu/100 ml)             | 1              |                                                                                          |               |         | 0 (DWL)                                            |
| Nitrate (mg/l NO <sub>3</sub> )                  | 1              | 4.22                                                                                     | 4.22          | n/a     | 50 (DWL) 37.5 (TV)                                 |
| Chloride (mg/l)                                  | 1              | <b>25.35</b>                                                                             | <b>25.35</b>  | n/a     | 250 (DWL), 24 (TV)                                 |
| Ammonium (mg/l NH <sub>4</sub> )                 | 1              | 0.05                                                                                     | 0.05          | n/a     | 0.3 (DWL), 0.225 (TV)                              |
| Iron (µg/l)                                      | 13             | 11.2                                                                                     | <b>276.36</b> | 88      | 200 (DWL)                                          |
| Manganese (µg/l)                                 | 13             | 1.2                                                                                      | 20.19         | 12      | 50 (DWL)                                           |
| Potassium:sodium ratio                           | 1              | 0.11                                                                                     | 0.11          | n/a     | 0.4 (indicator)                                    |

#### **Hardness, alkalinity, electrical conductivity and groundwater signature:**

Groundwater from boreholes BH2 (supply borehole) and BH1 (back-up borehole) has a calcium bicarbonate hydrochemical signature. Water hardness and alkalinity are very high, which is typical of groundwater from pure limestones. Electrical conductivity is high. Data for BH1 show that it is variable, and exceeds the threshold value (TV) on one occasion.

#### **Turbidity:**

In BH1, turbidity is variable in the 2000-2001 sampling period, from <0.01 NTU up to a very high 46 NTU. It ranged from <0.25 to 7.21 NTU in BH2 in 2016-2017.

#### **Iron and manganese<sup>5</sup>:**

BH 2 (supply borehole) manganese levels are variable and below the drinking water limit (DWL). Iron levels are similarly variable and exceed the DWL in only one sample. The levels are consistent

<sup>4</sup> MPN is most probable number

<sup>5</sup> Iron and manganese concentrations for BH1 from the 2017 sampling round were not included, as they were from a borehole that was not continuously pumped and are not considered representative.



with the natural hydrochemistry of the groundwater. In the samples from Bullaun, increased levels of the parameters are, in part, associated with slightly increased aluminium and turbidity, suggesting they are associated with mobilisation of sediments with the fracture/fissure system, which is then captured in the samples taken for analysis. This is potentially caused by the pumping regime. BH 1 (backup) iron levels are less variable and lower than BH 2. Manganese in BH1 is slightly higher than BH2 but does not exceed the DWL.

#### **Microbiological parameters:**

BH 1 Microbiological parameters were sampled monthly during 2000 -2001. 45% of samples exceed the DWL for total coliforms. E. Coli were below the drinking water limits in all samples. Microbiological sampling on Bullaun was found to be unreliable, as was the single *Cryptosporidium parfringens* result for BH1. These data are not reported here.

#### **Ammonium and nitrate:**

In BH2, Ammonium and nitrate levels from the single sample are low and below their respective threshold (TV) and drinking water limits (DWL). It should be noted that this is snapshot of the groundwater chemistry. Ammonium levels in BH 1 are higher and exceed the TV in 4/10 samples and the DWL in 2/10 samples. Nitrate levels are low, and well below their TV and DWL. Ammonia has a low mobility in soil and subsoil and its presence at concentrations greater than 0.1 mg/l in groundwater indicates a nearby waste source. Low nitrates in this area are probably reflective of relatively low-intensity farming, and plentiful rainfall (dilution), rather than deoxygenation.

#### **Chloride:**

Chloride in both boreholes slightly exceeds the threshold value (TV) of 24 mg/l. Chloride is a constituent of organic wastes, such as septic effluent, but can also come from road salts or inorganic fertilisers.

The combination and pattern of parameter exceedances in BH 1 indicate that groundwater abstracted from BH 1 has been impacted by organic pollutant sources, in part local to the borehole. There are insufficient data (ammonia, microbiological data) to determine whether this type of pollution is significantly impacting the supply borehole, BH2.



Organic pollutants in rural environments predominantly result from animal and human wastes such as from slurry, on site waste water treatment systems (including septic tanks), farmyard manures, silage clamps/bales and yard run-off.

The two boreholes are constructed differently and result in different inflow zones contributing to the sampled water. BH1 (the original, now back-up borehole) appears to allow shallow groundwater flow into the borehole, as well as flow from a deeper fracture/fissure at 55 m b.g.l. BH 2 excludes water from above 57 m depth b.g.l., thus receiving water only from a deep (85 m b.g.l.) fracture/fissure.

There are not enough data to verify that shallow (potentially more polluted groundwater) is being excluded from BH2, although the 2017 sampling didn't indicate that it is taking place. The single chloride value from BH2 does indicate, however, that the groundwater is impacted by human activities. Chloride can arise from inorganic fertiliser, road salts, or silage percolating down to the water table. Chloride is conservative (it doesn't bond to soils or rock), so its presence doesn't mean that bacterial contamination can occur, just that human activities have had an impact.

Compliance of treated water with appropriate standards was reviewed in DBO Operator Monthly Status Reports from 2011 to 2017. Treated water quality of the standard specified in the DBO contract has consistently been achieved at the treatment plant from 2011 to 2017.

The analysis of a full groundwater suite of parameters in BH2, undertaken in 2017 as part of this study, did not show any other naturally-occurring elements dissolved into the groundwater at concentrations that would cause concern for human health.



## 4 Zone of Contribution

### 4.1 Conceptual Model

The current understanding of the geological and hydrogeological setting is given as follows and as shown schematically in **Diagram 3**.

A zone of contribution has been delineated for the pair of boreholes, assuming that supply could come from either one.

High rainfall amounts fall across the area. Effective<sup>6</sup> rainfall becomes either surface water run-off or infiltrates through soil and subsoils to recharge the groundwater system. Recharge rates are currently mapped as low, but may be greater due to the proximity of a fault c 0.6 km to the east and south east of the boreholes. Faults are surrounded by zones of smaller fractures, which potentially increase the recharge acceptance capacity of the bedrock as well as increasing its ability to transmit groundwater. There is a relatively low density of surface water drainage. A spring is marked on the historic 6 inch map series as discharging c. 400 m south west of the boreholes, the flow from which appears to re-enter the groundwater system via a swallow hole direct recharge point a short distance away. A spring named Tobergradan and Tobernalacht is denoted on the historic 6 inch map series c. 200 m north north-east of the boreholes.

Groundwater flow in the pure unbedded Waulsortian limestone bedrock aquifer supplying the boreholes is in discrete openings in the rock, caused by weathering, fractures and/or fissures, rather than between the rock grains. Groundwater flow in the area of the boreholes is in a shallow, few metre thick, weathered zone at the top of the bedrock, and in two zones of fracturing. Mid-depth fracturing was encountered in boreholes at c. 55 m b.g.l. and deep fracturing at c. 85 m b.g.l. The fractures are probably enlarged by solution of the limestone to become fissures. Flow from the weathered zone and mid-depth fractures are intercepted in BH 1. Flow from these zones and a deeper one, were encountered during the drilling of BH2, but the groundwater flow from the weathered and mid-depth fractures were excluded from the borehole

---

<sup>6</sup> Effective rainfall is the proportion of rainfall which is not taken up by plants or evaporated and is the amount which is available for recharge of groundwater and surface water run-off.



by the design of its construction. Groundwater chemistry indicates that the deep fractures, and possibly also the mid-depth fractures, are not connected to the shallow weathered zone close to the boreholes. Groundwater flow into BH2 in the deep fractures is partially confined, which is to say, constrained within the fracture/fissure under a pressure head.

Regional groundwater flow direction follows the groundwater gradient, which largely coincident with the topographic gradient. Flow is therefore from the upland area to the southeast of the boreholes towards the tributary of the Craughwell river to the north. The groundwater that is not intercepted by the GWS boreholes will continue to flow northwestward. Groundwater (probably only from the shallow weathered zone) discharges as springs to the north of the boreholes, at the junction between the pure unbedded limestones and the upper impure limestones, as these latter rocks have lesser groundwater transmissivity. The fault and its associated fractures/fissures provide discrete pathways within which groundwater flows, while responding to the regional groundwater gradient.

Where the bedrock aquifer is overlain by thin or absent soils and subsoils, as occurs in pockets to the south east of the boreholes, groundwater vulnerability is classified as extreme. The area around any swallow hole will also have extreme vulnerability. Areas of high vulnerability dominate the areas, with some areas of moderate and low permeability occurring in the east and south east.



