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APPENDIX 1

GSI Establishment of Groundwater Zones of Contribution New Inn Report

Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

Geological Survey
Suirbhéireacht Gheolaíochta
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Geological Survey Ireland

Establishment of Groundwater Zones of Contribution

New Inn 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 New Inn 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). 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. Therefore, variation in subsoil type and thickness is 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[1]. 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.

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.

New Inn GWS (G131) currently abstracts an average of 307 m^3/day from three boreholes pumping from a shallow locally important sand and gravel aquifer. The GWS comprises a total of seven adjacent operational boreholes. Three of these currently provide the supply.

[1] Geological Survey of Ireland, 2000

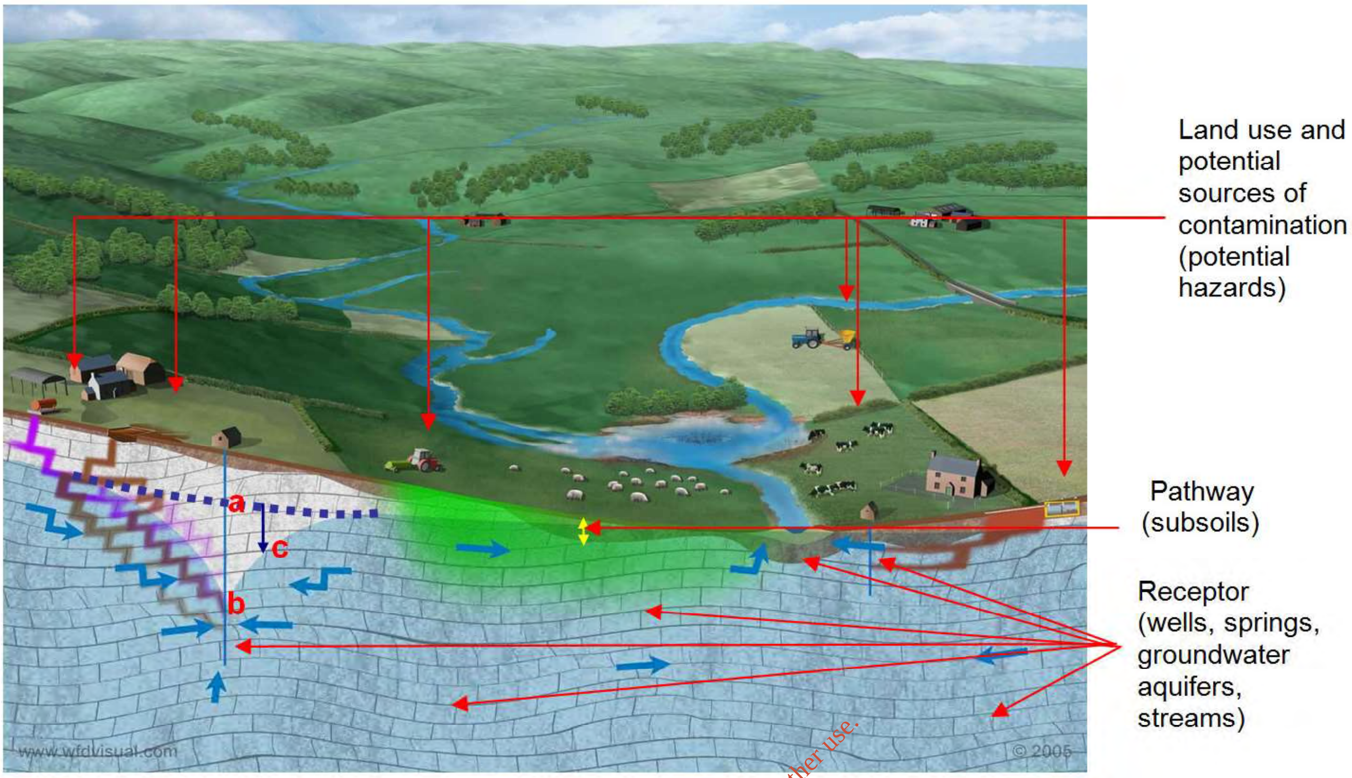

Diagram 1. Rural Landscape highlighting the Interaction between Surface Water, Groundwater and Potential Hazards

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

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

New Inn GWS is currently supplied from boreholes located in the grounds of the community centre on the western outskirts of New Inn village, Co. Galway (**Figure 1**). The scheme has comprised a maximum of nine boreholes, of which seven are still in existence and three provide the current supply. All of the seven existing boreholes have

[2] DELG/EPA/GSI, 1999

working, networked, pumps installed. A table of the nine boreholes and available report information is included in **Appendix 5**. The positions of the nine boreholes are set out in **Diagram 2**.

