Establishment of Groundwater Zones of Contribution

Crossmolina/Eskeragh Group Water Scheme

Crossmolina GWS Spring

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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 Crossmolina/Eskeragh 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).

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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 overlying soil and subsoil; thick, impermeable clay soil and subsoil provide good protection while thin, very permeable gravel will provide limited protection. Therefore, variations in subsoil type and thickness are 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.

Crossmolina/Eskeragh GWS is supplied predominantly by a locally productive sand and gravel aquifer (Lg) with intergranular flow. The supply is sourced from a spring abstraction point which also serves the Crossmolina public water supply and periodically overflows.

[1] Geological Survey of Ireland, 2000.

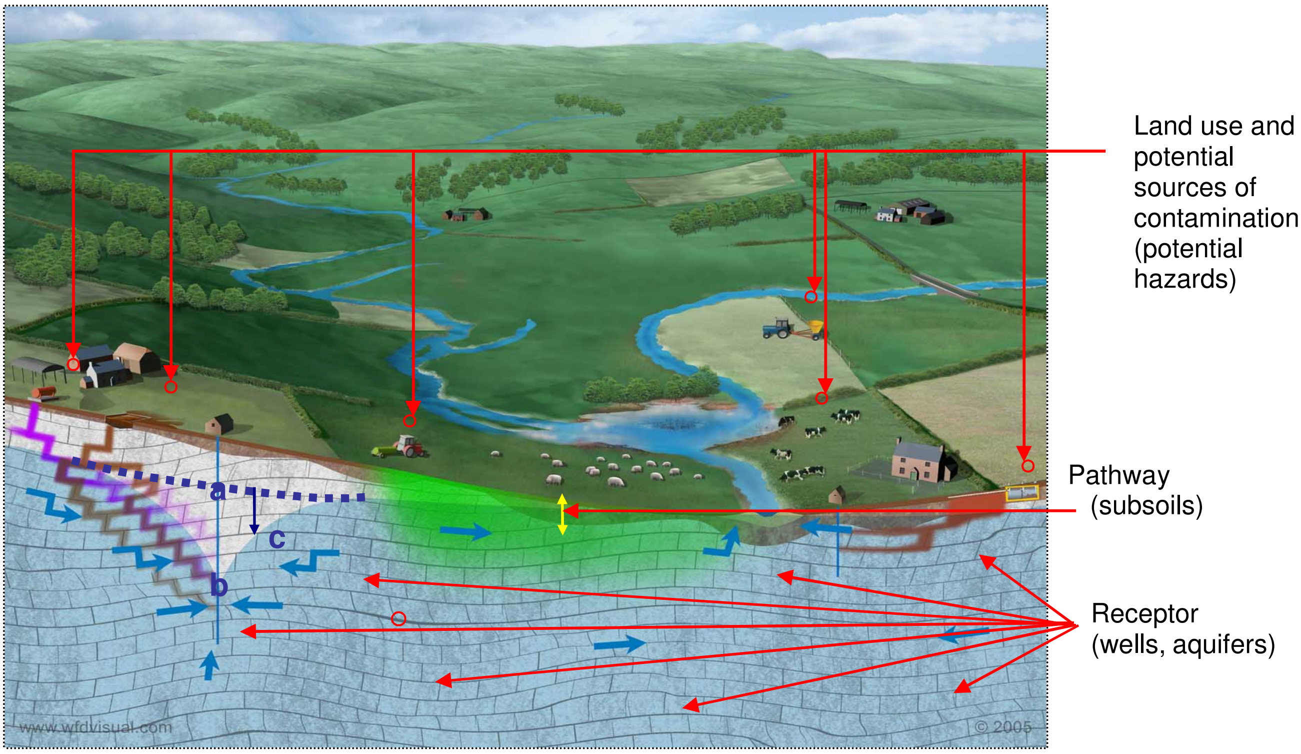

Diagram 1. Rural Landscape Highlighting Interaction between Surface Water, Groundwater and Potential Land Use Hazards.

2 Location, Site Description, Well Head Protection and Summary of Borehole Details

The Crossmolina/Eskeragh Group Water Scheme (GWS) is located in the townland of Tobermore, approximately 4 km west of Crossmolina along the N59 primary route. The GWS supply spring is marked on mid-1800s Ordnance Survey Maps as Tobermore. It is located in the south east corner of a junction of the N59 with a third class road, on which third class road the entrance to the treatment plant and spring infrastructure are both located. (See **Figure 1**). The GWS serves 125 connections, comprising domestic and house and lands connections. The network has been in place for more than 15 years.

Tobermore spring discharges on a break in slope and all of the spring discharge volume appears to be collected by the spring infrastructure. The spring infrastructure comprises a partially closed concrete sump from which the local authority (LA) abstracts water for Crossmolina public water supply and from which an overflow pipe directs overflow to an open topped concrete collection box. The GWS extracts water from this open-topped collection box. There is a seasonal influenced overflow via a v-notch weir at the end of the collection box, which is the source of a short watercourse that flows into a tributary of the Deel River.

The GWS supply has been managed and treated under a DBO contract with Coffey Water Ltd. since 29/6/2010. Previous to this the GWS abstracted water from a point in the overflow watercourse approximately 20 m downstream of the spring and treatment comprised chlorine dosing.

Under the current DBO abstraction system, overflow from the LA sump flows by gravity through a pipe to the adjacent open topped GWS collection box. The box is open to rainfall, vermin and surface water run-off from the surface of the LA sump and concrete surround, which slopes towards the collection box from the roadside. The area is unfenced and has no gate, therefore fully open to animals and people. The GWS constructed an approximately 0.1m high roadside kerb along the third class road which runs within 1m of the spring infrastructure, at approximately 0.3 m above the top of the LA collection sump, in order to reduce the possibility of run-off from the road entering the spring across the sump surface (Photo 2). Water flows by gravity from the GWS open topped collection box, via a pipe to a below ground raw water reservoir inside the treatment works compound, approximately 20 m to the south. The raw water reservoir is covered, locked, vermin proof and likely largely watertight. The treatment works compound is dressed with gravel and surrounded by stock-proof fencing, with a lockable gate. The entrance slopes into this compound from the adjacent third class road (Photo 5). The pump and treatment shed is concrete built, well roofed and has a tightly fitting, lockable door. A pair of duty and stand-by pumps are located in the shed (Photo 6), and pump water via rising mains from the below ground reservoir, via the treatment system and to an external below ground treated water reservoir/contact tank. The treated water is then pumped, by two pairs of variable speed (duty and stand-by pumps) located in the shed to the two separate areas of the GWS network. The system is closed, with no open access to reservoirs/sumps. Average daily abstraction by the GWS is 207 m^3/day (30/6/14-14/8/2014).

Treatment comprises a pressurised sand filter, Ultra Violet irradiation (which includes UVT recording and can be validated) and chlorination. Back-wash from the sand filter is pumped to an external below ground tank, which discharges to ground via a percolation area. No removal of sludge from the tank is required. A locked and palisade fenced container on a concrete pad is used for chemical storage.

The local authority abstraction sump, which overflows into the GWS open topped collection box, has two access points, one outside and one inside the treatment shed. The treatment shed is neither vermin nor waterproof and the sump access inside it is thought to be open. Average daily abstraction by the LA is 770 m^3/day (February 2006 - June 2014). The LA source is dosed with chlorine at a continuous rate into the outflow pipes from the sump. A locked metal shed is used for storage of the LA chlorine dosing chemicals (See Photo 2).

The total discharge from the spring (including the overflow, the group water scheme and local authority abstractions) for which the Zone of Contribution is delineated, is estimated to be of the order of 1,500 m^3/day. (See Appendix 5 for details). **Table 1** below provides a summary of the spring with currently known information.

Table 1. Supply Details

	Tobermore Spring
Grid reference	109970, 317050
Townland	Tobermore
Source type	Spring
Drilled	Current abstraction pipe added to LA infrastructure in 2010
Drilling Contractor	n/a
Owner	Crossmolina GWS Coffey Water Ltd. is scheme DBO contractor
Elevation (m OD) (Estimated from OSI	48 m
Total depth (m)	0 m
Construction details	GWS Supply: Open topped GWS collection box, with approx.. 0.75 m high concrete walls, an area of approximately 5 m x 4 m and with a widely spaced open metal grid over the top and a gravel base. GWS collection box takes piped overflow from adjacent LA covered concrete sump. (Photos 3 and 4) and water overflows via a v-notch weir. Flow from the collection box is by gravity to the treatment works. LA Supply: Cast concrete sump, approximately 1 m deep, approximately 4 x 5 m in area and appears to be comprised of two separate sections connected by a pipe. There are two access points to the sump, one inside an approximately 3x3 m corrugated iron shed, part of the inside sump may be open (See Photo 1) and an exterior one with a manhole type cover. Flow from the sump is by continuous gravity flow, via a 152mm and a 102 mm pipe to an approximately 409 m^3 reservoir.
Depth to rock (m bgl)	Unknown (Estimated >3 m based on High vulnerability classification and ranges of 10 - 23m depth estimated across the Moy sand and gravel groundwater body (Appendix 2)).
Static water level (SWL) when drilled (m bgl)	Unknown
Pump intake depth (m bgl)	No pump in GWS collection box or LA sump.
Current abstraction rate (GWS)	Average 207 m^3/d.
Reported yield (m^3/d)	Estimated 1,500 m^3/d

Photographs of Crossmolina spring infrastructure and treatment compound

Photo 1: Local Authority sump, external access and treatment shed

Photo 2: LA chemical storage shed (right) and roadside kerb installed by GWS

Photo 3: GWS collection box, with overflow weir (under yellow bucket) adjacent to LA sump (with open access point)

Photo 4: Looking into gravel base of collection box, through v-notch overflow weir

