

An Coimisiún Pleanála PAX07.323761

Expert Opinion

for

Barnaderg Gortbeg GWS Observation & Objection

in the context of

European Union (Drinking Water) Regulations 2023 (S.I. No. 99 of 2023)

Cooloo Wind Farm, Co. Galway

Private Development - REDIII Application

in the groundwater and surface water catchments of

Mid Galway PWS

Barnaderg Gortbeg GWS

Briarfield GWS

Lough Corrib PWS

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An Coimisiún Pleanála PAX07.323761



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List of Abbreviations

BH	Borehole
EPA	Environmental Protection Agency
CALCDA	Climate Action and Low Carbon Development Act (2015)
GSI	Geological Survey of Ireland
GW	Groundwater
HES	Hydro Environmental Services, Dungarvan. Consultants to MKO.
HSE	Health Service Executive
MKO	EIAR Authors
NFGWS	National Federation of Group Water Schemes
PWS	Public Water Supply
WTP	Water Treatment Plant
ZOI	Zone of Influence
ZOC	Zone of Contribution

Executive Summary

- Dr. Pamela Bartley of Hydro-G was commissioned by the Barnaderg Gortbeg GWS to prepare this report in support of the Objection to a proposed High Risk & High Hazard development in the vicinity of groundwater and surface water supplying their Group Water Supply groundwater spring and borehole abstraction locations. The author of this report is an expert PWS water supply engineer with karst aquifer expertise who supervised water supply borehole drilling at the Barnaderg Gortbeg GWS site and within the compound of the nearby Mid Galway PWS. The variability in the karst of this area is phenomenal. The largest groundwater strike of my drilling supervision career was at Barnaderg GWS. Amongst the most mediocre karst conduit groundwater strikes of my career was at the nearby Mid Galway PWS WTP compound.
- This report presents information for An Bord Pleanála in relation to a 'Private Development - REDIII Application' by Neoen Renewables Ireland Limited named Cooloo Wind Farm (ABP Reference No. PAX07.323761). No quantitative Risk Assessment has been presented by the applicant with respect to the onerous obligations, when catchment changes are proposed, of the European Union Drinking Water Regulations 2023 (SI 99 of 2023).
- The applicant proposes construction in the lands overlying the karst conduit groundwater system supplying water to the Group Water Scheme sources Barnaderg Gortbeg and Briarfield, the latter is not mentioned at all in the EIAR. In addition, the applicant proposes construction in the lands contributing groundwater and surface water to the Mid Galway PWS. The agents for this turbine project propose abnormally excessive loads and infrastructure in the Groundwater Body (GWB) and catchment of the Mid Galway PWS, Barnaderg Gortbeg GWS and Briarfield GWS and Lough Corrib, although the latter is remote from the proposal.
- Whilst the agents cite a 2012 Source Protection Zone report for the Mid Galway Scheme, the GSI and the EPA (2012) state very clearly that "Source Protection Zones are a landuse planning tool which enables a more objective, geoscientific assessment of the risk to groundwater quality to be made". The emphasis is on quality: A Source Protection Zone is defined by a 100-day time of travel to the source and is designed to protect the source from microbial and viral contamination (DELG/EPA/GSI 1999). In this conduit karst groundwater setting the potential for collapse of surface karst into subterranean karst is high when the scale of the abnormal and excessively abnormal loads are considered. The issue is that all groundwater in this GWB has the potential to flow to the Mid Galway PWS, Barnaderg Gortbeg GWS, Briarfield GWS and Lough Corrib. Even groundwater outside the 100-day time of travel Source protection Zone, mapping for microbial and viral contamination, can travel to the named PWS sources.
- No defensible assessment of groundwater flow systems has been submitted to An Coimisiún Pleanála regarding the groundwater system beneath the areas proposed for excessively abnormal loads, including all haul roads, crane pads, foundations and turbine masts. A Geotechnical Karst Risk Assessment (GDG, 2025) in "support of the application". However, that Geotechnical Karst Risk Assessment was completed by geologists and not hydrogeologists. This is evident in their opening quote from Drew (2018) in which a "simple" definition of karst is presented in favour of Drew's (2018) "more sophisticated and hydrogeologically orientated definition of what is meant by karst": An integrated mass transfer system in soluble rocks with a permeability structure dominated by conduits dissolved from the rock and organised to facilitate the circulation of fluids." The Geotechnical Karst Risk Assessment (GDG, 2025), in support of the application, fails to convey the connection between the surface expressions of karst on the landscape with the known conduit system conveying large volumes of groundwater in the immediate vicinity of the PWS sources and two GWS sources. Over 10,000 m³/d of groundwater is discharged in the vicinity of the proposed development. Subterranean conduits are the mechanism of that groundwater flow system. This is not acknowledged by the geotechnical engineers, who by their nature are interested in solid geology and not conduit groundwater systems.
- Turbines and blades will be maintained with persistent chemicals, details for which are absent from the baseline groundwater and surface water monitoring data. The Hub of each turbine, at c.100m above ground, will contain lubricant to ensure efficient operation of the three rotating blades on each of the masts. The Drinking Water Regulations (2023) and the Groundwater Regulations (20120, as amended 2016) specify Parametric Values for chemicals and lubricants associated with the maintenance of Turbine blades and masts. No baseline information is presented in the EIAR for those parameters.
- The purpose of this report is to present expert hydrogeological information for An Coimisiún Pleanála's consideration with respect to the hydrogeological environment, Drinking Water Regulations and the potential for impact arising from the proposed development. The construction area is connected to groundwater and surface water that are sources for a significant PWS and significant GWS boreholes and springs. The conclusions of no potential for impact are not justified by virtue of the fact that no specific foundation designs are presented in the EIAR for EIA and no mapping for mains distribution networks are presented.
- The Risk Impacts outlined in the Geotechnical Karst Risk Assessment (GDG, 2025) include "Detailed ground investigation, mitigation through use of grouted piled foundations, or bridging cavities with concrete, or geogrid and coarse granular fill if appropriate". Sanctioning grouting in response to collapsing caves is not advised. Sanctioning the placement of excessive and abnormally excessive loads over conduit karst supplying 1000's of homes with no water supply contingency is not advised in the interest in public health and safety.
- Whilst CALCDA demands that An Coimisiún Pleanála must enable furtherance of Ireland's Climate Action Plan, the words "IN SO FAR AS PRACTICABLE" are KEY words that must be remembered by all parties. The potential to affect the QUALITY of groundwater supply to 1000's of homes and farms rules out the "IN SO FAR AS PRACTICABLE" option of the CALCDA. The rights of the public to have safe water delivered to their homes and farms is a Human Right that must be maintained.