The scheme boreholes were drilled in five phases. These occurred in the 1970s (sited by Bob Aldwell, GSI), in 1989-1990 (sited and designed by Shane O'Neill of Environmental Resource Analysis) and in 1996, 2000 and 2003-4, these latter with design and/or supervision by David Ball. In addition, three observation piezometers were installed in 1994 around BH 2 (drilled 1989-1990), as part of a research project carried out by Heidi Price of Trinity College Dublin. These piezometers, BH1 (drilled in 1970s, use stopped pre-1999) and BH5 (drilled in 2000) have been covered over (not de-commissioned), using a digger, then surfaced over with Clause 108 type hardstand material. They are all in un-fenced grassed areas. BH 2, BH 3, BH 4 and BH 6 are within 1-2 m of roadway and/or parking.

The scheme has a complicated borehole supply history. This is due to the boreholes being supplied by a thin layer of sand, gravel and/or cobbles varying from 2 to 8 m thick, with seasonally limited ability to transmit water, when water levels drop within the sand and gravel body during periods of low rainfall. Various combinations of the nine boreholes have been used, as they were commissioned, to supply the scheme's usage over time, while avoiding subsidence of surrounding land (such as occurred when BH 2 (drilled 1989-1990) was pumped alone) and also to avoid reduction in supply due to accumulation of sediment pulled into the screen/boreholes. The boreholes drilled in each of Summers 1996 (BH 3 and BH 4) and in 2000 (BH 5 and BH 6) were essentially 'emergency' boreholes drilled and commissioned rapidly, to supplement an insufficient supply. BH S1, BH S2 and BH S3 (drilled 2003) were a planned drilling and testing programme. The headworks of BH S1, BH S2 and BH S3 (drilled 2003) are all above ground level, surrounded by water-proof, insulated kiosks and have individual discharge meters. The headworks of BH 2, BH 3, BH 4 and BH 6 were surrounded by a variety of below ground chamber types post-drilling and their casing tops cut down to below ground level to fit within the chambers. These boreholes are not measured by individual or grouped borehole discharge meters.

The three boreholes BH 2, BH 4, and BH 6 currently provide the supply.

Recorded scheme usage has reduced from an estimated average of 680 m^3/day from July 1996 – March 1999 (Ball, D. (1999) see **Appendix 5**) to an average usage of 307 m^3/day in May 2017 (Treated water flow, Coffey Water Monthly Status Report May 2017). Individual premises were metered in 2010-2011, which resulted in a significant reduction in usage. Boreholes S1, S2 and S3 were taken out of usage as a result. A second significant reduction in usage occurred following an upgrade of part of the network in 2015 coupled with metering of the distribution line, which allows for rapid location of leaks (Coffey Water Monthly Status Reports, March 2007 – May 2017).

The scheme currently serves 385 domestic connections and 156 non-domestic, which include two schools, a community hall, commercial, domestic and agricultural connections.

Pumping of the current three supply boreholes, BH 2, BH 4, and BH 6, occurs simultaneously in response to a level switch in the raw water reservoir (c. 33 m^3 capacity) which precedes the treatment system. The pumps are set at a rate which pumps an estimated 60% of the abstraction from BH 2 and 20% from each of BH 4 and BH 6. The pump rates are specifically set by the DBO operator to avoid the pumps tripping out due to low water levels, based on previous pumping experience. The relative percentage estimate is based on visual observation of flow into the raw water tank by the DBO operator. The raw water is pumped through the treatment system, by two pumps working in rotation, to a reservoir with a capacity of 630 m^3 at Lisnamoultan, approximately 2 km away. Flow in the distribution network is predominantly by gravity from the reservoir. Supply to an area to the north of the reservoir is pumped by a booster station beside the reservoir.

The treatment system, which follows the raw water reservoir, comprises a three-medium pressure filter, ultra violet irradiation disinfection and residual chlorine disinfection.

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

Diagram 2. Aerial photo showing location of GWS abstraction points

Photo 1. BH2 headworks in pump chamber

Photo 2. BH2 chamber top and setting

Photo 3. BH4 headworks in pump chamber. Note water ingress to borehole

Photo 4. BH4 chamber top and setting

Photo 5. BH6 headworks in pump chamber.

Photo 6. BH6 chamber on left and setting. Tank is a FloGas fuel tank, with gas piped to the community centre.