Photo 5: Fenced compound with treatment shed and treated water reservoir/contact tank

Photo 6: Raw water duty and stand-by pumps

3 Physical Characteristics and Hydrogeological Considerations

Table 2. Physical Characteristics of the Area of Interest

	Spring Location	Description/Comments
Annual Rainfall (mm)	1429	Met Eireann average annual rainfall data grid 1981-2010
Annual Evapotranspiration and Run-off Losses (mm)	-388	(Annual rainfall – Annual Effective rainfall)
Annual Effective Rainfall (mm)	1041	GSI Recharge mapping (GSI Website, 2013)
Topography	Tobermore spring is located on a break in slope at an estimate height of 48 m O.D.. The surrounding topography is defined by the hummocky surface and extent of the sand and gravel aquifer. The land rises overall to the west and north west, to a maximum of 74m O.D. at a distance of 1 km. The surrounding landscape has a low gradient south east towards Lough Conn which is at height of 5 m O.D. at a distance of 5km.	
Land use	The land is predominantly used for grazing and silage production. There is a high density of farmsteads on the good land defined by the extent of the sand and gravel aquifer and a number of domestic dwellings.	
Surface Hydrology	The spring at Tobermore is the source of a short south wards flowing watercourse (c.120 m). This watercourse joins another arising from springs to the west, (including Tobergalias at a distance of approx. 300m) to form a south easterly, then north easterly flowing tributary of the Deel River, which discharges into Lough Conn. Current 1:50,000 scale O.S.I. mapping shows a watercourse flowing from north to south through the ZOC and Tobergalias. Detailed O.S.I. and aerial mapping indicates that this watercourse does not exist and that Tobergalias is the source of a watercourse which joins the Tobermore watercourse. The density of surface water drainage is low on the sand and gravel aquifer, and at least some is likely to arise from groundwater. All surface watercourses within the ZOC drain south east towards the Deel river.	
Topsoil	Shallow well drained basic mineral soils, interspersed with some shallow poorly drained basic mineral soils. (Teagasc/EPA, 2006).	
Subsoil (**Figure 3**)	Limestone sands and gravels, derived from Carboniferous rocks, dominate. The sands and gravels are classified as hummocky sands and gravels (GSI Quaternary Map, 2014). Cutover peat subsoils occur downhill (downgradient) of the break in slope occurring at approximately 48 m O.D. (Teagasc/EPA, 2006) Limestone till subsoils occur to the north.	
Groundwater Vulnerability (**Figure 4**)	**High** on limestone sands and gravels; **Moderate** on limestone tills to the north. The area within an area 200m uphill (upgradient) of the spring is classified in this project as having extreme vulnerability. See **Appendix 1**	
Bedrock Geology (Long *et al*, 1992) and Rock Unit Group (**Figure 5**)	Ballina Limestone Lower Formation, classified as belonging to the Dinantian Upper Impure Limestone Rock Group.	
Aquifer (**Figure 6**)	A locally productive limestone sand and gravel aquifer (**Lg**) overlies a poor bedrock aquifer, productive only in local zones (**Pl**).	
Groundwater Body	Moy Gravel	Categorised as having 'good' status. https://www.gsi.ie/NR/rdonlyres/B92E993A-0648-4079-BD63-8996B7938342/0/MoySG.pdf
Recharge Coefficient (%) (**Appendix 2**)	A: 60; B: 42.5 C: 85	Low recharge occurs on c. 18% on tills overlying poorly productive aquifer (A). Moderate recharge (442 mm/yr) occurs across c. 9% of the ZOC on poorly drained soils over sand and gravel (B) . High recharge occurs on c.73%, on dry soils over limestone. sand and gravel (C) (GSI Recharge Mapping). The proportion of the ZOC receiving the high recharge rate is potentially greater than the percentages above as currently mapped (See Conceptual model, below and **Appendix 2**)
Recharge (mm/yr) (**Appendix 2**)	A: 200 B: 442 C: 885	

3.1 Hydrochemistry and water quality

Raw water samples have been compared to the drinking water standard (SI 122 of 2014) (Drinking Water Limits) and the European Communities Environmental Objectives (Groundwater) Regulations (SI No. 9 of 2010) (Threshold Values and Groundwater Quality Standards). Five relevant raw water parameters are measured monthly by the DBO contractor, with data available from 20/7/2012 to 8/8/2014 (26 samples). A full suite of groundwater parameters was analyzed in August 2014 (See Appendix 5).

Table 3. Summary of Untreated Water Parameters

Parameter	Number of Values	Maximum	Minimum	Average	Parametric Value/Comment
Total Hardness (mg/l as $CaCO_3$)	1	309	309	n/a	-
Electrical Conductivity (µS/cm)	1	591	591	n/a	800 (TV-lower)
Total Coliforms (number/100ml)	27	20	0	1.37	0 (MAC)
E. coli (number/100ml)	27	3	0	0.27	0 (MAC)
Clostridium Perfrinigens (including spores) (number/100ml)	27	1	0	0	0 (MAC)
Nitrate (mg/l NO_3)	1	11.2	11.2	n/a	37.5 (Groundwater Quality Standard)
Nitrite (µg/l NO_2)	1	<17	<17	n/a	375 (TV)
Ammonium (µg/l N)	1	<32	<32	n/a	65 (TV - lower)
Chloride (mg/l Cl)	1	23.4	23.4	n/a	24 (TV- lower)
Iron (µg/l Fe)	1	57	57	n/a	200 (MAC)
Manganese (µg/l Mn)	1	<5	<5	n/a	50 (MAC)
Turbidity (4 NTU)	27	0.8	<0.2	<0.2	Acceptable to consumers and no abnormal change
Potassium:Sodium	1	0.4	0.4	n/a	-

Raw water electrical conductivity (E.C.) values and also total hardness values are high and within the range of measurements of E.C. (496 – 801 µS/cm) from within the Moy sand and gravel groundwater body. High E.C. and total hardness is consistent with calcareous characteristics and source of the sands and gravels. Hydrochemistry of groundwater at this spring and elsewhere in the Moy sand and gravel groundwater body has a calcium bicarbonate signature (GWB Characterization Report, Appendix 2).

There has been one exceedence of Clostridium Perfringens, five exceedences of E. Coli and nine exceedences of Total Coliforms in twenty seven raw water samples. The numbers of each of these indicator species are, however, low. The E. Coli values indicate pollution resulting from human and/or animal wastes, There is one Clostridium Perfringens, which is used as an indicator of *Cryptosporidium* pollution. This is most usually associated with human and/or animal wastes. The Potassium to Sodium ration of 0.4 is indicative of animal waste rather than human waste sources of pollution, but does not excluded the possibility of human waste also occurring.

There are a number of potential pollutant sources:

- Direct pollution of the open spring collection box or LA sump by animals and/or birds;
- There are a number of domestic dwellings with on-site waste water treatment systems (OSWWTS) local to the spring, with one at approximately 100 m to the north;
- There is potential for surface water drainage, including from the road, to the spring collection box or percolating to groundwater via road side ditches;
- Examination of aerial photographs from 2005, indicate that there are at least four farmsteads within one 1 km to the north west of the spring. Land spreading occurs on almost all of the good land formed by the sand and gravel aquifer to the north west of the spring, according to local knowledge.

These are all potential sources of pollution. However, based on general groundwater flow velocities normally associated with sand and gravel aquifers (e.g. 0.5 m/day), assumed groundwater gradients and the parameter exceedances, nearer sources (conservatively sources within 200m) are more likely to be causing the exceedances.

Other parameters measured have values below detection limits or very low values.

Treated water samples from 2010 when the current DBO abstraction and treatment began to 2014, compiled by Mayo County Council have been compared to the drinking water standard (SI 122 of 2014) (Drinking (Drinking Water Limits). The treated water samples comprise from 100 to 3 analyses of the individual parameters tabulated below.

Parameter	Number of Values	Maximum	Minimum	Average	Parametric Value/Comment
Electrical Conductivity (µS/cm)	25	684	257	623	2,500 (MAC)
Turbidity (NTU)	25	0.60	<0.2	-	Acceptable to consumers and no abnormal change or 0.2 in high Cryptospiridium risk catchments
Total Coliforms (number/100ml)	100	0	0	0	0 (MAC)
E. coli (number/100ml)	100	0	0	0	0 (MAC)
Clostridium Perfrinigens (including spores) (number/100ml)	100	0	0	0	0 (MAC)
Nitrate (mg/l)	25	8.30	<2	-	50 (MAC)
Nitrite (mg/l)	25	<0.02	<0.043	<0.02	0.50 (MAC)
Chloride (mg/l)	3	21.10	19.80	20.40	250 (MAC)
Ammonium (mg/l as N)	26	0.05	0.01	<0.03	0.30 (MAC)
Iron (µg/l)	25	<20	12.90	<20	200 (MAC)
Manganese (µg/l)	25	<20	<1	<20	50 (MAC)
Aluminum (µg/l)	26	<20	<20	<20	200 (MAC)

All of the parameters are below the relevant thresholds and/or detection limits, with the exception of turbidity. There have been 13 exceedences of the 0.2 NTU threshold in treated water recommended in EPA (2009) where there is a risk of the presence of *Cryptosporidium* in the raw water. However, the turbidity exceedences are relatively small and there has been no contamination of treated water or no gross contamination of raw water by species indicative of *Cryptosporidium* risk.