Statement of Expertise Pamela Bartley B.Eng., MSc., Ph.D

Pamela is a water focussed civil engineer. After more than 25 years of field based practice in borehole drilling, groundwater monitoring and abstraction point management she can be considered a karst hydrogeology specialist: her Ph.D was a field based-karst limestone environment study and in the years after she completed CPD training with the GSI at their karst specialist course run in the Burren. Pamela is qualified and IOSH certified to act as PSDP (Project Supervisor Design Phase) & PSCS (Project Supervisor Construction Stage) as defined by the Construction Regulations. The company is a registered Irish Water Supplier (no. 1855) and Pamela Bartley is HSQE approved within Irish Water and is one of their Hydrogeologist Framework service providers.

Upon completion of a Diploma in Water and Wastewater Technology at Sligo RTC, she completed a degree in Civil Engineering at Queens University, Belfast and then completed a Master of Science in Environmental Engineering followed by a hydrogeological focussed Ph.D. on Karst Groundwater Impact: both postgraduate degrees were completed within the school of Civil Engineering at Trinity College, Dublin.

Her key work areas are groundwater impact and groundwater use. She specialises in the engineering of groundwater from large scale water supply boreholes for PWS, GWS, Motorway Service Stations & Hotels. Other work areas include evaluation of discharges to groundwater and surface waters for compliance with Irish Regulations and the hydrological and hydrogeological assessments required for EIARs for quarries. She has a skillset in the assessment of groundwater quality for water treatment process parameters and working in collaboration with water treatment plant designers.

Pamela has successfully completed post doctorate formal course training in the areas of:

- PSDP & PSCS (IOSH certified, 2016).
- Karst Hydrogeology (GSI, 2013).
- Planning & Development Act (IE, 2010) & Expert Witness (IE, 2011).
- On Site Wastewater & Water Services Amendment Act 2012 (IE, 2012 & Dublin 2012).
- Zero Discharge Willow Wastewater Systems Design Courses (Denmark 2008 & 2011 & Ireland 2012).
- Surface Water Regulations 2009 (DoE, 2010 & 2011).
- Sustainable Drainage (Wallingford/CIRIA, 2005 & 2008).
- Source Protection Zone Delineation (IGI/GSI, 2007).
- Groundwater & Contaminant Microbiology (IGI/GSI, 2006).
- Site Suitability Assessment (FETAC, 2002) & Applied Groundwater Modelling (ESI, UK, 2000).