Table 1. Water Supply Details

NFGWS No. G131	BH 2	BH 4
Grid reference ITM:	Easting 567276, Northing 728009	Easting 567248, Northing 727954
Townland	Castlebin South	Castlebin South
Source type	Borehole	Borehole
Drilled	1989-1990	1996
Drilling Contractor	Not known, partially supervised by S. O'Neill.	Unknown, supervised by David Ball
Owner	New Inn GWS, Coffey Water DBO Operator.	New Inn GWS, Coffey Water DBO Operator.
Elevation in metres above Ordnance Datum	c. 85 m (Estimated from OSI 1:2,000 Scale Map)	c. 85 m (Estimated from OSI 1:2,000 Scale Map)
Total depth (m)	11.5	9
Construction details (See Ball, D. (1999) **Appendix 5**)	c. 2 m 200 mm diameter PVC casing; c. 7 m slotted (2mm) screen, but broken in transit. Presumed extension of 200 mm diameter PVC casing; Pea gravel; (Screen and gravel combination too large to keep out fine sand); No grouting. (BH info. collated by Ball, D. (1999)). BH headworks in b.g chamber with base at 1.29 m g.l., top of casing is at 0.13 m above base of chamber. Water in chamber observed winter 2011 (EPA/WRBD, 2011).	Unknown depth of 400 mm diameter PVC casing; 2 m 200 mm diameter HG PVC casing 5.5 m 200 mm diameter HG PVC slotted casing (Cut on site with saw); 1.5 m 200 mm diameter HG PVC casing; No grouting (Ball, D., 1999) BH headworks in b.g chamber with base a at 1.2 m g.l., top of casing is at 0.18 m above base of chamber. Direct ingress of surface water to BH observed on 21/6 and 4/9/2017 and in winter 2011 (EPA/WRBD, 2011).
Depth to rock in metres below ground level (m bgl)	c. 8 m	9 m
Inflow zones (m bgl)	Not known	Not known
Static water level (SWL) (m bgl)	1.79 Site visit 4/9/2017, w.l. probably impacted by previous pumping.	1.43 Site visit 4/9/2017, w.l. probably impacted by previous pumping
Pumping water level (PWL) (m bgl)	4.06 Site visit 4/9/2017, pump rate estimated 26 m^3/hr)	c. 4.0 Site visit 4/9/2017, pump rate estimated 9 m^3/hr)
Pump intake depth (m bgl)	Initially > 8 m, currently unknown.	Unconfirmed
Current abstraction rate (m^3/d)	184 (Estimate based on DBO operator estimate that BH 2 provides 60% of total abstraction)	61 (Estimate based on DBO operator estimate that BH 4 provides 20% of total abstraction)
Number of Connections (3 BHs)	541	
Reported yield (m^3/d) Based on current sustainable rate	184 in conjunction with BHs 4 and 6; 660 in conjunction with BH1	61 in conjunction with BHs 4 and 6;
Specific Capacity (m^3/d/m)	Not available	Not available
Transmissivity (m^2/d) (See **Appendix 6** Calculations)	150	
Photograph Nos.	Photo 1 and 2	Photo 3 and 4

NFGWS No. G131	BH 6
Grid reference ITM:	Easting 567257, Northing 727991
Townland	Castlebin South
Source type	Borehole
Drilled	June 2000
Drilling Contractor	Unknown, supervised by David Ball
Owner	New Inn GWS, Coffey Water DBO Operator.
Elevation in metres above Ordnance Datum	c. 85 m (Estimated from OSI 1:2,000 Scale Map)
Total depth (m)	9
Construction details (See Ball, D. (2005) **Appendix 5**)	3 m 127 mm diameter PVC casing; 6 m 127 mm diameter slotted (1mm) screen; Screen enclosed in 300 micron pore size geotextile sleeve; Natural gravel pack partially developed. No grouting. BH headworks in b.g chamber with base a at 1.2 m g.l. Top of casing is at 0.23 m above base of chamber. Direct ingress of surface water to BH observed in winter 2011 (EPA/WRBD, 2011).
Depth to rock in metres below ground level (m bgl)	c. 8 m
Inflow zones (m bgl)	Not known
Static water level (SWL) (m bgl)	1.89 Site visit 4/9/2017, w.l. probably impacted by previous pumping.
Pumping water level (PWL) (m bgl)	Not known
Pump intake depth (m bgl)	Not known.
Current abstraction rate (m^3/d)	61 (Estimate based on DBO operator estimate that BH 4 provides 20% of total abstraction)
Number of Connections (3 BHs)	541
Reported yield (m^3/d)	216 estimate during drilling (Ball, D., 1999); 61 in conjunction with BHs 4 and 6.
Specific Capacity (m^3/d/m)	Not available.
Transmissivity (m^2/d) (See **Appendix 6** Calculations)	150
Photograph Nos.	Photos 5 and 6.