4 Zone of Contribution

4.1 Conceptual model

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

Rain falling on the catchment reaches the groundwater aquifer by diffuse recharge, that is, recharge occurs across the whole land area, rather than at discrete locations. Recharge rates are very high where the high permeability sand and gravels are overlain by dry soils (See Appendix 2), with 85% of effective rainfall percolating down to the groundwater table. Surface water run-off rates are correspondingly low in these areas. These conditions dominate the catchment of the spring. Wet soils are mapped as overlying the sand and gravel aquifer in some areas, here 42.5% of effective rainfall reaches the groundwater table, with a correspondingly higher rate of surface run-off. An area to the north of the spring is currently mapped as limestone till subsoils overlying a limestone, aquifer, that is moderately productive only in local zones (**LI**). Recharge into this aquifer is considered to be limited by its lower capacity to accept the recharge. It is considered likely that part of this area is in fact overlain by an extension of the sand and gravel aquifer, resulting in recharge at the higher (85% rate) over part of this area. (See Appendix 2).

This sand and gravel aquifer in which the majority of the Zone of Contribution supplying the spring zone is located extends north west, west and south of the spring, with a local extent of approximately 1.2 km^2, while being part of the much larger Moy sand and gravel groundwater body. The limestone sands and gravels are hummocky, with varying depth, expected to have a thickness of generally greater than 10m, but with thicknesses of up to 23m recorded elsewhere in the Moy SG groundwater body. .They have high permeability. Groundwater flow through the sands and gravels is intergranular.

The sand and gravel aquifer overlies and is adjacent to the locally important bedrock (limestone) aquifer, productive only in local zones. This bedrock aquifer has no intergranular porosity and flow is confined to fractures and faults, which is typically in the top 15 m, comprising a top weathered zone and a connected fracture zone below this. Groundwater may also flow through deeper, more isolated, fissures, though no such fissures/fractures have been mapped in the area. The characteristics of the sand and gravel and the spring hydrochemistry indicate the sand and gravel, rather than the bedrock aquifer, supplies the majority of the groundwater discharging at the spring, although there may be a small contributions from the underlying bedrock aquifer.

The spring from which the GWS and LA are abstracting and which has a seasonal overflow, is estimated to discharge an annual average of 1,500 m^3/day. It discharges from a break in slope on the south eastern edge of a limestone sand and gravel where the unconfined water table in the sand and gravel aquifer intersects the topography at c. 48m O.D.

The regional direction of groundwater flow is controlled by topography and the discharge point of Lough Conn, Groundwater flow to the spring is therefore predominantly from the north west, and continues to flow onwards towards the south east and Lough Conn.

Groundwater gradients are low in sand and gravel aquifers, as a result of their high permeability. Overall in the Moy SG groundwater body, gradients are estimated to be greater than 0.001. Maximum flow path lengths in the catchment to the spring are estimated to be 1.5 km and are likely to be limited by the maximum up-gradient extent of the sand and gravel aquifer.

The sand and gravel and the possible area of bedrock aquifer to the northwest and up-gradient of the spring, where the recharge supplying the spring zone occurs is classified as high vulnerability. The groundwater vulnerability mapping in the ZOCs is provisional, as there are areas of sand and gravel that are currently unmapped by the GSI. These areas are being mapped under the current GSI Sand and Gravel mapping project, and the ZOC vulnerability and ZOC boundaries should be revisited when this is completed. An area of moderate vulnerability occurs to the north. This area of moderate vulnerability may in fact be high vulnerability if the sand and gravel body extends into this area as suggested here. This area is shown on Figure 7 as a grey hatched area, labelled 'Likely to be High Vulnerability due to the likely extent of as yet unmapped gravels'. Due to the low topographic and groundwater gradients, groundwater levels in the sand and gravel within 200 m up-gradient of the spring are likely to be less than 3 m beneath the ground surface. This area is therefore likely to have extreme vulnerability to groundwater pollution.

4.2 Boundaries

The area contributing groundwater to the spring (the ZOC) comprises 0.86 km^2. The boundaries of this area, which is estimated to support an annual average discharge of 1,500 m3/day are considered to be as follows (See Figure 7 and See Appendix 3 for details).

The **northern western boundary** forms the up-gradient boundary. The boundary is based on the up-gradient extent of the sand and gravel body, a reasonable flow path length in sand and gravel sediments and on the water balance. In addition, a 100 m buffer has also been applied to the up-gradient side of the sand and gravel body boundary.

The **south western and north eastern boundaries** are based on the groundwater flow lines resulting from the topographic and regional control on flow.

The south-**eastern** boundary, i.e. the downhill (down-gradient) extent of the ZOC, is delineated as an arbitrary 20 m buffer zone around the spring to protect it from direct ingress of contaminants.

The local authority and GWS abstractions have been the subject of an EPA/Western RBD site description and ZOC delineation report (EPA, 2011). The EPA/Western RBD ZOC was delineated for a spring discharge of 910 m^3/day and did not take account of the spring overflow. The ZOC area delineated by the EPA/Western RBD is therefore smaller at 0.37 km^2, than the ZOC of 0.86 km^2 delineated during this project.

4.3 Recharge and water balance

The full discharge from the spring (1,500 m^3/d – GWS, LA and overflow from the one source) is the discharge volume for which the Zone of Contribution is delineated. he area required to provide this average annual daily spring discharge rate by diffuse recharge comprises approximately **0.86 km^2**.

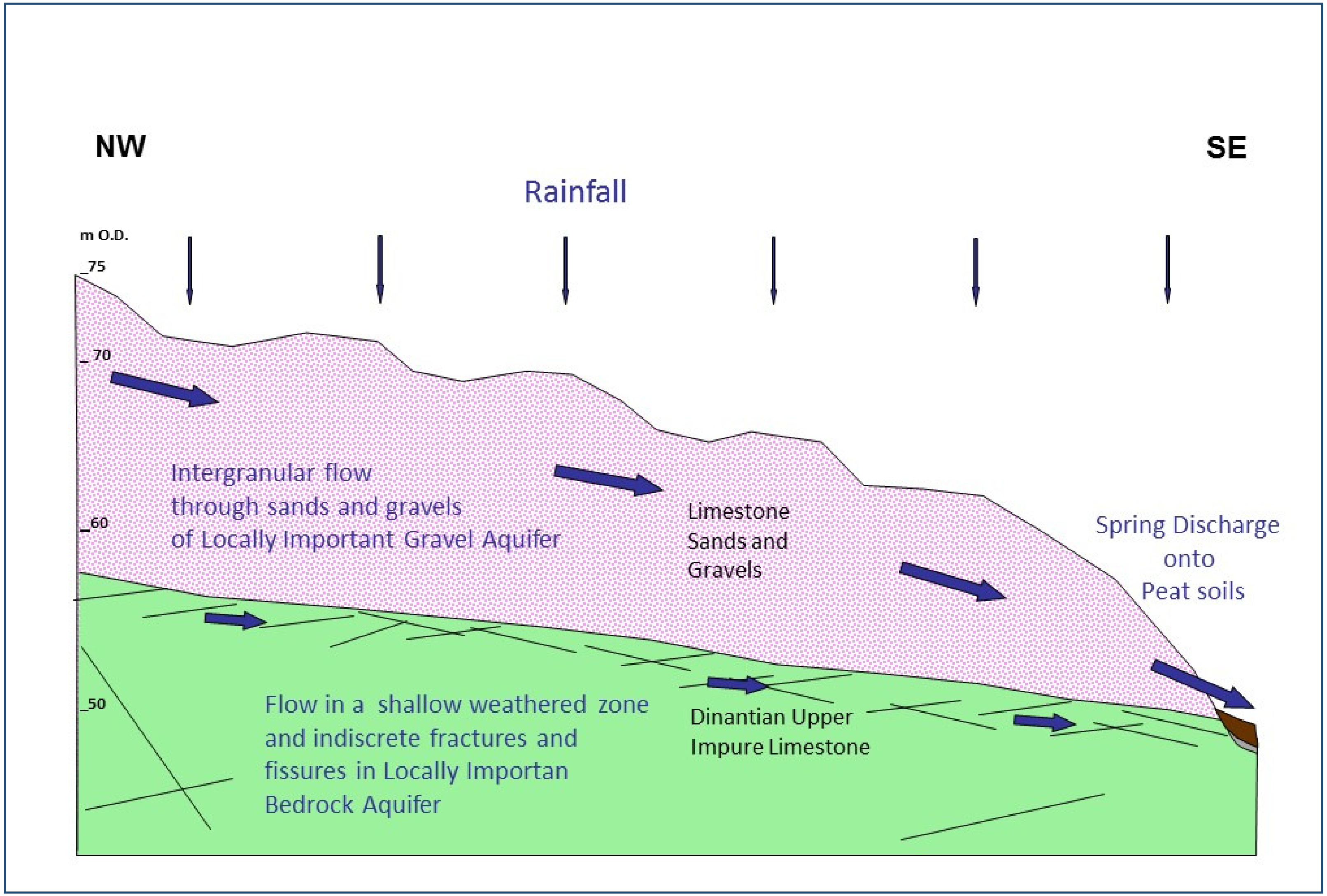

Diagram 3: Schematic Cross Section and Conceptual Model.

5 Conclusions

The GWS currently abstracts an estimated 207 m^3/day from an abstraction point in a spring, which is estimated to discharge an annual average of 1,500 m^3/day. The spring discharges from a break in slope on the south-eastern edge of a limestone sand and gravel aquifer. This high permeability sand and gravel aquifer is hummocky, and is expected to have a thickness of generally greater than 10 m. The sand and gravel aquifer overlies and is adjacent to a low permeability locally important (limestone) bedrock aquifer, which is productive only in local zones (**LI**). The spring hydrochemistry and the characteristics of the sand and gravel aquifer indicate that it provides the majority of the discharge at the spring. Groundwater flow to the spring zone is from the north west.

A ZOC delineation was based on a combination of hydrogeological mapping, water balance calculation and topography. The area delineated as the ZOC comprises 0.86 km^2 and provides an annual average recharge of approximately 1,500 m^3/day to the spring discharge zone.