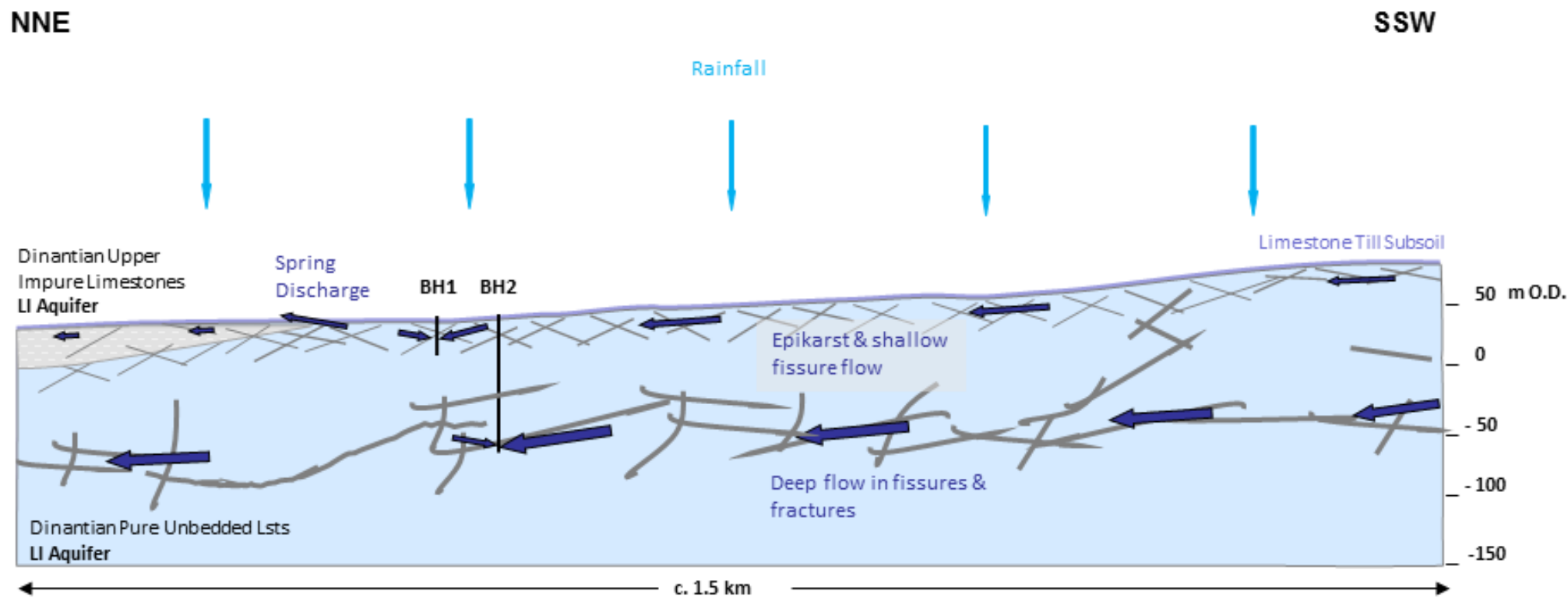


Diagram 3. Vertical cross-section showing conceptual model of groundwater flow

## 4.2 Boundaries

The Zone of Contribution (ZOC) delineated for Bullaun GWS is based mainly on a combination of hydrogeological mapping and inferences, and geological boundaries.

The **southern** boundary is a groundwater divide, which is assumed to correspond with the surface water divide. It has therefore been delineated based on topography and an assessment of groundwater flow directions.

The **western** and **eastern** boundaries are located along groundwater flow lines, interpreted from the assumed groundwater flow direction. The **western** flow line boundary has been extended westwards, beyond the flow line boundary to include the area contributing ground and surface water to a suspected swallow hole c. 400 m south west of the supply boreholes. A swallow hole represents a direct entry point for flow into the groundwater system.

The **south eastern** boundary is located along the north eastern – south west trending fault, with an additional buffer of 100 m, to allow for uncertainty in the location of the fault. This fault will act either as a barrier to groundwater flow or as a boundary along which groundwater flow is occurring.

The **northern** down-gradient boundary of 260 m arises from a 372 m down-gradient distance estimated using the Uniform Flow Equation. However, transmissivity values used in this equation are subject to significant uncertainty, due to the borehole construction and a naturally high variability in transmissivity in the Waulsortian pure unbedded rock unit. This downgradient distance is likely to be very conservative. (See **Appendix 4** Calculations). The distance has been constrained to 260 m by the presence of a spring groundwater discharge point.

## 4.3 Recharge and water balance

The recharge and water balance calculations are used to support the hydrogeological mapping and to confirm that the ZOC delineated is big enough to supply the quantity of water at the source.



The Zone of Contribution area of  $0.72 \text{ km}^2$ , which includes area for uncertainty in the fault position, in transmissivity and the suspected swallow hole, is more than sufficient to provide an average abstraction of  $210 \text{ m}^3/\text{day}$  at the boreholes.  $210 \text{ m}^3/\text{day}$  is the average daily abstraction rate plus 50%. The water balance calculation assumes that recharge occurs at a rate of 165 mm to 200 mm across the area of the ZOC. This latter figure is conservative and is likely to underestimate the amount of recharge available to supply the annual average borehole abstraction. The  $0.72 \text{ km}^2$  area of the ZOC defined in order to take account of a number of uncertainties is therefore larger than the actual area required to balance out abstraction (about  $0.45 \text{ km}^2$ ).

## 5. Conclusions

Bullaun GWS is currently supplied by a borehole (BH2) from which  $138 \text{ m}^3/\text{d}$  is pumped over a set 10 hour period. A second borehole (BH1), which previously provided the supply acts as a back-up and has a yield of approximately  $140 \text{ m}^3/\text{d}$ .

Effective rainfall recharges the groundwater diffusely across the area. Groundwater flow is in a shallow weathered zone, and in two fracture/fissure zones intercepted in boreholes at 55 m b.g.l. and 85 m b.g.l.. These fractures/fissures are likely to relate to a fracture zone surrounding a major fault c 0.6 km to the east and south-east of the boreholes.

The ZOC, which encompasses an area of  $0.72 \text{ km}^2$  is bounded by the fault zone, by the southern groundwater divide and by flow line boundaries, interpolated from groundwater flow directions. The flow line boundaries have been modified to account for uncertainty in the position of the fault and to include the area contributing to a suspected swallow hole (direct entry point into the groundwater system). The area comprising the ZOC may be an overestimate, as conservative recharge rates were used in the water balance calculation.

Raw water quality in BH 2 is acceptable, based on the available samples. However, there are insufficient data to conclude that this is the case, and there were no microbiological data. Raw water quality in BH 1 is impacted by human activities, with microbial contamination and



ammonium exceedances of the TV and DWL occurring. The parameter exceedances indicate a source of organic pollution proximal to the boreholes. The differing water qualities may reflect the better borehole construction in BH2, which excludes shallow groundwater inflow, than at BH 1, which does not.

Treated water quality for water abstracted under the DBO contract from BH 2 has achieved all of the required drinking water standards.

## 6. Recommendations

### Essential:

- A regular survey of water quality parameters of untreated water at BH 2 to include coliforms (total and faecal), *Clostridium perfringens*, pH, alkalinity, electrical conductivity, nitrate, ammonium, chloride, potassium and sodium. The samples should be filtered prior to preservation (to prevent particles containing iron, aluminium being dissolved into the sample).
- This survey should be taken on a monthly basis for the first year, preferably on the same day as the DBO operator monitoring of the BH 2 supply. It should ideally incorporate samples following a variety of wet and dry rainfall conditions in the preceding week<sup>7</sup>. The results should be shared with the GSI. The need for future monitoring can be determined on the basis of these results, and in discussion with a hydrogeologist

### Desirable:

- The BH 2 pumping rate to be kept as low as possible while maintaining supply. This is in order to avoid mobilisation of sediment and any associated metals, particularly during periods of low water levels. This could be achieved by pumping for longer at lower abstraction rates, or using a soft-start pump motor.
- A survey of on-site waste water treatment systems (including septic tanks) and an audit of any already assessed, could be carried out, in order to identify whether poorly functioning

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<sup>7</sup> Any sampling of BH1 that may be necessary should only be undertaken after significant pumping and with clean rising mains.



systems are contributing to the pollutant load at BH 1. Hazard mapping, relating to other organic pollutant sources could be carried out.

- Investigation of whether there is a spring discharge re-entering the groundwater system at a swallow hole to the east of the boreholes, as shown on historic 1:10,560 (6 inch) scale mapping. This would contribute to delineation of areas of extreme vulnerability within the ZOC. This could be traced from if it does still exist, to ascertain whether it contributes water to the supply
- Monitoring of water levels in BH1 and BH2 simultaneously would allow an understanding of flow pathways and improved calculation of transmissivity, allowing a less conservative ZOC to be delineated.

#### Other:

- The following EPA guidelines may serve as future useful reference documents for the GWS:
  - o EPA Guidance on Landspreading of Organic Waste<sup>8</sup>. Adherence by landowners with the European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2017 is necessary for the effective protection of groundwater sources.
  - o EPA Drinking Water Advice Note No. 7: Source Protection and Catchment Management to Protect Groundwater Sources. Of particular interest would be Section 4.1 – Step 2 – Hazard Mapping<sup>9</sup>.
  - o EPA Drinking Water Advice Note No. 8: Developing Drinking Water Safety Plans. This document contains checklists for hazards which would assist in hazard mapping within the ZOC<sup>10</sup>.
  - o EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection<sup>11</sup>

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<sup>8</sup> [http://www.epa.ie/pubs/advice/waste/waste/EPA\\_landspread\\_organic\\_waste\\_guide.pdf](http://www.epa.ie/pubs/advice/waste/waste/EPA_landspread_organic_waste_guide.pdf)

<sup>9</sup> [http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvisenote-advisenoteno7.html#.UpNP\\_eJ9KEp](http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvisenote-advisenoteno7.html#.UpNP_eJ9KEp)

<sup>10</sup> <http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvisenote-advisenoteno8.html#.UpNQf-J9KEo>

<sup>11</sup> <http://www.epa.ie/pubs/advice/drinkingwater/advisenote14.html#.UpNR8eJ9KEo>



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EPA (2011) Drinking Water Advice Note No. 7: Source Protection and Catchment Management to Protect Groundwater Sources.