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

	Description/Comments
Topography (**Figure 1 & Figure 2**)	The boreholes are located at approximately 85 m OD in a relatively low-lying area. The regional topography rises gently eastwards to a height of c. 120 m O.D. at Hazelfort 6 km east. Locally the topography is hummocky, due to the presence of sands and gravel deposits, broadly orientated north-east to south-west and resulting in up to c. 10 m local variation in land height.
Land use	Land use adjacent and to and east of the borehole comprises the urban area of New Inn village. The rural area is dominated by grassland with grazing livestock. There is some commercial plantation forestry. Farmyards and houses and one national school served by septic tanks occur in the area. A waste water treatment plant and percolation area serving a second school and a commercial premises is located on the south east side of the tributary Clogeravaun river.
Surface Hydrology (**Figure 1 & Figure 2**)	The surrounding area is drained by streams and drains which join to form a tributary of the Clogeravaun river. Local and regional drainage is towards the south west, discharging to the sea at Kilcolgan 25 km away, although the local drainage pattern is influenced by the presence of the sand and gravel deposits, generally draining from the edges of and around the deposits where they are overlain by thin, dry soils.
Topsoil http://gis.epa.ie/envision	The soils immediately surrounding the boreholes comprise made ground and peat. Well drained soils occur elsewhere.
Subsoil (**Figure 3**) www.gsi.ie/mapping	Made ground of variable permeability, low permeability peat and lacustrine deposits overlie limestone sands and gravels at the boreholes. To the north east and south west, high permeability glaciofluvial hummocky limestone sands and gravels occur. Low permeability peat extends west and moderate permeability limestone tills dominate to the east of the boreholes.
Groundwater Vulnerability (**Figure 4**) www.gsi.ie/mapping	Bedrock aquifer vulnerability is currently classified as 'Low' at and surrounding the boreholes. The sand and gravel aquifer vulnerability should instead be classified as 'High' or 'Extreme' on the sands and gravels where they are overlain by well drained, thin soils and water levels are <10 or <3 m b.g.l. respectively. (**Appendix 1**).
Geology (**Figure 5**) www.gsi.ie/mapping	The bedrock unit group is Dinantian Upper impure Limestone, comprising the Lucan bedrock formation.
Aquifer Classification (**Figure 6**) www.gsi.ie/mapping	The sands and gravels are classified as the New Inn Gravel Aquifer (**Lg**). The aquifer extends further than its currently mapped extents, which only includes areas of exposed sand and gravel and does not include areas beneath other subsoils. The underlying bedrock aquifer is classified as a Locally Important Aquifer - Bedrock which is Moderately Productive only in Local Zones (**LI**).
Groundwater Body (GWB) www.wfdireland.ie	The groundwater body classification for the bedrock aquifer underlying the New Inn Gravel Aquifer is GWDTE-Rahasane Turlough (SAC000322). www.gsi.ie/Programmes/Groundwater/Projects/Groundwater+Body+Descriptions)
Recharge Coefficient % (**Appendix 3**)	4%–85% Very low recharge rates occur on peat and low rates on limestone till subsoils. Recharge rates have not been mapped by GSI for the areas

	Description/Comments	
Recharge (mm/yr) www.gsi.ie/mapping	29-615	where the sand and gravel aquifer is overlain by thin dry soils to the north of the boreholes, but are considered to be as high as those defined for the hummocky sands and gravels further south (85%).

3.2 Hydrochemistry and water quality

DBO Operator circa monthly check monitoring (2012 to 2017), GWS rural water monitoring data (2000-2001) and a sample collected by the GWS for this project (2017) were used to assess the hydrochemistry and untreated (raw) water quality arising from combinations of adjacent boreholes BH2, BH3, BH4 and BH 6. A single sample from borehole BH S1 (2005) is available. Sampling from 1995 to 2015 was carried out by the EPA. It is likely, that this sample was taken from the combination of boreholes providing supply at the given time of sampling. These data are not therefore included in the summary tables below, although the results are consistent with those tabulated below. All available raw water quality data are presented in **Appendix 3**. BH S1 data is listed in Ball, D. (2005), **Appendix 5.**

The raw water data, excluding the EPA data, are summarised in **Tables 3 and 4**, where they have been compared to the drinking water limits (DWL) from the Drinking Water Regulations (S.I. No. 122 of 2014).

Table 3. Key Hydrochemistry and Water Quality values in raw water samples from unknown combinations of BH 2, BH3, BH 4 and BH 6.

Parameter	No. of samples	Min	Max	Average*	Drinking Water Limit (DWL) or Threshold Value (TV)
Total Hardness (mg/l as $CaCO_3$)	1	326	326	n/a	[-]
Electrical Conductivity (µS/cm) (laboratory)	12	670	773	740	800 (TV), 2,500 (DWL)
Turbidity (NTU)	74	<0.2	1	0.28	[-]
Total Coliforms (MPN[3] /100 ml)	74	0	**201**	44 exceedances (<100 counts) 7 exceedances (>100 counts)	0 (DWL)
	74	0	**165**	29 exceedances	0 (DWL)

[3] MPN is most probable number.