Exceedences of water quality thresholds for Clostridium Perfrinigens, Total Coliforms Faecal Coliforms have been recorded in the raw water samples. These, with the potassium to sodium ratio, indicate localised sources of pollution by animal and/or human wastes. These are considered likely to arise from the open nature of the spring collection box and from localised sources of pollution. Potential sources are on-site waste water treatment systems, surface water drainage from the adjacent third class road and/or landspreading. Although the ZOC is mapped as having high and moderate vulnerability to groundwater pollution, areas within 200m of the source are likely to have extreme vulnerability and polluting activities within this area have a high risk of impacting on raw water quality.

Treated water quality is good, with all of the relevant standards being achieved.

The EPA/Western RBD site description and ZOC delineation report did not take account of the spring overflow and therefore delineated a significantly smaller at ZOC (EPA, 2011).

6 Recommendations

6.1 Essential

- The area around the spring should be fenced off, with stock proof fencing and a lockable gate.

- The GWS spring collection box should be covered and closed, in so far as possible, to animals and vermin. The overflow could be piped and a raw water sampling point installed.

- If the LA abstraction point includes an open access to the sump, the LA shed should be made vermin and waterproof.

- Drainage and concrete surround should be designed and emplaced such that there is no possibility of road run-off percolating into the immediate area of the spring (there is currently un-paved ground at the road side of the LA shed) or running across the surface of the LA sump to reach the currently open spring collection box.

- Enforcement of the European Communities (Good Agricultural Practise for Protection of Waters) S.I> No. 610 of 2010 regulations, concerning the spreading of organic fertilizer or soiled water, must occur. Organic fertilizer or soiled water should not be spread within 200 m of the up-gradient side of the abstraction point.

- Routine water quality monitoring should be carried out on raw water at the source. The monitoring programme should include a regular survey of water quality parameters that would include coliforms (total and faecal), pH, alkalinity, hardness, electrical conductivity, nitrate, ammonia, chloride, iron, manganese, potassium and sodium. This survey should be taken on a monthly basis for the first year, or at least incorporate samples following a variety of wet and dry rainfall conditions in the preceding week. The chemistry results should be reviewed and if the parameters are generally stable, the frequency (and possibly the list of parameters) could be reduced to quarterly, as recommended by a hydrogeologist.

- Hazard mapping should be undertaken, particularly within 200m of the spring. The design of on-site waste water treatment systems within 200 m of the spring source should be identified, to eliminate or identify whether local on-site waste water treatment systems pose a pollutant risk.

- The groundwater vulnerability mapping in the ZOCs is provisional, as there are areas of sand and gravel that are currently unmapped by the GSI. These areas are being mapped under the current GSI Sand and Gravel mapping project, and the ZOC vulnerability and ZOC boundaries should be revisited when this is completed.

6.2 Desirable

- Further investigations to verify whether the current conceptual model is correct and to identify the extent of the sand and gravel aquifer would assist in the definition of the ZOC and the current assessment of groundwater vulnerability. This would ensure that pollutant pressures within the ZOC could be correctly identified.

- Consultation with the local authority is recommended. The development of a co-ordinated approach between the group water scheme and the local authority could aid in ensuring the best protection of the abstraction area and the Zone of Contribution.

6.3 Other

- The following EPA guidelines may serve as future useful reference documents for the GWS:

    - 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. See http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno7.html

- 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. See http://www.epa.ie/pubs/advice/drinkingwater/epadrinkingwateradvicenote-advicenoteno8.html

- EPA Drinking Water Advice Note No. 14. Borehole Construction and Wellhead Protection. See http://www.epa.ie/pubs/advice/drinkingwater/advicenote14.html

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8 Acronyms and glossary of terms

BGL	Below Ground Level
EPA	Environmental Protection Agency
DEHLG	Department of Environment Heritage and Local Government
EQS	Environmental Quality Standard
EU	European Union

GPZ	Groundwater Protection Zone
GSI	Geological Survey of Ireland
GWB	Groundwater Body
GWD	Groundwater Directive (European Union)
GWS	Group Water Scheme
IGI	Institute of Geologist of Ireland
MOD	Metres Ordnance Datum
MRP	Molybdate-Reactive Phosphorus
NRG	National Grid Reference
NRWMC	National Rural Water Monitoring Committee
PVC	Polyvinyl Chloride
SPZ	Source Protection Zones
TOT	Time of Travel
TVs	Threshold Values
UV	Ultra-Violet
ZOC	Zone of Contribution
WFD	Water Framework Directive (European Union)

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.

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.

Confined Aquifer
A confined aquifer occurs where the aquifer is overlain by low permeability “confining” material. Once all the void space in the aquifer is full of water up to the confining layer, the addition of more water to the aquifer causes the stored water to become pressurised and, the additional water is stored by compression, sealed in

by the overlying confining layer (the water is added upgradient where the confining layer is absent). Where a borehole punctures the confining layer, the water will rise up into the borehole to equalise the confining pressure.

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

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.

Down-gradient

The direction of decreasing groundwater levels, i.e. flow direction. Opposite of upgradient.

Dry Weather Flow (Receiving Water)

The minimum flow likely to occur in a surface water course during a prolonged drought.

Environmental Quality Standard (EQS)

The concentration of a particular pollutant or group of pollutants in a receiving water which should not be exceeded in order to protect human health and the environment.

Enclosed Depression

See doline

Fissure

A natural crack in rock which allows rapid water movement.

Good Groundwater Status

Achieved when both the quantitative and chemical status of a groundwater body are good and meet all the conditions for good status set out in Groundwater Regulations 2010, regulations 39 to 43.

Groundwater

All water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil (Groundwater Regulations, 2010).

Groundwater Body (GWB)

A volume of groundwater defined as a groundwater management unit for the purposes of reporting to the European Commission under the Water Framework Directive. Groundwater bodies are defined by aquifers capable of providing more than 10 m3/d, on average, or serving more than 50 persons.

Groundwater Protection Scheme (GWPS)

A scheme comprising two principal components: a land surface zoning map which encompasses the hydrogeological elements of risk (of pollution); and a groundwater protection response matrix for different potentially polluting activities (DELG/EPA/GSI, 1999).

Groundwater Protection Responses (GWPR)

Control measures, conditions or precautions recommended as a response to the acceptability of an activity within a groundwater protection zone.

Groundwater Protection Zone (GPZ)

A zone delineated by integrating aquifer categories or source protection areas and associated vulnerability ratings. The zones are shown on a map, each zone being identified by a code, e.g. SO/H (outer source area with a high vulnerability) or Rk/E (regionally important karstified aquifer with an extreme vulnerability). Groundwater protection responses are assigned to these zones for different potentially polluting activities.

Groundwater Recharge

Two definitions: a) the process of rainwater or surface water infiltrating to the groundwater table; b) the volume (amount) of water added to a groundwater system.

Groundwater Resource

An aquifer capable of providing a groundwater supply of more than 10 m3/d as an average or serving more than 50 persons.

Hydraulic Conductivity

The rate at which water can move through a unit volume of geological medium under a potential unit hydraulic gradient. The hydraulic conductivity can be influenced by the properties of the fluid, including its density, viscosity and temperature, as well as by the properties of the soil or rock.

Hydraulic Gradient

The change in total head of water with distance; the slope of the groundwater table or the piezometric surface.

Igneous

Igneous rock is formed through the cooling and solidification of magma or lava.

Indirect Input

An input to groundwater where the pollutants infiltrate through soil, subsoil and/or bedrock to the groundwater table.

Input

The direct or indirect introduction of pollutants into groundwater as a result of human activity.***Karst***

A distinctive landform characterised by features such as surface collapses, sinking streams, swallow holes, caves, turloughs and dry valleys, and a distinctive groundwater flow regime where drainage is largely underground in solutionally enlarged fissures and conduits.

Karstification

Karstification is the process whereby limestones are slowly dissolved by acidic waters moving through them. This results in the development of an uneven distribution of permeability with the enlargement of certain fissures at the expense of others and the concentration of water flow into these high permeability zones. Karstification results in the progressive development of distinctive karst landforms such as caves, swallow holes, sinking streams, turloughs and dry valleys, and a distinctive groundwater flow regime. It is an important feature of Irish hydrogeology.

Pathway

The route which a particle of water and/or chemical or biological substance takes through the environment from a source to a receptor location. Pathways are determined by natural hydrogeological characteristics and the nature of the contaminant, but can also be influenced by the presence of features resulting from human activities (e.g., abandoned ungrouted boreholes which can direct surface water and associated pollutants preferentially to groundwater).

Permeability

A measure of a soil or rock‘s ability or capacity to transmit water under a potential hydraulic gradient (synonymous with hydraulic conductivity).

Point Source

Any discernible, confined or discrete conveyance from which pollutants are or may be discharged. These may exist in the form of pipes, ditches, channels, tunnels, conduits, containers, and sheds, or may exist as distinct percolation areas, integrated constructed wetlands, or other surface application of pollutants at individual locations. Examples are discharges from waste water works and effluent discharges from industry.

Pollution

The direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment (Groundwater Regulations, 2010).

Poorly Productive Aquifers (PPAs)

Low-yielding bedrock aquifers that are generally not regarded as important sources of water for public water supply but that nonetheless may be important in terms of providing domestic and small community water supplies and of delivering water and associated pollutants to rivers and lakes via shallow groundwater pathways.

Preferential Flow

A generic term used to describe water movement along favoured pathways through a geological medium, bypassing other parts of the medium. Examples include pores formed by soil fauna, plant root channels, weathering cracks, fissures and/or fractures.

Saturated Zone

The zone below the water table in an aquifer in which all pores and fissures and fractures are filled with water at a pressure that is greater than atmospheric.

Soil (topsoil)

The uppermost layer of soil in which plants grow.