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<http://www.igi.ie/publications/codes-guidelines.htm>



# ***Figures***

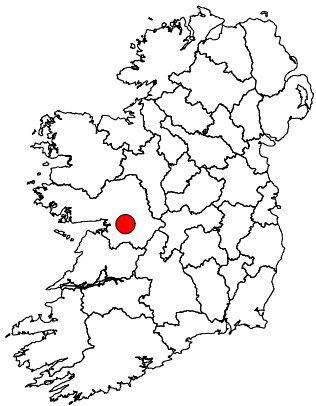
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Legend:

● Bulaun GWS, Co. Galway



Title:

Figure 1 Regional Setting

Drawing No: 140\_1

Project:

Zone of Contribution Delineation

Stage:

Client:  
Bullaun Group Water Scheme

Scale: 1:50,000 @ A4

| surveyed | drawn | checked | date     |
|----------|-------|---------|----------|
|          | ST    |         | 16/11/17 |

Revisions: Rev 1

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Legend:

- GWS Location
- ZOC Boundary
- Rivers & Flow Direction
- ➔

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Title:

Figure 2 Topography and Regional Hydrology

Drawing No: 140\_2

Project:

Zone of Contribution Delineation

Stage:

Client:

Bullaun Group Water Scheme

Scale:

1:20,000 @ A4

surveyed

drawn

checked

date

ST

21/1/18

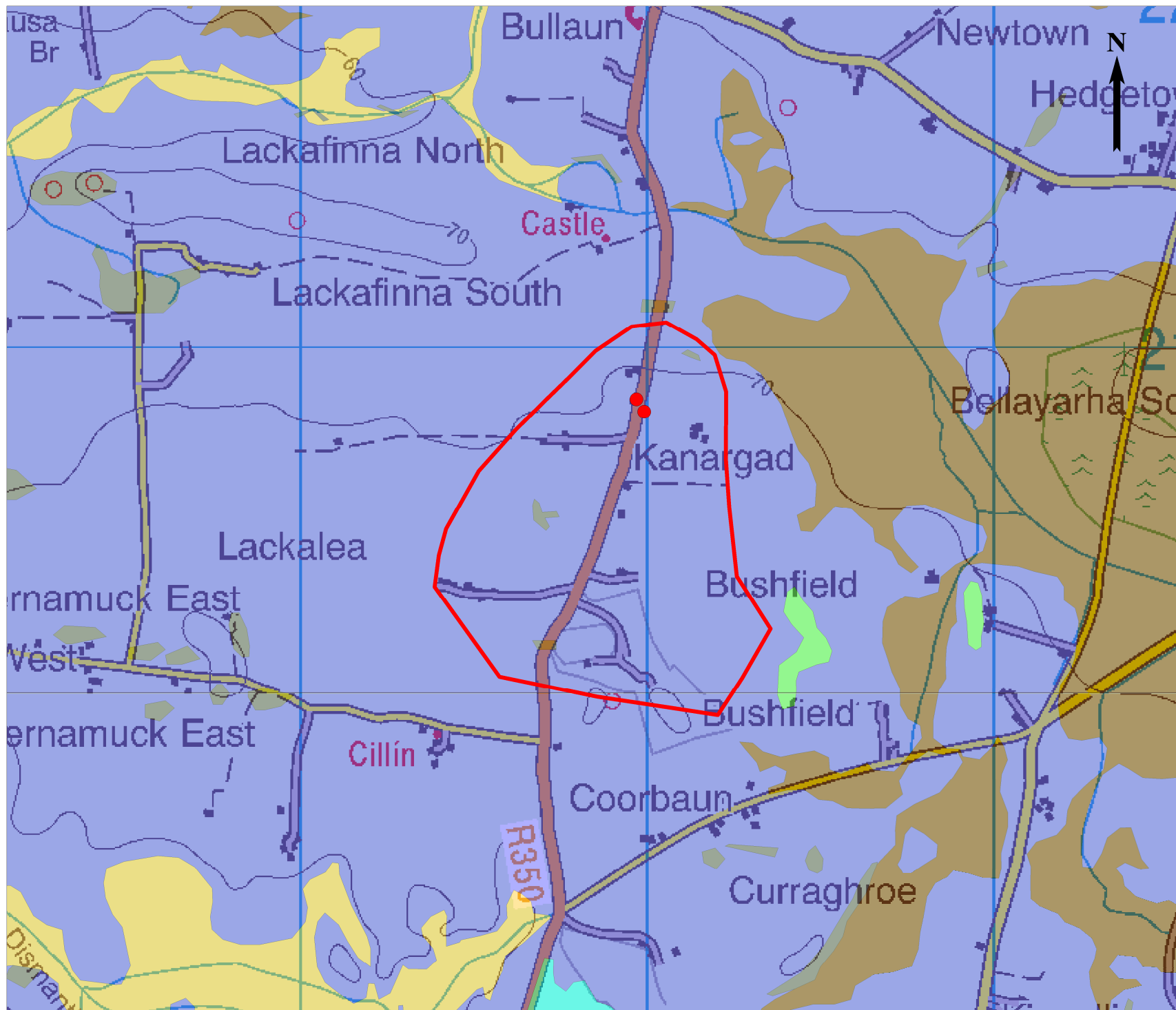
Revisions:

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Legend:

- Supply Boreholes
- Zone of Contribution
- Subsoils**
  - Alluvium
  - Cutover Peat
  - Lacustrine Sediments
  - Made Ground
  - Rock Exposed
  - Limestone Till

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Title:  
Figure 3 Subsoils

Drawing No: 140\_3

Project:  
Zone of Contribution Delineation

Stage:

Client:  
Bullaun Group Water Scheme

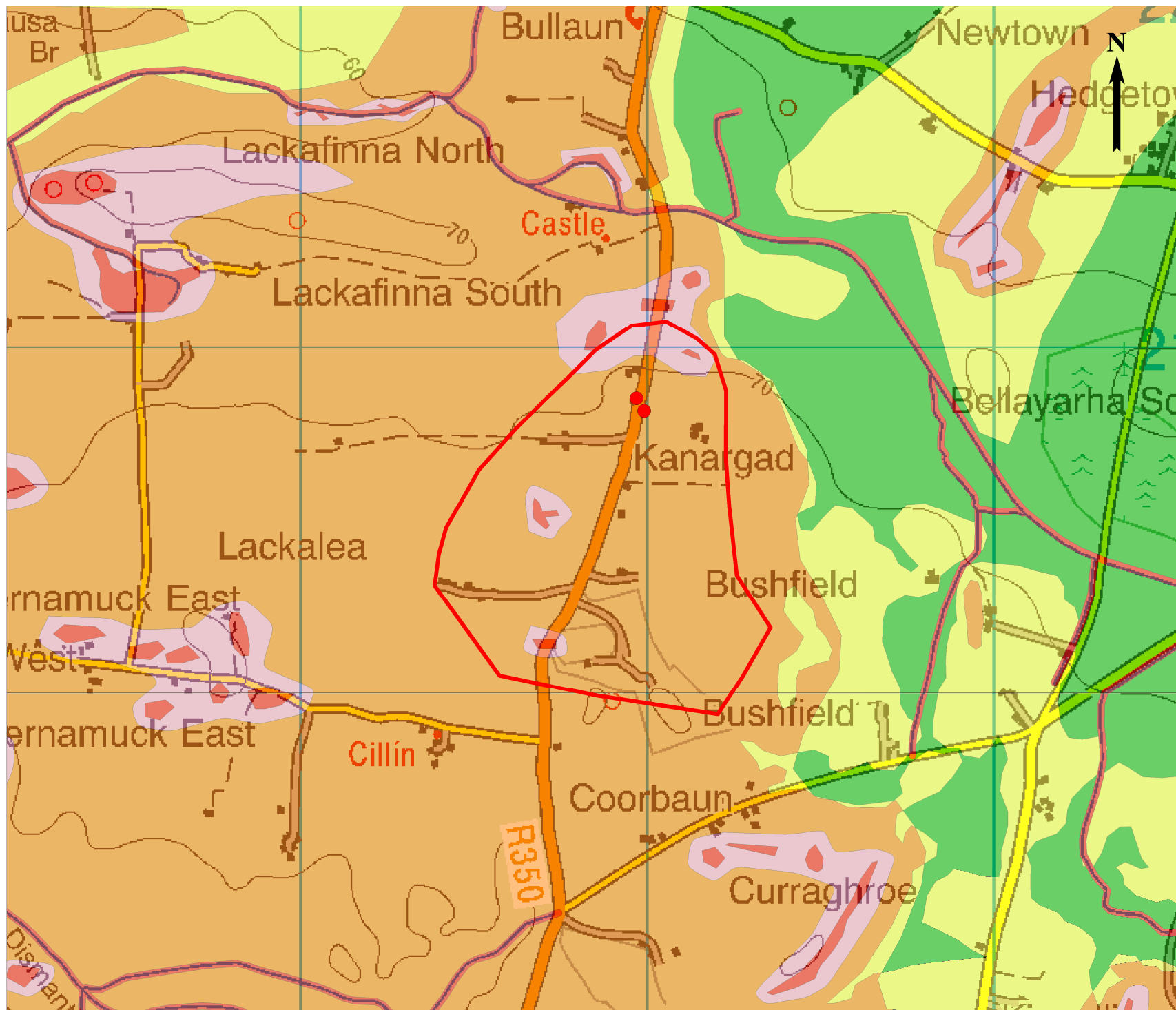
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|          | ST    | CH      | 25/1/18 |

Revisions: Rev 2

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Legend:



Supply Boreholes



Zone of Contribution

#### Groundwater Vulnerability



Rock at or near surface or Karst



Extreme



High



Moderate



Low

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Title:

Figure 4 Bedrock Aquifer Vulnerability

Drawing No: 140\_4

Project:

Zone of Contribution Delineation

Stage:

Client:

Bullaun Group Water Scheme

Scale:

1:15,000 @ A4

surveyed

drawn

checked

date

ST

25/1/18

Revisions:

Rev 2

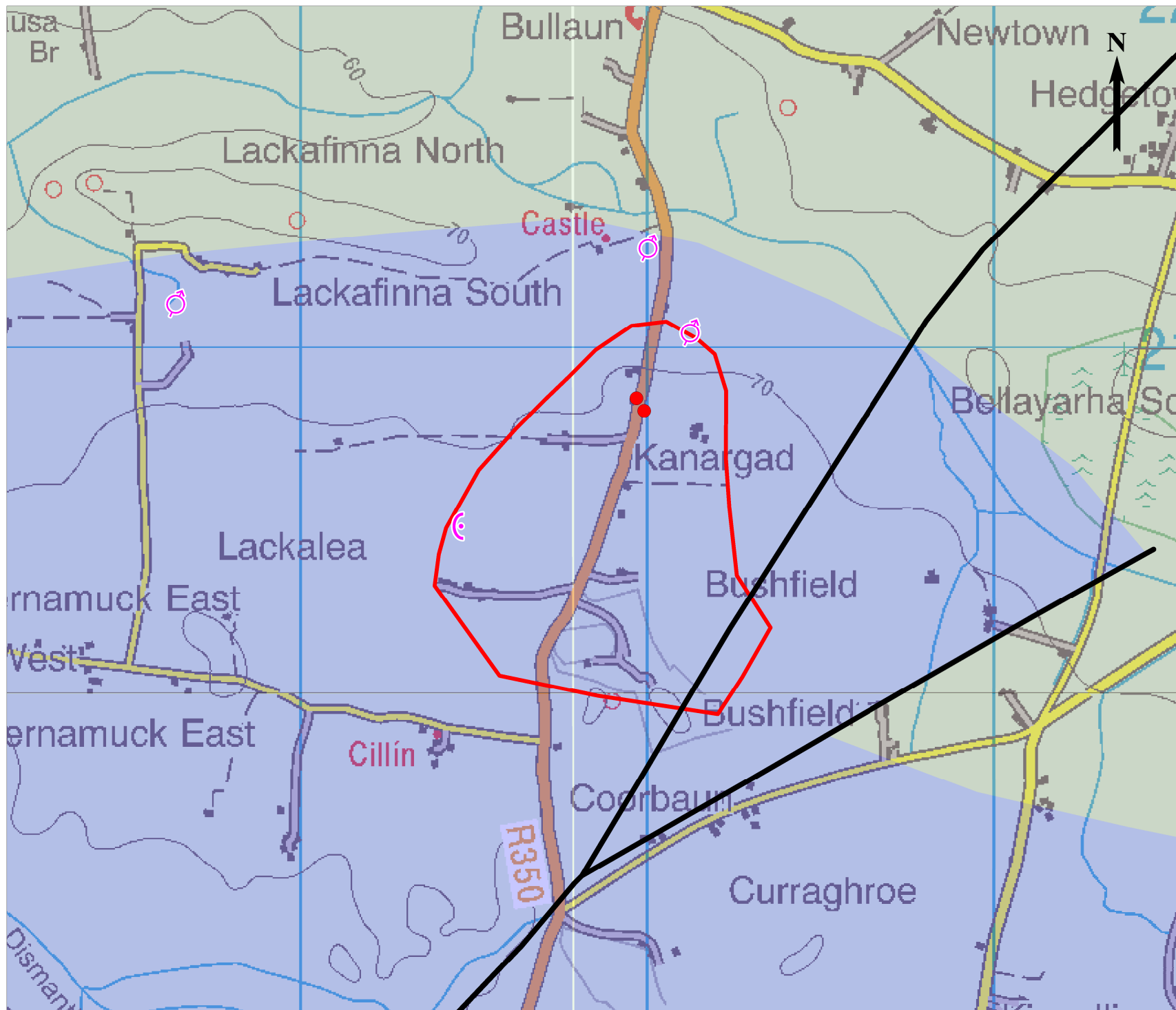


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Legend:



Supply Boreholes



Zone of Contribution

Geological Rock Units



Dinantian Pure Unbedded Lsts



Dinantian Upper Impure Lsts



Bedrock Fault

Karst Feature Types



Spring



Swallow hole

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Title:  
Figure 5 Bedrock Geology & Karst Features

Drawing No: 140\_5

Project:  
Zone of Contribution Delineation

Stage:

Client:  
Bullaun Group Water Scheme

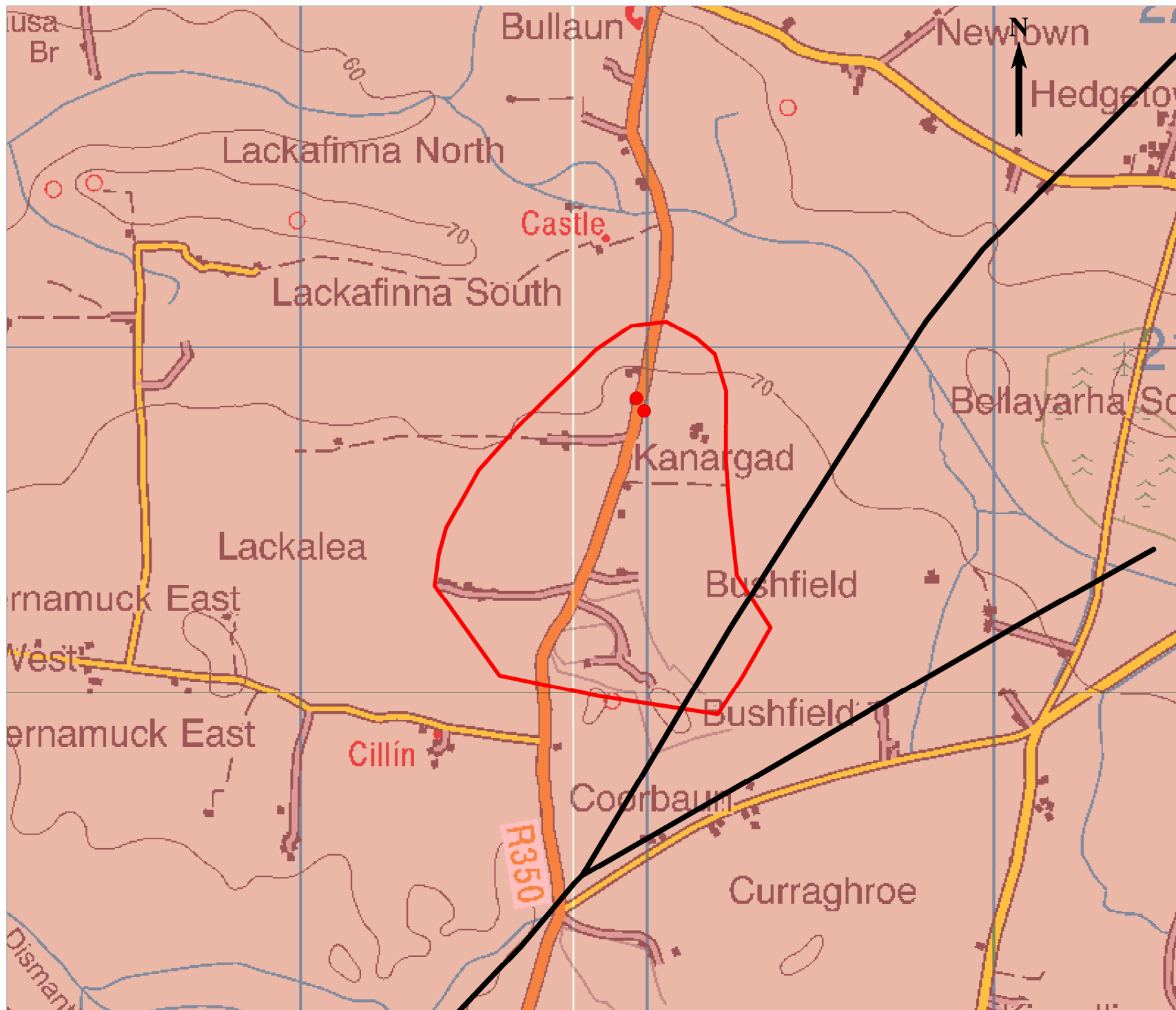
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| surveyed | drawn<br>ST | checked<br>CH | date<br>25/1/18 |
|----------|-------------|---------------|-----------------|

Revisions: Rev 2

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Legend:

- Supply Boreholes
- Zone of Contribution
- Bedrock Aquifer Type & Productivity**
  - Local - Mod. Productive in Local Zones
- Bedrock Fault

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Title:  
Figure 6 Aquifer Type

Drawing No: 140\_6

Project:  
Zone of Contribution Delineation

Stage:

Client:  
Bullaun Group Water Scheme

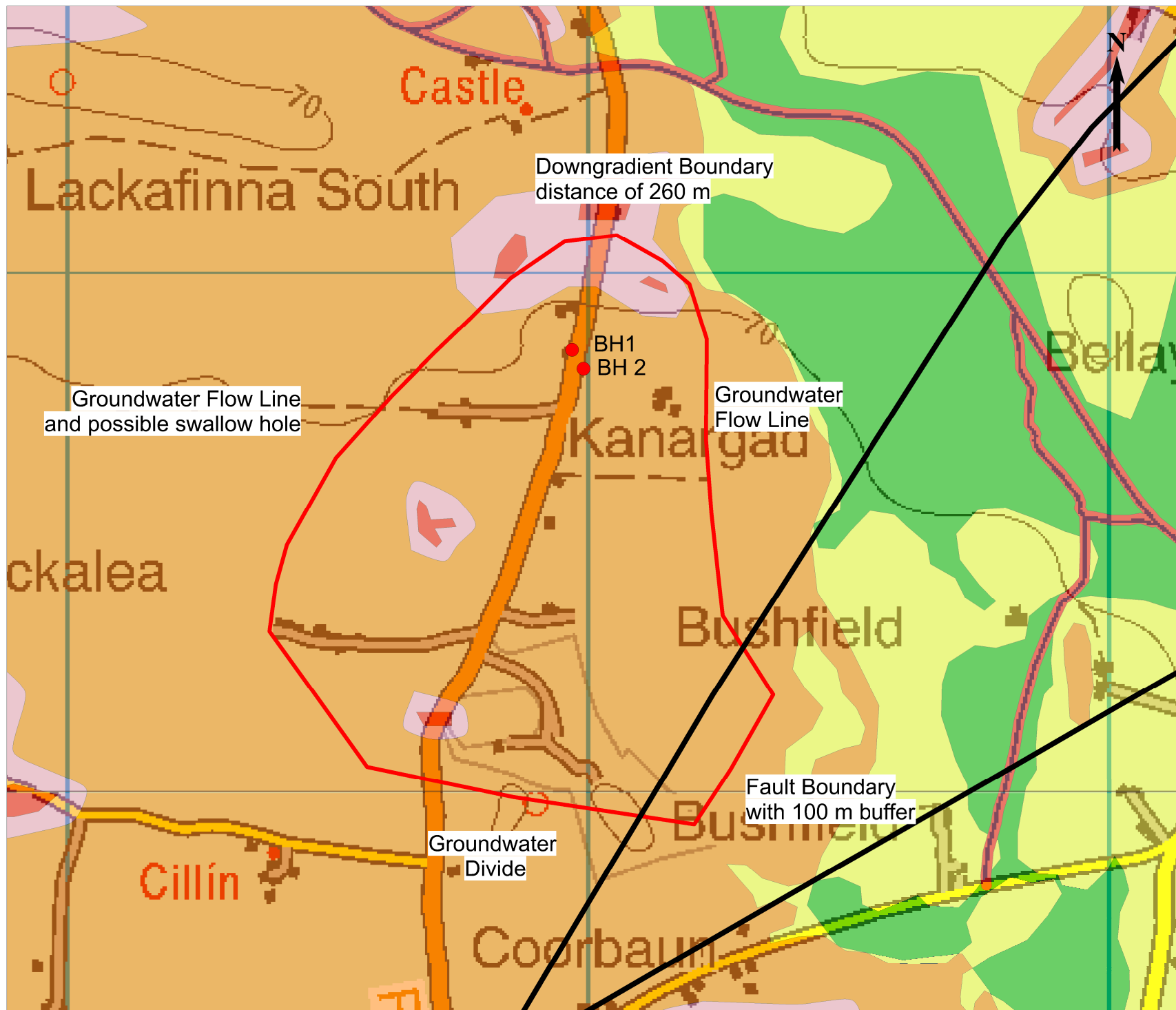
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|          | ST    | CH      | 25/1/18 |

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Legend:



Supply Boreholes



Zone of Contribution

#### Groundwater Vulnerability



Rock at or near surface or Karst



Extreme



High



Moderate



Low



Bedrock Fault

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Title:

Figure 7 ZOC Boundaries

Drawing No: 140\_7

Project:

Zone of Contribution Delineation

Stage:

Client:

Bullaun Group Water Scheme

Scale:

1:10,000 @ A4

surveyed

drawn

checked

date

ST

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25/1/18

Revisions:

Rev 2



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# ***Appendix 1***

## ***Groundwater Vulnerability***

---



## Introduction

The term 'vulnerability' is used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities (DELG *et al.*, 1999). The vulnerability of groundwater depends on:

- the time of travel of infiltrating water (and contaminants)
- the relative quantity of contaminants that can reach the groundwater
- the contaminant attenuation capacity of the geological materials through which the water and contaminants infiltrate.

All groundwater is hydrologically connected to the land surface; the effectiveness of this connection determines the relative vulnerability to contamination. Groundwater that readily and quickly receives water (and contaminants) from the land surface is more vulnerable than groundwater that receives water (and contaminants) more slowly and in lower quantities. The travel time, attenuation capacity and quantity of contaminants are a function of the following natural geological and hydrogeological attributes of any area:

- the type and permeability of the subsoils that overlie the groundwater
- the thickness of the unsaturated zone through which the contaminant moves
- the recharge type – whether point or diffuse.

In other words, vulnerability is based on evaluating the relevant hydrogeological characteristics of the protecting geological layers along the pathway, and the possibility of bypassing these layers. In summary, the entire land surface is divided into four vulnerability categories: **Extreme**, **High**, **Moderate** and **Low**, based on the geological and hydrogeological characteristics. Further details of the hydrogeological basis for vulnerability assessment can be found in 'Groundwater Protection Schemes' (DELG *et al.*, 1999).

The Groundwater Vulnerability Map shows the vulnerability of the first groundwater encountered, in either sand/gravel or bedrock aquifers, by contaminants released at depths of 1-2 m below the ground surface. Where the water-table in bedrock aquifers is below the top of the bedrock, the target needing protection is the water-table. However, where the aquifer is fully saturated, the target is the top of the bedrock. The vulnerability map aims to be a guide to the likelihood of groundwater contamination, if a pollution event were to occur. It does not replace the need for site investigation. Note also that the characteristics of individual contaminants are not considered.

Except where point recharge occurs (*e.g.* at swallow holes), the groundwater vulnerability depends on the type, permeability and thickness of the subsoil.

The groundwater vulnerability map is derived by combining the permeability and depth to bedrock maps, using the three subsoil permeability categories: high, moderate and low; and four depths to rock categories: <3m, 3–5m, 5–10m and >10m. The resulting vulnerability classifications are shown below.

### Vulnerability mapping guidelines (adapted from DELG *et al.*, 1999)

| Thickness of Overlying Subsoils                                                                                                                                                                                                                                                                                                                                                                             | Hydrogeological Requirements for Vulnerability Categories |                                          |                                                  |                                 |                                       |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|------------------------------------------|--------------------------------------------------|---------------------------------|---------------------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                             | Diffuse Recharge                                          |                                          |                                                  | Point Recharge                  | Unsaturated Zone                      |
|                                                                                                                                                                                                                                                                                                                                                                                                             | Subsoil permeability and type                             |                                          |                                                  |                                 |                                       |
|                                                                                                                                                                                                                                                                                                                                                                                                             | High permeability<br>(sand/gravel)                        | moderate permeability<br>(sandy subsoil) | low permeability<br>(clayey subsoil, clay, peat) | (swallow holes, losing streams) | (sand & gravel aquifers <u>only</u> ) |
| 0–3 m                                                                                                                                                                                                                                                                                                                                                                                                       | Extreme                                                   | Extreme                                  | Extreme                                          | Extreme (30 m radius)           | Extreme                               |
| 3–5 m                                                                                                                                                                                                                                                                                                                                                                                                       | High                                                      | High                                     | High                                             | N/A                             | High                                  |
| 5–10 m                                                                                                                                                                                                                                                                                                                                                                                                      | High                                                      | High                                     | Moderate                                         | N/A                             | High                                  |
| >10 m                                                                                                                                                                                                                                                                                                                                                                                                       | High                                                      | Moderate                                 | Low                                              | N/A                             | High                                  |
| Notes: (i) N/A = not applicable.<br>(ii) Release point of contaminants is assumed to be 1–2 m below ground surface.<br>(iii) Permeability classifications relate to the engineering behaviour as described by BS5930.<br>(iv) Outcrop and shallow subsoil (i.e. generally <1.0 m) areas are shown as a sub-category of extreme vulnerability (amended from Deakin and Daly (1999) and DELG/EPA/GS1a (1999)) |                                                           |                                          |                                                  |                                 |                                       |



## Sources of Vulnerability Data

Specific vulnerability field mapping and assessment of previously collected data were carried out as part of this project. Fieldwork focused on assessing the permeability of the different subsoil deposit types so that they could be subdivided into the three permeability categories. This involved:

- Describing selected exposures/sections according to the British Standard Institute *Code of Practice for Site Investigations* (BS 5930:1999).
- Collection of subsoil samples for laboratory particle size analyses
- Assessing the recharge characteristics of selected sites using natural and artificial drainage, vegetation and other recharge indicators.

The following additional sources of data were used to assess the vulnerability and produce the map:

- Subsoils Map (EPA/Teagasc Subsoil Map, 2006), which is the basis for the main permeability boundaries. 'Clean' sands and gravels are usually high permeability. Alluvium deposits are either moderate or low permeability.
- Depth to bedrock map, compiled by the mapping team for the current project in the Geological Survey of Ireland, using data compiled from GSI, consultant and county council reports, along with purpose-drilled auger holes
- Geological Survey of Ireland Bedrock Geology Map
- Geological Survey of Ireland well and karst database, which supplied information on well yields and depth to bedrock, as well as locations of point recharge.
- General Soils Map of Ireland (Gardiner and Radford, 1980). This gives additional, indirect information on subsoil permeability in the areas mapped by Teagasc as 'till'.

## Thickness of the Unsaturated Zone

The thickness of the unsaturated zone, or the depth of ground free of intermittent or permanent saturation, is only relevant in vulnerability mapping over unconfined sand and gravel aquifers. As described in Table 6.1, the critical unsaturated zone thickness is 3m; unconfined gravels with unsaturated zones thicker than 3m are classed as having a 'high' vulnerability, while those with unsaturated zones thinner than 3m are classed as having an 'extreme' vulnerability.



## ***Appendix 2***

# ***Groundwater Recharge***

---



## Introduction

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).

The main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient (Table 1). The recharge coefficient is estimated using Hunter Williams et al (2013), which is based on Guidance Document GW5 (Groundwater Working Group 2005).