Parameter	No. of samples	Min	Max	Average*	Drinking Water Limit (DWL) or Threshold Value (TV)
Faecal Coliforms (*E. Coli*) (MPN/100 ml)				(<100 counts) 3 exceedance (>100 counts)	
Clostridium Perfringens (cfu/100 ml)	63	0	**3**	8 exceedances (<100 counts)	0 (DWL)
Nitrate (mg/l NO_3)	12	0.3	13.02	6.6	50 (DWL) 37.5 (TV)
Chloride (mg/l)	1	**26.53**	**26.53**	n/a	250 (DWL), 24 (TV)
Ammonium (mg/l NH_4)	12	0	0.18	0.09	0.3 (DWL), 0.225 (TV)
Iron (µg/l)	12	1	20	9	200 (DWL)
Manganese (µg/l)	11	6	8	6.2	50 (DWL)
Potassium:sodium ratio	1	**0.6**	**0.6**	n/a	0.4 (indicator)

*Values below detection limits, are set as the detection limit value for the purposes of calculating averages.

Table 4. Key Hydrochemistry and Water Quality values in raw water sample from BH S1

Parameter	No. of samples	Min	Max	Average	Drinking Water Limit (DWL) or Threshold Value (TV)
Electrical Conductivity (µS/cm) (laboratory)	1	**1193**	**1193**	n/a	800 (TV), 2,500 (DWL)
TVC (cfu/ml @22°C)	1	**2890**	**2890**	1 exceedance (>100 counts)	0 (DWL)
Faecal Coliforms (*E. Coli*) (MPN/100 ml)	1	0	0	1 exceedance (<100 counts)	0 (DWL)
Nitrate (mg/l NO_3)	1	0.2	0.2	n/a	50 (DWL) 37.5 (TV)
Chloride (mg/l)	1	**41**	**41**	n/a	250 (DWL), 24 (TV)
Ammonium (mg/l NH_4)	1	**1.44**	**1.44**	n/a	0.3 (DWL), 0.225 (TV)
Iron (µg/l)	1	111	111	n/a	200 (DWL)
Manganese (µg/l)	1	66	66	n/a	50 (DWL)
Potassium:sodium ratio	1	**1.8**	**1.8**	n/a	0.4 (indicator)

The data summarised above indicate that the water is 'hard' (326 mg/l as $CaCO_3$) in the 2017 sample, which is typical of gravel aquifers derived from limestone, since the limestone dissolves readily into the groundwater. The average laboratory pH is approximately neutral.

Electrical conductivity (E.C.) is consistently high to very high. High E.C. is to be expected in groundwater derived from limestone gravels, however the higher values are also likely to be indicative of the persistent presence of organic or other pollutants. Extremely high E.C. occurred in BH S1 in 2005, at a level which can only be caused by human-induced pollutants.

Nitrate concentrations are low, at levels below the respective TVs and DWLs. Ammonium levels are low during the 2000-2001 period, except for one significant exceedance in the single sample from BH S1.

Iron and manganese concentrations are very low during the period monitored, except for higher values in the single sample from BH S1, which are likely to be related to the organic pollutants impacting on the borehole.

Faecal coliforms were present in 45% of the untreated (raw) water samples, with gross contamination (greater than 100 faecal coliforms per 100 ml) in combined BHs 2, 3, 4 and 6 in Summer 2012 and 2013 and in BH SP1 in Summer 2005. Total coliforms occur in 69% of samples with gross contamination (greater than 100 faecal coliforms per 100 ml) in in combined BHs 2, 3, 4 and 6 in Summer 2012, in Summer and early Winter 2013 and in BH SP1 in Summer 2005.

Clostridium perfringens was present on 8 occasions in raw water in 2012, 2013, 2014 and 2016, 2017, in each case during Spring and/or Summer in samples from combined boreholes BH 2, BH3, BH 6 and previously BH 4. Presence of this bacterium in water is an important indicator of water pollution and useful marker to alert water suppliers to the possible presence of the other stress-resistant pathogens. Treated water monitoring indicates that the treatment system is effective in removing this pathogen.

Chloride is high in both available samples, from BH S1 and the combined BH 2, BH 4 and BH 6 combined sample. The higher level in BHS1 is indicative of pollution, rather than natural sources, since it is associated with high ammonium, conductivity and a high sodium to potassium ratio.

The potassium:sodium (K:Na) ratios measured in both available samples from BH S1 and the combined BH 2, BH 4 and BH 6 2017 are very high and high respectively. The background potassium:sodium ratio in most Irish groundwater is less than 0.4 and often less than 0.3. A K:Na ratio of >0.4, such as occurs here, can be used to indicate contamination by plant organic matter (e.g., slurry).