Source Protection Area

The catchment area around a groundwater source which contributes water to that source (Zone of Contribution), divided into two areas; the Inner Protection Area (SI) and the Outer Protection Area (SO). The SI is designed to protect the source against the effects of human activities that may have an immediate effect on the source, particularly in relation to microbiological pollution. It is defined by a 100-day time of travel (TOT) from any point below the water table to the source. The SO covers the remainder of the zone of contribution of the groundwater source.

Specific Yield

The specific yield is the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline of the water table.

Spring

A spring is a natural feature where groundwater emerges at the surface. Springs usually occur where the rate of flow of groundwater is too great to remain underground. The position of a springs usually reflects a change in soil or rocktype or a change in slope.

Subsoil

Unlithified (uncemented) geological strata or materials beneath the topsoil and above bedrock.

Surface Water

An element of water on the land's surface such as a lake, reservoir, stream, river or canal. Can also be part of transitional or coastal waters. (Surface Waters Regulations, 2009.).

Swallow Hole

The point where concentrated inflows of water sink underground. They are found in karst environments.

Threshold Values (TVs)

Chemical concentration values for substances listed in Schedule 5 of the Groundwater Regulations (2010), which are used for the purpose of chemical status classification of groundwater bodies.

Till

Unsorted glacial Sediment deposited directly by the glacier. It is the most common Quaternary deposit in Ireland. Its components may vary from gravel, sands and clays.

Transmissivity

Transmissivity is the product of the average hydraulic conductivity of the aquifer and the saturated thickness of the aquifer.

Unsaturated Zone

The zone between the land surface and the water table, in which pores, fractures and fissures are only partially filled with water. Also known as the vadose zone.

Vulnerability

The intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities (Fitzsimmons et al, 2003).

Water Table

The uppermost level of saturation in an aquifer at which the pressure is atmospheric.

Weathering

The breakdown of rocks and minerals at the earth's surface by chemical and physical processes.

Zone of Contribution (ZOC) The area surrounding a pumped well or spring that encompasses all areas or features that supply groundwater to the well or spring. It is defined as the area required to support an abstraction and/or overflow (in the case of springs) from long-term groundwater recharge

Figures

Figure No: 1		Client: Crossmolina/Eskeragh GWS
Sheet Size: A4		Job: ZOC Delineation
Date: 30/03/15		Title: GWS Location
Scale: NTS		Project No: 124
Drawn By: ST	Checked By: ST	Drawing No: 124_1 RevB

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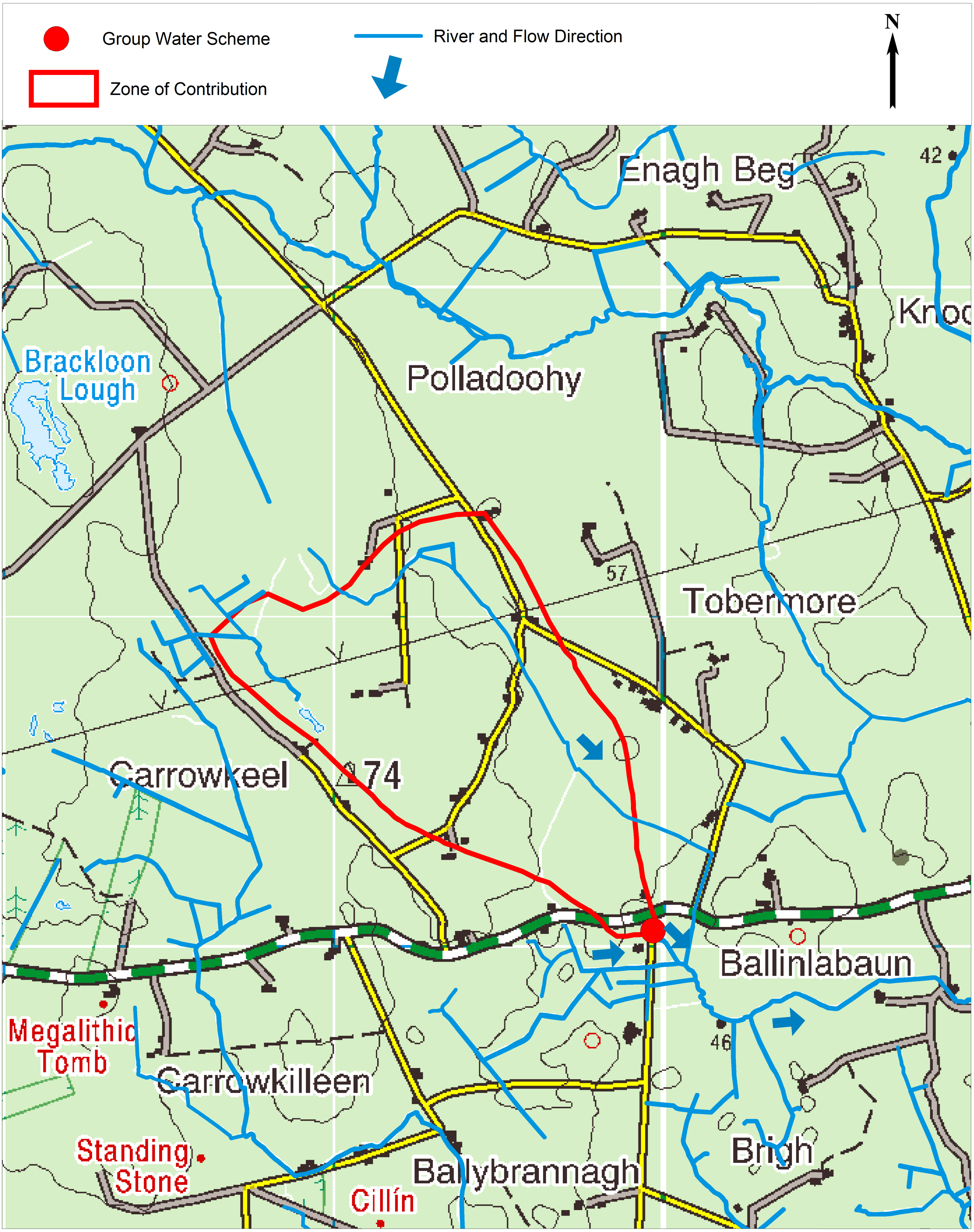

Figure No: 2	Client: Crossmolina/Eskeragh GWS
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Date: 30/3/15	Title: Topography and Regional Drainage
Scale: 1:15,000 @ A4	Project No: 124
Drawn By: ST / Checked By: ST	Drawing No: 124_2 RevB

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Group Water Scheme

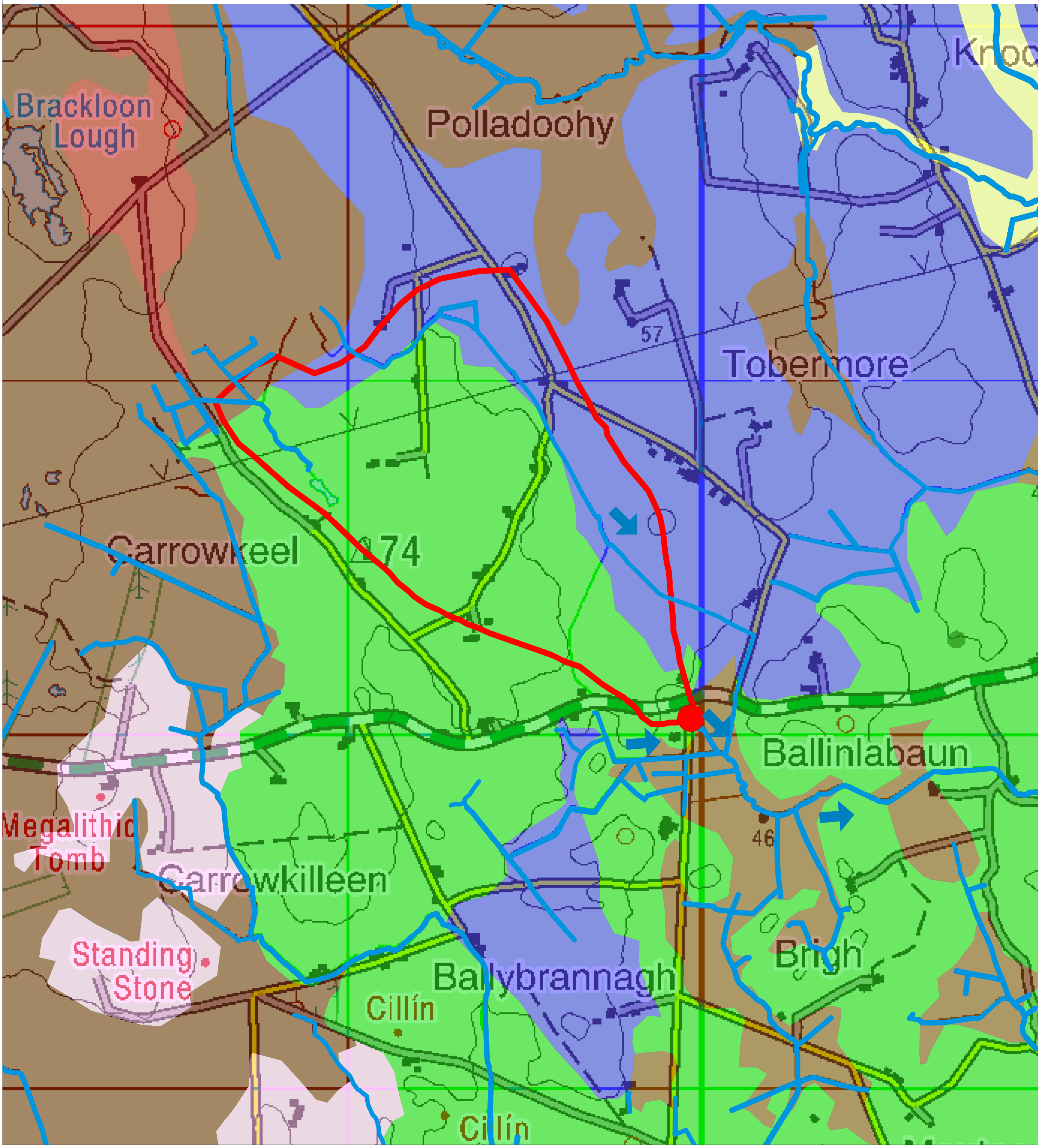
Zone of Contribution

Rivers and Flow Direction

Subsoils (Teagasc/EPA)