**Table 1. Recharge coefficients for different hydrogeological settings.**

| Groundwater vulnerability category | Hydrogeological setting |                                                                            | Recharge coefficient (RC) |             |         |
|------------------------------------|-------------------------|----------------------------------------------------------------------------|---------------------------|-------------|---------|
|                                    |                         |                                                                            | Min (%)                   | Inner Range | Max (%) |
| Extreme<br>(X or E)                | 1.i                     | Areas where rock is at ground surface                                      | 30                        | 80-90       | 100     |
|                                    | 1.ii                    | Sand/gravel overlain by 'well drained' soil                                | 50                        | 80-90       | 100     |
|                                    | 1.iii                   | Sand/gravel overlain by 'poorly drained' (gley) soil                       | 15                        | 35-50       | 70      |
|                                    | 1.iv                    | Till overlain by 'well drained' soil                                       | 45                        | 50-70       | 80      |
|                                    | 1.v                     | Till overlain by 'poorly drained' (gley) soil                              | 5                         | 15-30       | 50      |
|                                    | 1.vi                    | Sand/ gravel aquifer where the water table is $\leq$ 3 m below surface     | 50                        | 80-90       | 100     |
|                                    | 1.vii                   | Peat                                                                       | 1                         | 15-30       | 50      |
| High<br>(H)                        | 2.i                     | Sand/gravel aquifer, overlain by 'well drained' soil                       | 50                        | 80-90       | 100     |
|                                    | 2.ii                    | High permeability subsoil (sand/gravel) overlain by 'well drained' soil    | 50                        | 80-90       | 100     |
|                                    | 2.iii                   | High permeability subsoil (sand/gravel) overlain by 'poorly drained' soil  | 15                        | 35-50       | 70      |
|                                    | 2.iv                    | Sand/gravel aquifer, overlain by 'poorly drained' soil                     | 15                        | 35-50       | 70      |
|                                    | 2.v                     | Moderate permeability subsoil overlain by 'well drained' soil              | 35                        | 50-70       | 80      |
|                                    | 2.vi                    | Moderate permeability subsoil overlain by 'poorly drained' (gley) soil     | 10                        | 15-30       | 50      |
|                                    | 2.vii                   | Low permeability subsoil                                                   | 1                         | 20-30       | 40      |
|                                    | 2.viii                  | Peat                                                                       | 1                         | 5-15        | 20      |
| Moderate<br>(M)                    | 3.i                     | Moderate permeability subsoil and overlain by 'well drained' soil          | 35                        | 50-70       | 80      |
|                                    | 3.ii                    | Moderate permeability subsoil and overlain by 'poorly drained' (gley) soil | 10                        | 15-30       | 50      |
|                                    | 3.iii                   | Low permeability subsoil                                                   | 1                         | 10-20       | 30      |
|                                    | 3.iv                    | Peat                                                                       | 1                         | 3-5         | 10      |
| Low<br>(L)                         | 4.i                     | Low permeability subsoil                                                   | 1                         | 5-10        | 20      |
|                                    | 4.ii                    | Basin peat                                                                 | 1                         | 3-5         | 10      |

The recharge coefficients in this table are summarised in a paper by Hunter Williams *et al.* (2013) in the Quarterly Journal of Engineering Geology and Hydrogeology. Aquifer recharge acceptance capacity is generally limited in LI aquifers (200 mm/yr) and PI and Pul aquifers (100 mm/yr). Made ground has recharge coefficient of 20%.

## ***Appendix 3***

# ***Water Quality Results***

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***BH1 (Backup)***

***Water Quality Results***

---

# Summary Report on Samples of Raw Untreated Water, November 2000 to November 2001

Source : **GY130**, Bullaun  
 Michael Hynes  
 Ballyara  
 Bullaun  
 Loughrea, Co Galway

The experimental results for the samples collected during November 2000 to February 2001 and for May 2001 to November 2001 from the source of the raw water for the group water scheme **GY130**, Bullaun, are presented in the table below. (Samples were not collected for March and April 2001 due to F&M precautions). These results must be interpreted having regard to the national limit values for each parameter specified in the Quality of Drinking Water Regulations 1988 (S.I. No. 81 of 1988). This is the standard required at the consumers tap and will normally require treatment and disinfection of the raw water to achieve these values. A brief description of these chemical and bacteriological parameters and their associated limit values is provided in the explanatory leaflet that accompanies this report.

| Parameter   | Colour   | Turbidity | Conductivity | pH         | Ammonia    | Nitrate    | Nitrite    | Aluminium | Iron     | Manganese | Total Coliform | Faecal Coliform |
|-------------|----------|-----------|--------------|------------|------------|------------|------------|-----------|----------|-----------|----------------|-----------------|
| Limit Value | 20 Hazen | 4 NTU     | 1500 µS/cm   | 6.0 to 9.0 | 0.23 mgN/l | 11.3 mgN/l | 0.03 mgN/l | 200 µg/l  | 200 µg/l | 50 µg/l   | 0 per 100 ml   | 0 per 100 ml    |
| NOV2000     | 2.5      | 1.24      | 764          | 6.79       | 0.1        | 0.1        | 0.05       | <4        | 38       | <6        | <1             | <1              |
| JAN2001     | 7.5      | 46        | 781          | 6.97       | 0.2        | 0.6        | 0.05       | <4        | 82       | 18        | 6              | <1              |
| FEB2001     | 2.5      | 0.25      | 772          | 6.59       | 0.2        | 1          | <0.05      | 5         | 50       | 18        | <1             | <1              |
| MAY2001     | 5        | 0.76      | 802          | 6.82       | 2          | 1.1        | 0.006      | <4        | 78       | 20        | 3              | <1              |
| JUN2001     | 2.5      | 2.56      | 768          | 6.68       | 0.4        | 1          | 0.006      | 6         | 30       | 17        | <1             | <1              |
| JUL2001     | 2.5      | 1.16      | 872          | 7.1        | 0.15       | 0.9        | 0.005      | 10        | 47       | 19        | 1              | <1              |
| AUG2001     | <2.5     | <0.01     | 763          | 7.04       | 0.15       | 0.9        | 0.004      | <4        | 47       | 17        | <1             | <1              |
| SEP2001     | 5        | 0.33      | 765          | 7.16       | 0.15       | 0.7        | 0.002      | 4         | 45       | 18        | 3              | <1              |
| OCT2001     | <2.5     | 0.73      | 787          | 7.22       | 0.15       | 0.7        | 0.002      | 22        | 112      | 45        | <1             | <1              |
| NOV2001     | <2.5     | 0.54      | 784          | 7.25       | 0.15       | 0.9        | 0.002      | <4        | 71       | 15        | <1             | <1              |

# Test Report

**Lab Report Number:** 5023J02

**Analysis Number:**

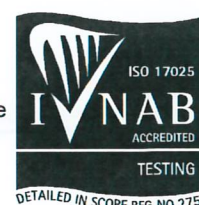
**GWS/11**

|                            |                                                           |                                 |                           |
|----------------------------|-----------------------------------------------------------|---------------------------------|---------------------------|
| <b>Customer ID:</b>        | BULL.G1                                                   | <b>Analysis Type:</b>           | GROUP WATER SCHEME (GWS)  |
| <b>Contact Name:</b>       | MICHAEL HYNES                                             | <b>Delivery By:</b>             | IAS Collection Chargeable |
| <b>Company Name:</b>       | NATIONAL FED GWS                                          | <b>Sample Card Number:</b>      | NFGWS/BULL/3              |
| <b>Address:</b>            | BULLAUN (LOUGHREA) GWS<br>BALLYARA<br>BULLAUN<br>LOUGHREA | <b>Sample Condition:</b>        | Acceptable                |
| <b>Sample Type:</b>        | Water                                                     | <b>Date Sample Received:</b>    | 24/07/2017                |
| <b>Sample Reference:</b>   | GALWAY, BULLAUN/LOUGHREA GWS                              | <b>Date Analysis Commenced:</b> | 24/07/2017                |
| <b>Sample Description:</b> | T2.10, SECONDARY                                          | <b>Date Certificate Issued:</b> | 03/08/2017                |

| Parameter                            | Method                       | Result | Unit       |
|--------------------------------------|------------------------------|--------|------------|
| Aluminium                            | ICP-MS                       | <20    | ug/l       |
| Alkalinity                           | Konelab Aquakem SOP2064      | 391.98 | mg/l       |
| Arsenic*                             | ICP-MS                       | <10    | ug/l       |
| Barium*                              | ICP-MS                       | <10    | ug/l       |
| Biochemical Oxygen Demand            | Oxygen Meter SOP 2006        | <1     | mg/l       |
| Calcium                              | ICP-MS                       | 123.8  | mg/l       |
| Cadmium                              | ICP-MS                       | <20    | ug/l       |
| Chloride                             | Konelab Aquakem SOP 2065     | 24.52  | mg/l       |
| Colour                               | Konelab Aquakem SOP 2063     | 5.6    | Pt Co      |
| Conductivity                         | Electrometry SOP 2076        | 644    | µS/cm 20°C |
| Chromium                             | ICP-MS                       | <20    | ug/l       |
| Copper                               | ICP-MS                       | <20    | ug/l       |
| E. Coli*                             | Quanti-tray SOP 2090         | 0      | MPN/100ml  |
| Iron*                                | ICP-MS                       | 11344  | ug/l       |
| Fluoride*                            | Konelab Aquakem SOP 2069     | 0.12   | mg/l       |
| Total Hardness                       | Ca & Mg Hardness             | 406.7  | mg/l CaCO3 |
| Potassium                            | ICP-MS                       | 1.95   | mg/l       |
| Clostridium Perfringens <sup>^</sup> | Membrane Filtration SOP 2093 | 4      | cfu/100 ml |
| Magnesium                            | ICP-MS                       | 23.7   | mg/l       |
| Manganese                            | ICPMS                        | 113    | ug/l       |
| Sodium                               | ICP-MS                       | 17.5   | mg/l       |
| Ammonium                             | Konelab Aquakem SOP 2057     | 0.04   | mg/l NH4   |
| Nickel                               | ICP-MS                       | <20    | ug/l       |
| Nitrite                              | Konelab Aquakem SOP 2059     | 0.03   | mg/l NO2   |
| Nitrate                              | Konelab Aquakem SOP 2060     | 4.80   | mg/l NO3   |
| P Orthophosphate                     | Konelab Aquakem SOP 2061     | <0.01  | mg/l P     |

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# Test Report

**Lab Report Number: 5023J02****Analysis Number:****GWS/11****Customer ID:** BULL.G1**Analysis Type:**

GROUP WATER SCHEME (GWS)