The pattern of occurrence of microbial pathogen indicators (E. Coliforms, T. Coliforms and Clostridium Perfringens), coupled with high conductivity indicate low-level year round pressure from organic pollutants, such septic tanks and agricultural organic wastes. The gross contamination events, predominantly in Spring-Summer are likely to be associated with land spreading of organic wastes (slurry, farmyard wash water, manure). The low nitrate and ammonium levels, except for one gross ammonium exceedance in 2005 in BH SP1 and a slightly elevated level in the BH 2, 4 and 6 group in 2017, may indicate spreading of organic wastes very close to the supply abstraction point or the presence of preferential flow pathways, such as buried land drains. The exceedance of the ammonia level in BH S1 in 2005, could also arise from the overlying peat subsoils. These results are consistent with the presence of locally extreme vulnerability conditions, resulting from the high permeability of the high sand and gravel and overlying soils, coupled with high groundwater levels (within 3 m of the ground surface). This indicates a vulnerability classification higher than those currently assigned to the area. In addition, at least three of the boreholes have seasonal (BH 2 and 6) or continuous (BH4) direct ingress of water from the chamber into the borehole. The water levels observed suggest that the water comprises groundwater, which floods into the chamber via the un-grouted boreholes, or via the un-sealed chamber base. These boreholes are therefore very vulnerable to any organic or other pollutants entrained in surface water run-off, which can enter the below-ground chamber, via non-sealed covers which are flush with the ground surface.

Raw water turbidity is variable and occasionally high. The pattern of high turbidity indicates that it probably results from sediment being drawn into the borehole by pumping.

The full chemical analysis undertaken of one BH2, BH4 and BH 6 combined sample as part of this study (2017) did not show any other naturally-occurring elements dissolved into the groundwater at concentrations that would cause concern for human health.

Compliance of treated water with appropriate standards was reviewed in DBO Operator Monthly Status Reports from (2007-2017).

Treated water quality of the standard specified in the DBO contract has consistently been achieved.

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**.

High rainfall amounts fall across the area. Effective[4] rainfall percolates down to the water table in the sand and gravel aquifer through any overlying subsoils, replenishing (recharging) it. The sand and gravel aquifer has a high recharge acceptance capacity and so there is little surface water run-off and a low drainage density in areas where the aquifer is overlain by high permeability or very thin soils and subsoils. Where the sand and gravel aquifer is overlain by very low permeability peat subsoils or by till subsoils, there is an increased drainage density. The bedrock aquifer underlying the study area has a relatively low recharge acceptance capacity and in areas where sand and gravels do not overlie it, there is also a higher density of surface water drainage.

The extents and elongated shape of the sands and gravel deposits are a result of its glacial deposition history and the sand and gravel aquifer is thus constrained in its extents. The aquifer extends further than its currently mapped extents, beneath other subsoils, including beneath peat and made ground. The margins of the aquifer to the west are overlain by very low permeability peat subsoils, under which the sand and aquifer is confined and groundwater is thus under higher pressure. In contrast, where there is no overlying peat, groundwater is not confined. Flow through the coarse and fine sediments of the sand and gravel aquifer is intergranular (between the sand and gravel grains) and the sediments have a high ability to transmit water. The sands and gravels are, however, relatively thin and variable in depth. When groundwater levels are low due to abstraction or during periods of low rainfall, this restricts the amount of water that can be transmitted into any borehole during pumping.

[4] 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.

Groundwater flow direction is from east north-east towards the west south-west. In the study area flow direction is influenced by the shape of the sand and gravel deposits. It is likely that groundwater flows from the east north-east and discharges into the tributary of the Clogeravaun river in the area immediately to the south west of the boreholes, where the tributary has been artificially deepened. It is not certain that this river is in connectivity with the sand and gravel where it flows across low permeability subsoils upstream (to the east and north east) or downstream of where it has been deepened, as drainage density in parts of these area is high. Groundwater gradients are very low.

This area is currently classified in GSI mapping as having a low vulnerability to contamination of groundwater. Based on additional information available to this study, it is considered likely that vulnerability to the north west of the boreholes is at least high, and probably extreme. Extreme vulnerability will occur where thin well drained soils overlie the sand and gravel aquifer and where groundwater levels are within 3 m of the surface (See areas of Sand and Gravel Aquifer Vulnerability - Extreme on **Figure 7**). Low vulnerability will occur where low permeability peat and thick limestone tills occur. The dominant pollutant pressures are the presence of on-site waste water treatment systems on or surrounding the mapped area of sands and gravels, and farmyards and the landspreading of organic wastes where thin or high permeability soils and subsoils overlie the sand and gravel aquifer.

The delineation of the zone of contribution boundaries includes a safety margin for some variability in groundwater flow direction and for seasonal variability in abstraction rates and water levels.