- Blanket Peat
- Cutover Peat
- Limestone Sands and Gravels
- Till derived from Carboniferous Sandstones
- Limestone Till
- Metamorphic Till

N



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Date: 30/3/15		Title: Subsoils
Scale: 1:15,000 @ A4		Project No: 124
Drawn By: ST	Checked By: ST	Drawing No: 124_3 RevB

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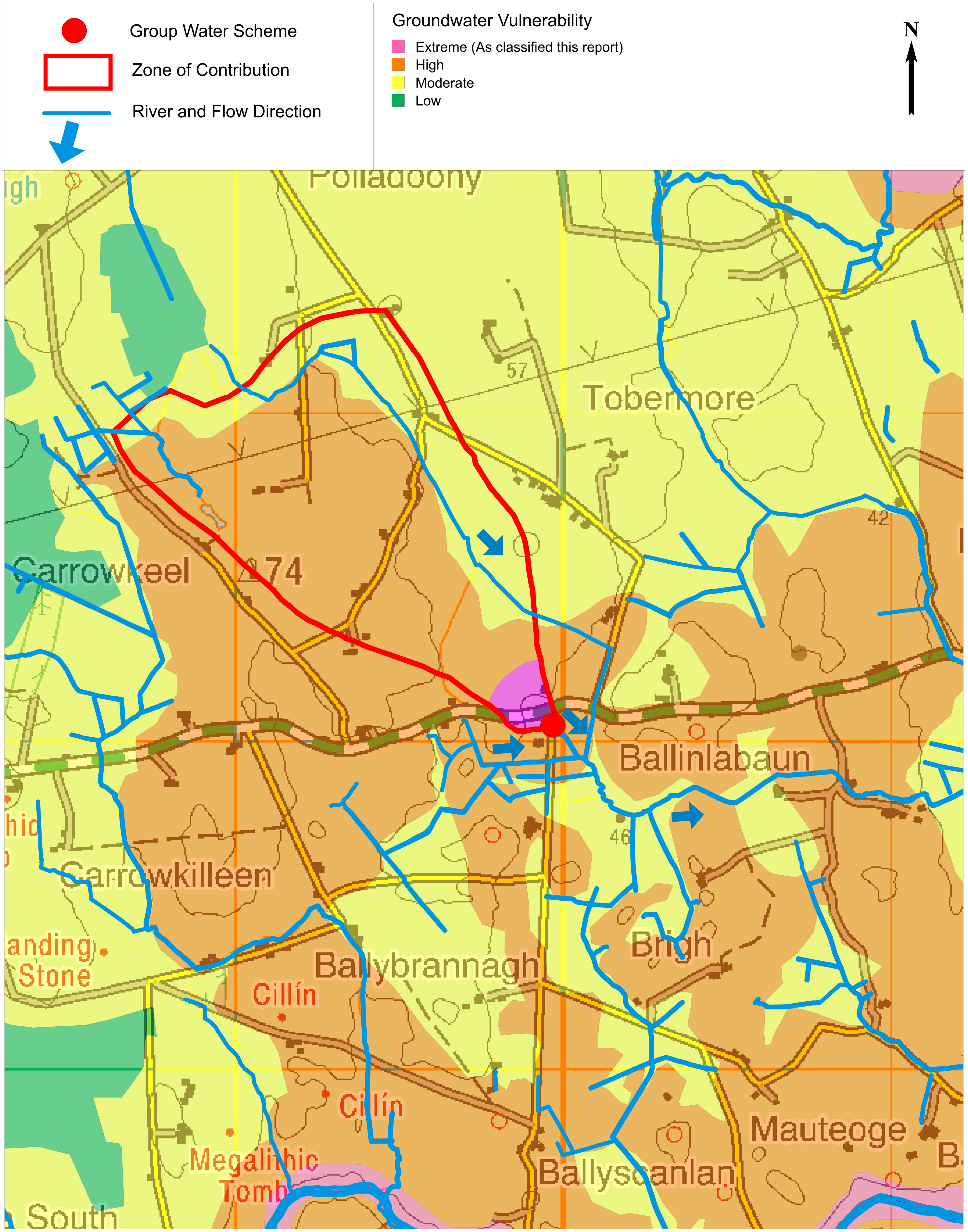

Figure No: 4	Client: Crossmolina/Eskeragh GWS
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Date: 30/3/15	Title: Groundwater Vulnerability
Scale: 1:15,000 @ A4	Project No: 124
Drawn By: ST / Checked By: ST	Drawing No: 124_4 RevB

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Group Water Scheme

Zone of Contribution

Rivers

Geological Rock Units

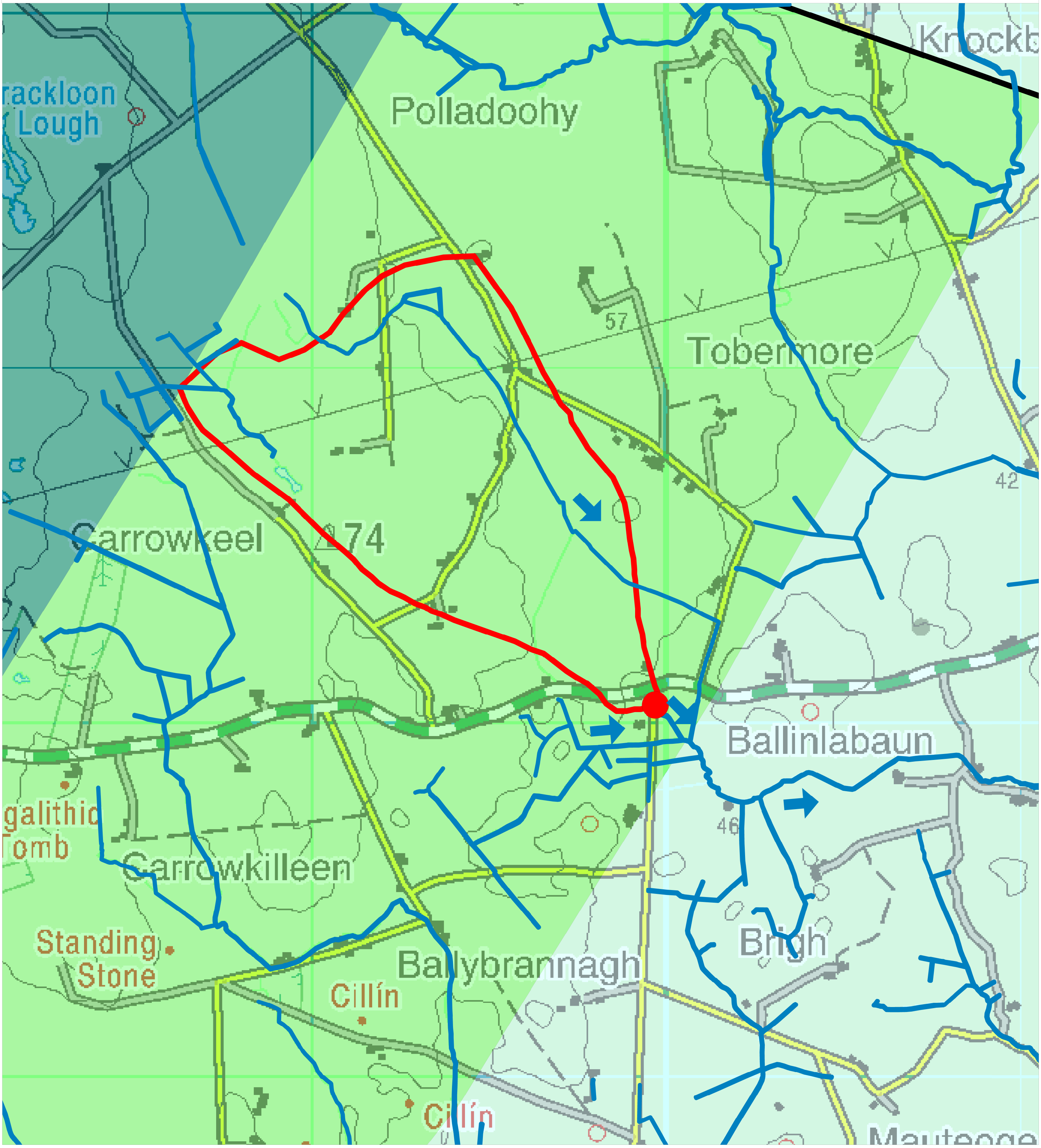
Dinantian Sandstones

Dinantian Upper Impure Limestones

Dinantian Pure Bedded Limestones

Geological Fault

N



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Date: 30/3/15	Title: Geological Rock Units and Faults
Scale: 1:15,000 @ A4	Project No: 124
Drawn By: ST Checked By: ST	Drawing No: 124_5 RevB

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Group Water Scheme

Zone of Contribution

Rivers

Geological Fault

Bedrock Aquifer

- Locally Important Aquifer - Bedrock Moderately Productive only in Local Zones
- Regionally Important Aquifer - Karstified