**Contact Name:** MICHAEL HYNES**Delivery By:**

IAS Collection Chargeable

**Company Name:** NATIONAL FED GWS**Sample Card Number:**

NFGWS/BULL/3

**Address:** BULLAUN (LOUGHREA) GWS**Sample Condition:**

Acceptable

BALLYARA

BULLAUN

LOUGHREA

**Sample Type:** Water**Date Sample Received:**

24/07/2017

**Sample Reference:** GALWAY, BULLAUN/LOUGHREA GWS**Date Analysis Commenced:**

24/07/2017

**Sample Description:** T2.10, SECONDARY**Date Certificate Issued:**

03/08/2017

| Parameter             | Method                   | Result | Unit      |
|-----------------------|--------------------------|--------|-----------|
| Dissolved Oxygen*     | Oxygen Meter SOP 2006    | 8.15   | mg/l O2   |
| Lead                  | ICP-MS                   | <20    | ug/l      |
| pH                    | Electrometry SOP 2004    | 6.9    | pH units  |
| Silica**              | Subcontracted            | 5.09   | mg/l      |
| Sulphate              | Konelab Aquakem SOP 2062 | 17.77  | mg/l SO4  |
| Strontium*            | ICP-MS                   | <10    | ug/l      |
| Total Coliforms*      | Quanti-tray SOP 2090     | 38     | MPN/100ml |
| Total Organic Carbon* | Oxidation & Colourimetry | 2.5    | mg/l      |
| Turbidity             | Turbidimetric SOP 2022   | <0.02  | NTU       |
| Zinc                  | ICP-MS                   | 54     | ug/l      |

Signed:

Date:

03/08/2017

**Wendy McCall - Laboratory Manager**

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***BH2 (Supply)***

***Water Quality Results***

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## Independent Analytical Supplies

# Test Report

|                                   |                                                           |                                 |                           |
|-----------------------------------|-----------------------------------------------------------|---------------------------------|---------------------------|
| <b>Lab Report Number:</b> 5023J01 |                                                           | <b>Analysis Number:</b> GWS/10  |                           |
| <b>Customer ID:</b>               | BULL.G1                                                   | <b>Analysis Type:</b>           | GROUP WATER SCHEME (GWS)  |
| <b>Contact Name:</b>              | MICHAEL HYNES                                             | <b>Delivery By:</b>             | IAS Collection Chargeable |
| <b>Company Name:</b>              | NATIONAL FED GWS                                          | <b>Sample Card Number:</b>      | NFGWS/BULL/3              |
| <b>Address:</b>                   | BULLAUN (LOUGHREA) GWS<br>BALLYARA<br>BULLAUN<br>LOUGHREA | <b>Sample Condition:</b>        | Acceptable                |
| <b>Sample Type:</b>               | Water                                                     | <b>Date Sample Received:</b>    | 24/07/2017                |
| <b>Sample Reference:</b>          | GALWAY, BULLAUN/LOUGHREA GWS                              | <b>Date Analysis Commenced:</b> | 24/07/2017                |
| <b>Sample Description:</b>        | T2.30, RAW 1                                              | <b>Date Certificate Issued:</b> | 03/08/2017                |

| Parameter                 | Method                       | Result | Unit       |
|---------------------------|------------------------------|--------|------------|
| Aluminium                 | ICP-MS                       | <20    | ug/l       |
| Alkalinity                | Konelab Aquakem SOP2064      | 413.54 | mg/l       |
| Arsenic*                  | ICP-MS                       | <10    | ug/l       |
| Barium*                   | ICP-MS                       | <10    | ug/l       |
| Biochemical Oxygen Demand | Oxygen Meter SOP 2006        | <1     | mg/l       |
| Calcium                   | ICP-MS                       | 123.4  | mg/l       |
| Cadmium                   | ICP-MS                       | <20    | ug/l       |
| Chloride                  | Konelab Aquakem SOP 2065     | 25.35  | mg/l       |
| Colour                    | Konelab Aquakem SOP 2063     | <1.0   | Pt Co      |
| Conductivity              | Electrometry SOP 2076        | 707    | µS/cm 20°C |
| Chromium                  | ICP-MS                       | <20    | ug/l       |
| Copper                    | ICP-MS                       | <20    | ug/l       |
| E. Coli*                  | Quanti-tray SOP 2090         | 0      | MPN/100ml  |
| Iron                      | ICP-MS                       | 44     | ug/l       |
| Fluoride*                 | Konelab Aquakem SOP 2069     | 0.12   | mg/l       |
| Total Hardness            | Ca & Mg Hardness             | 410.7  | mg/l CaCO3 |
| Potassium                 | ICP-MS                       | 2.12   | mg/l       |
| Clostridium Perfringens** | Membrane Filtration SOP 2093 | 0      | cfu/100 ml |
| Magnesium                 | ICP-MS                       | 24.9   | mg/l       |
| Manganese                 | ICPMS                        | <20    | ug/l       |
| Sodium                    | ICP-MS                       | 19.1   | mg/l       |
| Ammonium                  | Konelab Aquakem SOP 2057     | 0.05   | mg/l NH4   |
| Nickel                    | ICP-MS                       | <20    | ug/l       |
| Nitrite                   | Konelab Aquakem SOP 2059     | 0.03   | mg/l NO2   |
| Nitrate                   | Konelab Aquakem SOP 2060     | 4.22   | mg/l NO3   |
| P Orthophosphate          | Konelab Aquakem SOP 2061     | <0.01  | mg/l P     |

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IAS LABORATORIES, Unit 4 Bagenalstown Bus. Park, Bagenalstown, Co. Carlow,

# Test Report

|                                   |                                                           |                                 |                           |
|-----------------------------------|-----------------------------------------------------------|---------------------------------|---------------------------|
| <b>Lab Report Number:</b> 5023J01 |                                                           | <b>Analysis Number:</b> GWS/10  |                           |
| <b>Customer ID:</b>               | BULL.G1                                                   | <b>Analysis Type:</b>           | GROUP WATER SCHEME (GWS)  |
| <b>Contact Name:</b>              | MICHAEL HYNES                                             | <b>Delivery By:</b>             | IAS Collection Chargeable |
| <b>Company Name:</b>              | NATIONAL FED GWS                                          | <b>Sample Card Number:</b>      | NFGWS/BULL/3              |
| <b>Address:</b>                   | BULLAUN (LOUGHREA) GWS<br>BALLYARA<br>BULLAUN<br>LOUGHREA | <b>Sample Condition:</b>        | Acceptable                |
| <b>Sample Type:</b>               | Water                                                     | <b>Date Sample Received:</b>    | 24/07/2017                |
| <b>Sample Reference:</b>          | GALWAY, BULLAUN/LOUGHREA GWS                              | <b>Date Analysis Commenced:</b> | 24/07/2017                |
| <b>Sample Description:</b>        | T2.30, RAW 1                                              | <b>Date Certificate Issued:</b> | 03/08/2017                |

| Parameter             | Method                   | Result | Unit                 |
|-----------------------|--------------------------|--------|----------------------|
| Dissolved Oxygen*     | Oxygen Meter SOP 2006    | 3.53   | mg/l O <sub>2</sub>  |
| Lead                  | ICP-MS                   | <20    | ug/l                 |
| pH                    | Electrometry SOP 2004    | 6.8    | pH units             |
| Silica*^              | Subcontracted            | 4.73   | mg/l                 |
| Sulphate              | Konelab Aquakem SOP 2062 | 19.34  | mg/l SO <sub>4</sub> |
| Strontium*            | ICP-MS                   | <10    | ug/l                 |
| Total Coliforms*      | Quanti-tray SOP 2090     | 0      | MPN/100ml            |
| Total Organic Carbon* | Oxidation & Colourimetry | 0.3    | mg/l                 |
| Turbidity             | Turbidimetric SOP 2022   | 0.49   | NTU                  |
| Zinc                  | ICP-MS                   | 27     | ug/l                 |

Signed: Wendy McCall

Date: 03/08/2017

**Wendy McCall - Laboratory Manager**

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# Test Report

**Lab Report Number: 5023J03****Analysis Number: 99A/106096****Customer ID:** BULL.G1**Analysis Type:** Misc. Tests (99A)**Contact Name:** MICHAEL HYNES**Delivery By:** IAS Collection Chargable**Company Name:** NATIONAL FED GWS**Sample Card Number:** NFGWS/BULL/3**Address:** BULLAUN (LOUGHREA) GWS  
BALLYARA  
BULLAUN  
LOUGHREA**Sample Condition:** Acceptable**Sample Type:** Collection**Date Sample Received:** 24/07/2017**Sample Reference:** GALWAY, BULLAUN/LOUGHREA GWS**Date Analysis Commenced:** 24/07/2017**Sample Description:** COLLECTION**Date Certificate Issued:** 24/07/2017

| Parameter  | Method | Result | Unit |
|------------|--------|--------|------|
| Collection |        | -      |      |

Signed: Wendy McCall  
**Wendy McCall - Laboratory Manager**

Date: 24/07/2017

^ = Subcontracted

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## BH 2 DBO Operator Monthly Check Monitoring data compiled from Monthly Status Reports

| Sample Date | Aluminium<br>ug/l | Colour,<br>apparent<br>mg/l PtCo | Iron<br>Total ug/l | Manganese<br>Total ug/l | TOC<br>mg/l | Turbidity<br>N.T.U | pH<br>units |
|-------------|-------------------|----------------------------------|--------------------|-------------------------|-------------|--------------------|-------------|
| 13/06/2016  | 14.06             | <5                               | 35.3               | 9.83                    | <0.5        | <0.5               | 7.05        |
| 11/07/2016  | 13.41             | <5                               | 118.17             | 13.3                    | 1.34        | 0.85               | 7.29        |
| 08/08/2016  | 5                 | <5                               | 61.86              | 10.93                   | 0.61        | <0.5               | 7.12        |
| 12/09/2016  | 5.06              | <5                               | 276.36             | 18.09                   | <0.5        | 1.3                | 7.04        |
| 11/10/2016  | 8.34              | <5                               | 140.18             | 20.19                   | 0.93        | 2.55               | 6.9         |
| 14/11/2016  | 5.3               | <5                               | 27.2               | 11.8                    | 0.62        | <0.25              | 7.42        |
| 05/12/2016  | 21.16             | 8                                | 146.1              | 10.1                    | 0.83        | 1.02               | 6.98        |
| 09/01/2017  | <5                | <5                               | 179                | 13.4                    | 0.69        | 0.49               | 7.17        |
| 13/02/2017  | <5                | 62.5                             | 11.2               | 1.2                     | <0.25       | 7.21               |             |
| 13/03/2017  | 7.4               | <5                               | 51.3               | 10.7                    | 1.51        | 0.25               | 7.4         |
| 10/04/2017  | <5.0              | 7                                | 31.2               | 12.4                    | 1.08        | <0.25              | 7.08        |
| 08/05/2017  | <5.0              | <5.00                            | 16.8               | 10.3                    | <0.500      | 0.47               | 7.07        |
| 24/07/2017  | <20               |                                  | 44                 | 20                      | 0.3         | 0.49               | 6.8         |