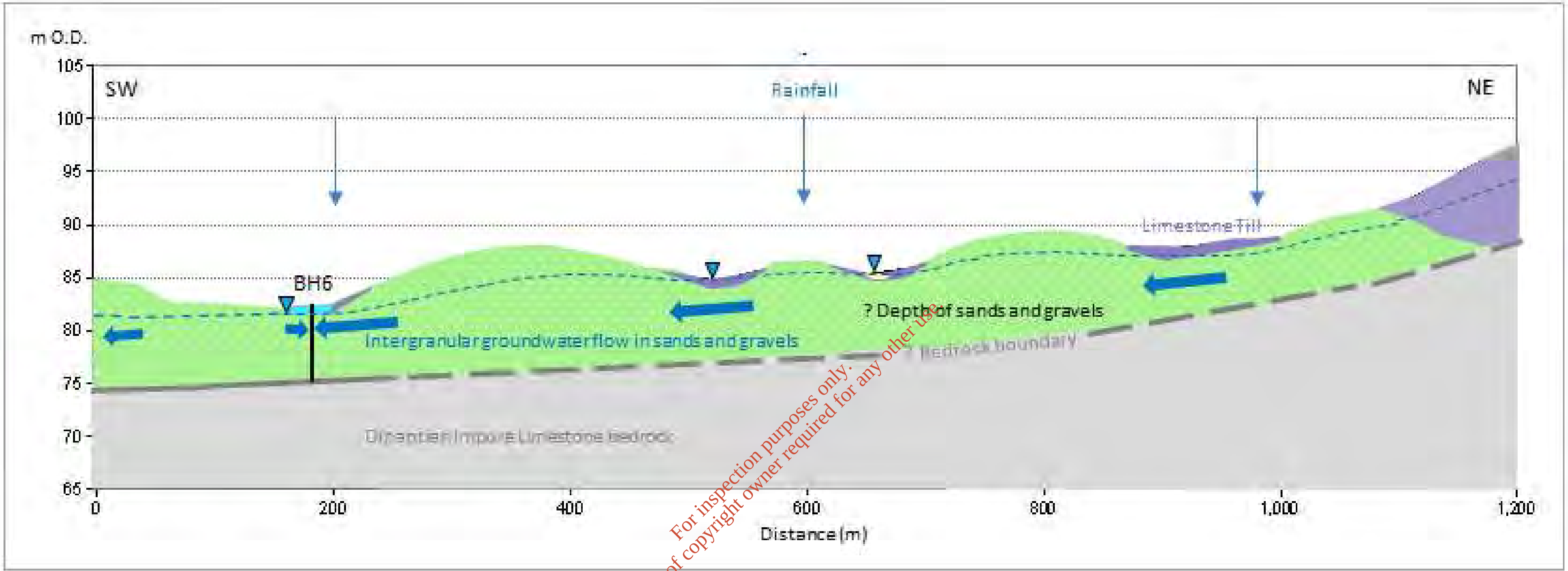

Diagram 3. Vertical cross-section showing conceptual model of groundwater flow. (This cross-section is based on work by N. Duncan of Geological Survey of Ireland's GW3D Programme).

4.2 Boundaries

The Zone of Contribution (ZOC) delineated for New Inn is based mainly on a combination of hydrogeological mapping and inferences, and geological boundaries. The ZOC is delineated for flow to each of the seven operational boreholes on the assumption that any of the boreholes may contribute to the supply.

The **west south-western** (down-gradient boundary) is based on a down-gradient distance of c. 230 m from each of the two groups of wells (BHs S1, S2, S3 and BHs 2, 4, 6) as calculated in **Appendix 6**. This is a conservative estimate of the downgradient distance in the area of BHs 2, 4 and 6 and assumes no connectivity with the river tributary. In fact this boundary is almost certainly defined by the tributary of the Clogeravaun river in the area immediately south west of BHs 2,4 and 6, where the tributary is likely to be in connectivity with the sand and gravel aquifer.

The **east northern-eastern** boundary is based on the likely up-gradient extent of the sand and gravel body, based on the information currently available.

The **north north-western** and **south south-eastern** boundaries are based on interpreted groundwater flow lines estimated from groundwater flow directions, which are likely to be constrained by a combination of the likely extent of the sand and gravel body and the regional topographic gradient.

The orientation of the ZOC boundaries are different to those set out in EPA (2011) and represent an update of that report. The position of the boundaries in this report are aligned to take account of a combination of the east north-east to south south-westerly regional orientation of the likely boundaries of the sand and gravel body and regional topographic gradients.

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 0.70 km^2 is sufficient to provide c. 528 m^3/day, which is c. 170% of the abstraction recorded during May 2017 of 307 m3/day. The water balance calculation assumes that the recharge occurs at a rate of 85% across the approximately 40% of the area where thin soils overlie the sand and gravel aquifer, and at a rate of 7.5% or less across the approximately 60% of the area overlain limestone till subsoils or peat. The area assigned the higher rate is conservative and is likely to underestimate the amount of recharge available to supply the annual average borehole abstraction.

5. Conclusions

New Inn GWS is currently supplied by three of a group of nine operational boreholes, which draw water from a variably thin sand and gravel aquifer. Historically up to six of these boreholes have been pumped simultaneouly, in order to supply a higher demand. Pumping rates have to be managed in order to avoid pump cut out, particularily when water levels drop during periods of low rainfall, and to avoid subsidence or inducing sediment influx into the boreholes.