Gravel Aquifers

- Locally Important Aquifer

N

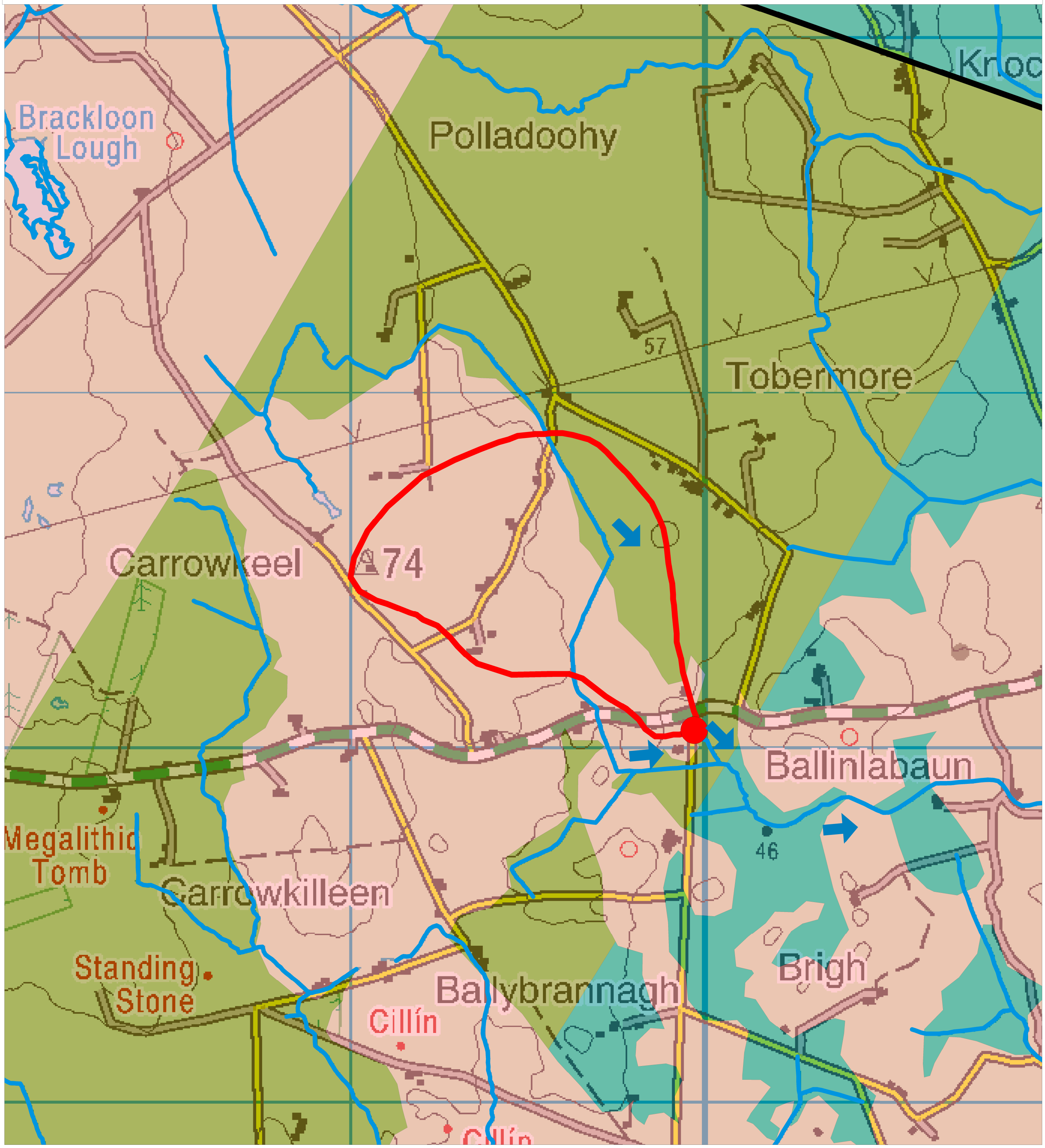

Figure No: 6	Client: Crossmolina/Eskeragh GWS
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Date: 10/6/15	Title: Aquifer Types
Scale: 1:15,000 @ A4	Project No: 124
Drawn By: ST / Checked By: ST	Drawing No: 124_6 RevB

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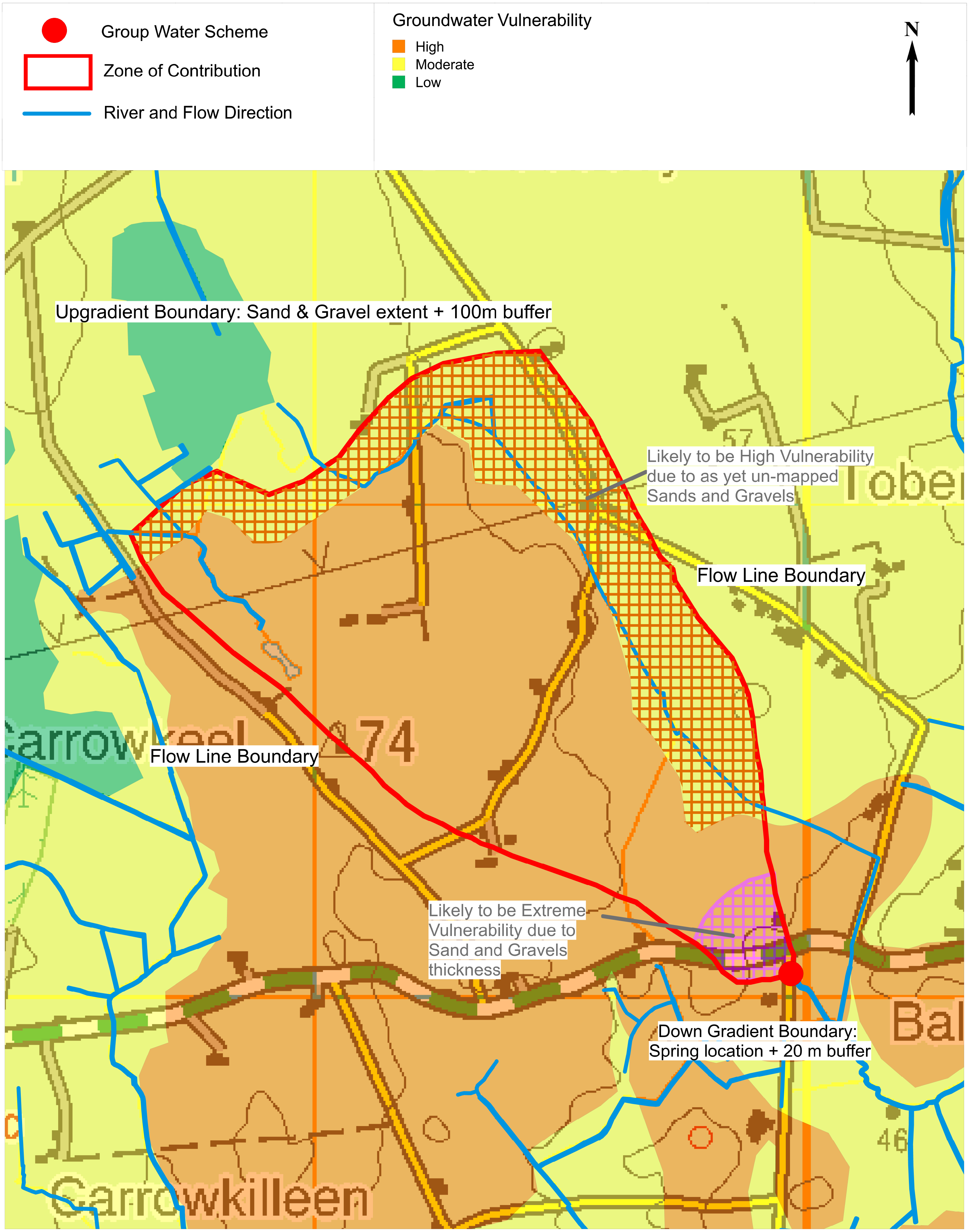

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Date: 24/9/15		Title: ZOC Boundary Types
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Drawn By: ST	Checked By: ST	Drawing No: 124_4 RevC

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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: **E**xtreme, **H**igh, **M**oderate and **L**ow, 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 in Table 1.

Table 1 Vulnerability mapping guidelines (adapted from DELG et al, 1999)

<table>
<tr><td rowspan="3">Thickness of Overlying Subsoils</td><td colspan="5">Hydrogeological Requirements for Vulnerability Categories</td></tr>
<tr><td colspan="3">Diffuse Recharge</td><td rowspan="2">Point Recharge</td><td rowspan="2">Unsaturated Zone</td></tr>
<tr><td colspan="3">Subsoil permeability and type</td></tr>
<tr><td></td><td>High permeability (sand/gravel)</td><td>moderate permeability (sandy subsoil)</td><td>low permeability (clayey subsoil, clay, peat)</td><td>(swallow holes, losing streams)</td><td>(sand & gravel aquifers <u>only</u>)</td></tr>
<tr><td>0–3 m</td><td>Extreme</td><td>Extreme</td><td>Extreme</td><td>Extreme
(30 m radius)</td><td>Extreme</td></tr>
<tr><td>3–5 m</td><td>High</td><td>High</td><td>High</td><td>N/A</td><td>High</td></tr>
<tr><td>5–10 m</td><td>High</td><td>High</td><td>Moderate</td><td>N/A</td><td>High</td></tr>
<tr><td>>10 m</td><td>High</td><td>Moderate</td><td>Low</td><td>N/A</td><td>High</td></tr>
<tr><td colspan="6">Notes: (i) N/A = not applicable.
(ii) Release point of contaminants is assumed to be 1–2 m below ground surface.
(iii) Permeability classifications relate to the engineering behaviour as described by BS5930.
(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/GSIa (1999))</td></tr>
</table>

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 (Figure 3), 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	1.i	Areas where rock is at ground surface	30	80-90	100
(X or E)	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 ≤ 3 m below surface	50	80-90	100
	1.vii	Peat	1	15-30	50
High	2.i	Sand/gravel aquifer, overlain by ‘well drained’ soil	50	80-90	100
(H)	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	3.i	Moderate permeability subsoil and overlain by ‘well drained’ soil	35	50-70	80
(M)	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	4.i	Low permeability subsoil	1	5-10	20
(L)	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 Ll aquifers (200 mm/yr) and Pl and Pul aquifers (100 mm/yr). Made ground has recharge coefficient of 20%.