## ***Appendix 4***

# ***Water Level Monitoring Calculations***

---



# Hydro-G

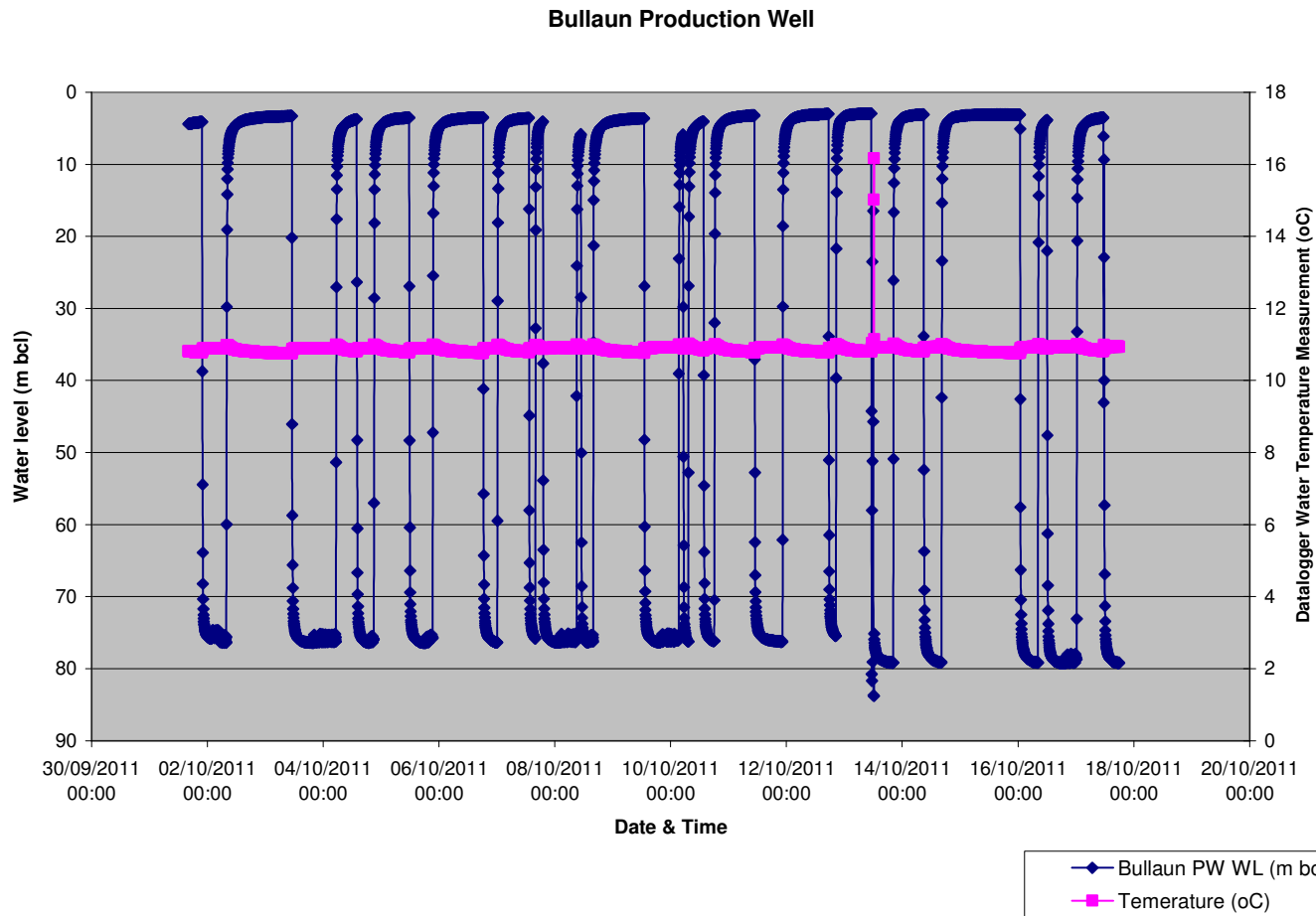


**Figure 1**

Bullaun PW Water Level Responses (1<sup>st</sup> to 17<sup>th</sup> Oct 2011). Requires receipt and integration of Glan Agua Flow (abstraction rate data for October – currently being downloaded by Glan Agua)

### Transmissivity Calculations and Sensitivity Analysis

| Borehole | Q (m <sup>3</sup> /hr)<br>(source avg<br>pump rate<br>recorded during<br>pump cycle) | Q<br>(m <sup>3</sup> /day) | Factor | b (m) | s (m) | Data source                                                                                                                                                                                                                                                                                                 | T (1) (m <sup>2</sup> /day)<br>(T = 1.22Q/s<br>Confined Logan) | T (2) (m <sup>2</sup> /day)<br>(T = 2.43 Qb/(s(2b-s))<br>Unconfined Logan,<br>after Misstear, 1998<br>GW Newsletter No. 34) | T (1) + Error<br>+10% | T (1) + Error<br>-10% |
|----------|--------------------------------------------------------------------------------------|----------------------------|--------|-------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|-----------------------|-----------------------|
| BH2      | 20                                                                                   | 480                        | 1.22   | 110   | 68    | s: 17-18/10/2011 Hydro-G diver<br>monitoringn for DBO Operator;<br>b: used full depth of BH since pump<br>depth not certain, therefore<br>probably in accurate ;<br>Q: Glan Agua DBO Operator MSR;<br>Note that the BH is designed to<br>exclude all water except from<br>fractures from 65 to 110 m b.g.l. | 9                                                              | 12                                                                                                                          | 9                     | 8                     |

### Uniform Flow Eqn (confined) Downgradient Distance (Todd D.K., 1980 Groundwater Hydrology)

Distance =  $Q/2\pi Kbi$

| Borehole | Q (m <sup>3</sup> /d) | T (m <sup>2</sup> /d) | i    | DGD (m) |
|----------|-----------------------|-----------------------|------|---------|
| BH1      | 280                   | 12                    | 0.01 | 372     |

### Uniform Flow Eqn (confined) Maximum Half Width calculation (Todd D.K., 1980 Groundwater Hydrology)

Distance = +/-  $Q/2Kbi$  Unconfined conditions met.

| Borehole | Q (m <sup>3</sup> /d) | T (m <sup>2</sup> /d) | i    | Max Half<br>Width (m) |
|----------|-----------------------|-----------------------|------|-----------------------|
| BH1      | 280                   | 12                    | 0.01 | 1167                  |

Groundwater gradient (i) estimated from 2 spring discharges across a distance of 900 m.

Transmissivity (T) unconfined value of 12 m<sup>2</sup>/day, estimated from BH2

# ***Appendix 5***

## ***Acronyms and Glossary***

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## Acronyms

EPA – Environmental Protection Agency  
DEHLG – Department of Environment Heritage and Local Government  
EU – European Union  
GSI – Geological Survey of Ireland  
GWB – Groundwater Body  
GWD – Groundwater Directive (European Union)  
GWS – Group Water Scheme  
IGI – Institute of Geologists of Ireland  
IG – Irish National Grid Reference  
m aOD – metres above Ordnance Datum  
m bgl – metres below ground level  
TVs – Threshold Values  
UV – Ultra-Violet  
ZOC – Zone of Contribution  
WFD – Water Framework Directive

## Glossary of Terms

### ***Aquifer***

A subsurface layer or layers of rock, or other geological strata, of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater (Groundwater Regulations, 2010).

### ***Attenuation***

A decrease in pollutant concentrations, flux, or toxicity as a function of physical, chemical and/or biological processes, individually or in combination, in the subsurface environment.

### ***Borehole***

A particular type of well - a narrow hole in the ground constructed by a drilling machine in order to gain access to the groundwater system.

### ***Boulder Clay***

See 'Till'

### ***Conceptual Hydrogeological Model***

A simplified representation or working description of how a real hydrogeological system is believed to behave on the basis of qualitative analysis of desk study information, field observations and field data.

### ***Diffuse Sources***

Diffuse sources of pollution are spread over wider geographical areas rather than at individual point locations. Diffuse sources include general land use activities and landspreading of industrial, municipal wastes and agricultural organic and inorganic fertilisers.

### ***Direct Input***

An input to groundwater that bypasses the unsaturated zone (e.g. direct injection through a borehole) or is directly in contact with the groundwater table in an aquifer either year round or seasonally.

### ***Doline***

Dolines, or enclosed depressions, are relatively shallow bowl or funnel shaped depressions that form in karst landscapes, and serve to funnel or concentrate recharge underground. Their presence indicates that subterranean drainage is in operation.

### ***Dolomitisation***

Is a process, whereby the calcite crystals in limestone is replaced by magnesium. This results in an increase in the porosity and permeability of the rock. Dolomitised rocks are a highly weathered, yellow/orange/brown colour and are usually evident in boreholes as loose yellow-brown sand with significant void space and poor core recovery. Dolomitisation often occurs preferentially in both fault zones and purer limestones.