The elongated shape and variably thin thickness of the sands and gravel aquifer is caused by its glacial depositional history, which result in constraints on its extents and ability to transmit water. Rainfall recharges the high permeability sand and gravel aquifer at high rates where it is overlain by thin, well drained soils and at significantly lower rates where it is overlain by low permeability soils and subsoils. The ZOC of 0.70 km^2 is bounded primarily by the likely extents of the sand and gravel aquifer, by a calculated downgradient distance and by interpreted groundwater flow lines, which result from a combination of regional topography and the local topography of the sand and gravel aquifer. Connectivity between surface water and groundwater is only likely to occur where surface water channels have been artificially deepened.

The available water quality data indicate that areas of the sand and gravel aquifer overlain by thin well drained soils where coupled with high groundwater levels have a high or extreme vulnerability to pressures caused by organic wastes. There is sub-optimum borehole construction and in particular, poor well head protection, at boreholes constructed before 2005 (i.e. BH2, BH3, BH4, BH6). The three current abstraction borehole chambers are seasonally or constantly flooded by groundwater, making them vulnerable to pollutants entrained in surface water run-off. Boreholes BH S1, BH S2 and BH S3 are well constructed and have sealed headworks. There are two filled in boreholes (BH 1 and BH 5) and a set of piezometers within an unfenced, trafficked area, which have not been de-commissioned. Treated water quality of the standard specified in the DBO contract has consistently been achieved, indicating that the treatment system is effective in removing monitored pollutants.

Groundwater vulnerability is likely to be extreme, rather than the currently mapped low, across a large area of the zone of contribution.

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.

6. Recommendations

Essential:

- A regular survey of water quality parameters of untreated water that would include alkalinity, hardness, electrical conductivity, nitrate, ammonia, chloride, iron, manganese, potassium and sodium, should be carried out in each of BH2, BH4, and BH6 . This survey should be taken on a monthly basis for the first year and should incorporate samples following a variety of wet and dry rainfall conditions in the preceding week. The above parameters and microbial parameters including E. Coli, T. Coliforms and Clostridium Perfringens should be monitored at one of BHs BH S1, BH S2 or BH S3. This borehole, which is not currently in use, will need to be purged in advance of sampling. All additional sampling should be carried out on the same day as the DBO operator monitoring of the current supply. 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.

- Improvement of head works at boreholes BH2, BH4 and BH 6. This would include:
  - Installation of waterproof chamber lids, raised above the surrounding ground level to exclude surface water run-off.
  - Fencing off of the borehole and adjacent area to exclude people and vehicles. (This has been carried out by the GWS, as of 23/8/2018).
- Landspreading should be undertaken in compliance with the 'Good Agricultural Practice' Regulations (EU, 2017). This means that organic waste should not be spread within 200 m of any of the abstraction points, and no fertiliser should be spread in the closed periods.
- Re-location of the FlowGas tank or, at a minimum, appropriate bunding of the tank and re-filling area.

Desirable:

- Installation of discharge meters on boreholes BH 2, BH4 and BH 6. This would allow more effective management of pumping rates, water levels and turbidity.
- A Landspreading set-back distance amendment study could be carried out to see if the set-back distances can be varied from 200 m statutory minimum. This is submitted to Galway Co. Co. for assessment.
- Use of the Cryptosporidium Risk Assessment prepared by Ryan Hanley, and update if needed. This can encourage appropriate land management practices in the area.
- Contingent on good raw water monitoring results at one borehole in the BH S1, BH S2 and BH S3 group, consideration should be given to using these boreholes for supply. These boreholes require careful management of the simultaneous pumping scheme (as does the current set of abstraction boreholes) in order achieve their

combined yield iof approximately 345 m^3/day. A suitable pumping scheme is proposed in Ball, D. (2005). Borehole and headworks construction at these boreholes is far superior to that at the other boreholes and they are therefore less vulnerable to pollutant pressures in the immediate vicinity of the boreholes.

- Hazard Mapping in ZOC coupled with mapping of groundwater vulnerability in the rural part of the ZOC.
- Location and de-commissioning of boreholes BH 1, BH 5 and the research project piezometers.

Other:

- The following EPA guidelines may serve as future useful reference documents for the GWS:
  - EPA Guidance on Landspreading of Organic Waste[5]
  - 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[6].
  - 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[7].
  - EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection[8]

[5] http://www.epa.ie/pubs/advice/waste/waste/EPA_landspread_organic_waste_guide.pdf
[6]]http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno7.html#.UpNP_eJ9KEp
[7] http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno8.html#.UpNQf-J9KEo
[8] http://www.epa.ie/pubs/advice/drinkingwater/advicenote14.html#.UpNR8eJ9KEo

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