Where the sand and gravel aquifer occurs beneath dry soils, the recharge co-efficient is estimated to be 85% of effective rainfall, resulting in an estimated annual average recharge of 850 mm in the area of the ZOC. Where wet soils overly the sand and gravel aquifer a moderate recharge co-efficient of 42.5% of effective rainfall has been assigned, resulting in an estimated annual average recharge rate of 450mm. Where subsoils other than the sand and gravel body, overlie Dinantian Upper Impure Limestone bedrock, the average annual recharge rate is capped at 200mm, due to the low recharge acceptance capacity of the bedrock aquifer.

A proportion (40%) of the area currently mapped as having a recharge rate of 200 mm/year in the north east of the ZOC is considered likely to have an actual recharge rate of 850 mm/year. This area is currently mapped as subsoils other than sand and gravel, overlying Dinantian Upper Impure Limestone bedrock, but is considered very likely to actually comprise an extension of the sand and gravel body. This presumption is based on an examination of aerial photographs and large scale topographic and drainage maps, which indicate that the hummocky pattern of topography, the well drained agricultural land and low drainage density extend north eastwards from the currently mapped boundary of the sand and gravel. The proportion of the ZOC receiving the high recharge rate (450 mm) is considered likely to include a small proportion of the area of that currently mapped at the moderate rate (450 mm). Estimated groundwater gradients in the area suggest that small wetland and lake areas within the ZOC are likely to be an expression of the unconfined groundwater table, where the groundwater level is locally higher than the topography in depressions which have no outflow route and which occur in the hummocky surface of the sand and gravel aquifer, rather than resulting from ponding of surface water run-off in areas of low permeability soils. This would result in an increase in the groundwater vulnerability classification in these areas, from the currently mapped high to extreme, as the unsaturated zone will be <3 m in depth (See Table 1, Appendix 1 Groundwater Vulnerability). This would then result in an increase in the recharge rate, based on the current methodology for assessing recharge rates (See Table 2, above).

In addition the water balance for the discharge at the spring discharge zone is only balanced, if the higher recharge rate occurs across a greater proportion of the area than the current recharge mapping indicates.

APPENDIX 3

ZOC Boundaries

ZOC Boundaries

The area contributing to the spring (the ZOC) comprises 0.86 km^2. The boundaries of this area contributing to the spring, which is estimated to discharge an annual average of 1,500 m3/day are considered to be as follows (See Figure 7):

The **northern western boundary** forms the up-gradient boundary. The boundary is based on the up-gradient extent of the sand and gravel body, a reasonable flow path length in sand and gravel sediments and on the water balance. In addition, a 100 m buffer has also been applied to the upgradient side of the sand and gravel body boundary. This buffer is due to uncertainty regarding the exact extent of the sand and gravel body. There is also uncertainty regarding where a topographic divide might occur, given the shallow gradient and hummocky nature of the topography. The north western boundary also encloses some south easterly draining groundwater fed springs and drains, some of which cross the sand and gravel body and may be exchanging water with the sand and gravel aquifer.

The **south western and north eastern boundaries** are delineated based on the water balance, on topography and on the groundwater flow lines resulting from the topographic and regional control on hydraulic gradient. The position of these boundaries relies on the assumption that the area to the north of the spring, is at least part comprised of an extension of the sand and gravel body. This area is currently mapped as comprising till subsoils overlying a low productivity (PI) aquifer, with correspondingly low recharge rates. A correct water balance for the ZOC, within these boundaries, relies on part of this area having the high recharge rates associated with sand and gravels.

The south-**eastern** boundary, i.e. the down-gradient extent of the ZOC, is delineated as an arbitrary 20 m buffer zone around the spring to protect it from direct ingress of contaminants.

APPENDIX 4

Water Analysis Results

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

Source : **MO085**, Eskeragh
Seamus Callaghan
Coolturk
Crossmolina
Co Mayo

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 **MO085**, Eskeragh, 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	<0.01	700	6.71	0.2	0.1	0.05	<4	<5	<6	4	<1
DEC2000	2.5	0.2	696	6.96	0.1	2	0.05	<4	<5	<6	<1	<1
JAN2001	2.5	0.11	669	6.61	0.2	1.4	0.05	<4	<5	<6	2	<1
FEB2001	2.5	<0.01	709	6.52	0.2	1.2	0.05	<4	<5	<6	2	<1
MAY2001	5	<0.01	722	6.73	0.1	0.8	0.005	<4	5	<6	5	<1
JUN2001	2.5	0.28	702	6.67	0.1	1.4	0.006	8	<5	<6	1	<1
JUL2001	2.5	0.01	732	7.1	0.15	1.2	0.004	10	<5	<6	3	<1
AUG2001	<2.5	<0.01	711	6.94	0.2	1.5	0.003	<4	6	<6	57	33
SEP2001	2.5	<0.01	740	6.94	0.1	1.3	0.003	4	5	6	2	1
OCT2001	<2.5	<0.01	788	7.17	<0.1	1.4	0.007	<4	<5	<6	<1	<1
NOV2001	<2.5	<0.01	778	7.08	<0.1	1.2	0.002	<4	<5	<6	7	<1

2014 GWS Sample Analysis Results

Sample No.	Report No.	Receipt Date	Sample ID	BOD	COD	Turbidity	pH	Conductivity @20C	Alkalinity, total	Sodium, total	Chloride	Ammonium as NH4	Nitrate as NO3	Nitrite as NO2	Dissolved Oxygen (%)	Potassium, total	Total Hardness (Kone)	Magnesium, total	Colour, apparent	Sulphate
				mg/l	mg/l	N.T.U.	pH Units	uS/cm	mg/l CaCO3	mg/l	mg/l	mg/l	mg/l	mg/l	%Sat	mg/l	g/l CaC(	mg/l	g/l Pt C	mg/l
533430	235075	31/07/14	Moylaw	<1	<10	<0.2	6.8	591	328	114	23.4	0.032	11.2	<0.017	43	48	309	8	<4	8.18

Sample No.	Orthophosphate as PO4-P	Calcium, total	Aluminium, dissolved	Iron, dissolved	Manganese, dissolved	Copper, dissolved	Lead, dissolved	Chromium, dissolved	Nickel, dissolved	Cadmium, dissolved	Arsenic, dissolved	Zinc, dissolved	Silica	Barium, dissolved	TOC	Clostridium Perfringens in Water	Strontium, dissolved	E coli (Filtration) (Environmental Waters)	Total Coliforms (Filtration) (Environmental Waters)	Fluoride by ISE
	mg/l	mg/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	mg/l	ug/l	mg/L	cfu/100ml	ug/l	cfu/100ml	cfu/100ml	mg/l
533430	<0.01	104	<2	57	<5	3	<0.5	<0.5	3	<0.5	<0.5	<5	1.04	24	1.72	0	439	0	20	0.4

APPENDIX 5

Spring Discharge Volume

Volume Discharging from the Spring

The Local authority currently abstracts an average daily abstraction of **770 m^3/day** (February 2006 - June 2014). Previous to 2006, up to 1000 m^3/day was abstracted from this abstraction point, when a larger area was being supplied by the local authority (E. Munley, Mayo Co. Co. pers. comm.) The abstraction leaves the spring as a piped continuous gravity flow

The GWS Average daily abstraction by the GWS is **207 m^3/day** (30/6/10-14/8/2014) and was previously approximately this value. The abstraction leaves the spring as a pumped/gravity, with an average number of pumping hours per day (30/6/14-14/8/2014) is 17 hours.

The spring overflow has a minimum of 0 m^3/day, based on on-going observations by the caretaker and on EPA flow measurements made in 2007-2008 (7 values, EPA Station No. 34112). The 0 m^3/day overflows are observed during late Summer – Autumn by the caretaker and occur in Summer 2007 measurements by the EPA. The combined GWS and LA abstraction volume of **977 m^3/day** is considered to be the spring base flow volume. Flow recorded by the author on 8/7/14 averaged 0.000315 m^3/s corresponding to 27 m^3/day, assuming consistent flow over 24 hours. The maximum value recorded by the EPA was 0.025 m^3/s in December 2007, which corresponds to 2,160 m^3/day, assuming that the flow was consistent over 24 hours. The maximum likely flow based on the presence of mossy vegetation on the V-notch weir is calculated to be of the order of 2,000 m^3/day, though this is subject to high uncertainty. The volume of overflow is therefore considered to be highly seasonal and impacted by the two abstractions. There is a high degree of uncertainty surrounding the annual average daily spring overflow, due to the small number of overflow measurements and also lack of knowledge about whether the GWS was abstracting at the time of measurement (the LA water supply is assumed to be discharging constantly). An annual average overflow of approximately 500 m^3/day has therefore been arbitrarily assigned.

The full discharge from the spring comprises the combined LA abstraction, the GWS abstraction and the corresponding weir overflow. This is the discharge volume for which the Zone of Contribution will be delineated, since there is a single source area (Zone of Contribution) for all of the water discharging in this zone. Any pressures occurring in this Zone of Contribution will potentially equally effect all of the water discharging in this zone, including the GWS abstraction.

For the purposes of delineation of the ZOC, an annual average spring discharge volume of **1,500 m^3/day** has therefore been assumed.