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Pamela's water supply borehole expertise has been gained in the field by her personal supervision of drilling and designing required subsurface completions for large scale abstractions for DBO2's East Galway Group Water Scheme BHs: Ballinabanba GWS; Barnaderg GWS; CBC GWS; Kiltiernan GWS and Ballyaneen GWS as well as many PWS groundwater well sources for Galway County Council, Clare County Council and later for Irish Water in Counties from Donegal to Galway and the Roscommon border. Amongst many other private sites, she has completed successful potable boreholes for Kilonan Castle in Roscommon; Lakeland Dairies, Co. Cavan; The Killeslin Hotel, Co. Laois; The Loughrea Hotel; The Charleville Park Hotel and the Motorway Service Stations at the Obama Plaza, Galway Plaza and the Supermacs Service station in Tipperary. She has developed competency in review of camera surveys of boreholes in need of rehabilitation and design of subsequent programmes to improve yield.

As a result of work in evaluating planning appeals, Pamela has become specialist in planning evaluations in the context of enacted Irish Regulation and EU Directives concerning the water environment such as the Groundwater Regulations (S.I. No. 9 of 2010 & Amendment Regulations S.I. No. 366/2016), Surface Water Regulations (S.I. No. 272 of 2009 & Amendment Regulations S.I. No. 386 of 2015), Water Framework and Habitats' Directives. She has been an invited guest speaker at An Bord Pleanála, The Irish Concrete Federation, The Health Service Executive, Environmental Health Officers National Conference, The Irish Planning Institute's National Conference, The International Association of Hydrogeologist's National Conference (Irish Branch) and has delivered hydrogeological lectures to the public during Science Week. In the past, she has held full time lecturing positions in third level institutions (WIT & CIT, 1996 – 1999), delivered practical laboratory instruction in the assessment of subsoils for the FETAC Site Assessor programme and also demonstrated hydraulics laboratory and practical field survey tutorial modules at Trinity College Dublin (1996). Pamela is a qualified and certified 'Site Assessor' and has been an interviewer of examination candidates in respect of eligibility for the Site Suitability FETAC Qualification.

Pamela Bartley's company is Bartley Hydrogeology Ltd., registered to trade as Hydro-G. The company holds professional indemnity insurance of €2million for each and every claim in each period and the company holds both employers, public and products liability insurances (Employers Liability : €13,000,000 any one claim/unlimited any one period of insurance, Public Liability : €6.5 million, Products Liability : €6.5 million). Pamela is an expert provider to Uisce Eireann on the Hydrogeologists Framework Panel and Supply Demand Balance Programme.

1.0 Introduction

In September 2025 the Cooloo Wind Farm, Co. Galway, was presented to An Coimisiún Pleanála for their consideration under the mechanism of 'Private Development - REDIII Application Development' with an application code PAX07.323761. The Project description is provided by agents for the applicant, as follows:

- i. 9 no. wind turbines with the following parameters:
 - a. Total turbine tip height of 180 metres;
 - b. A rotor blade diameter of 150 to 162 metres;
 - c. A hub height of 99 to 105 metres;
- ii. Permanent turbine foundations, hard-standing and assembly areas;
- iii. Underground electrical (33kV) and communications cabling;
- iv. 1 no. temporary construction compound (including site offices and welfare facilities);
- v. A meteorological mast with a height of 100 metres, security fencing and associated foundation and hard-standing area;
- vi. 1 no. new site entrance on the R332 in the townland Lisavally;
- vii. 1 no. new access and egress point off the L6056 Local Road in the townland of Dangan Eighter;
- viii. 1 no. new access and egress point on to an existing access track in the townland of Dangan Eighter;
- ix. 2 no. new access and egress points off the L6301 Local Road in the townland of Cooloo and Lecarrow;
- x. Upgrade of existing site tracks/roads and provision of new site access roads, clear span crossings, junctions and hard-standing areas;
- xi. A new temporary access road from N63 national road and to R332 Regional Road in the townland of Slievegorm to facilitate the delivery of turbine components and other abnormal sized loads;
- xii. Demolition of an existing derelict house and adjacent outbuilding in the townland of Cooloo;
- xiii. Peat and Spoil Management Areas;
- xiv. Tree felling and hedgerow removal;
- xv. Biodiversity Management and Enhancement measures;
- xvi. Site Drainage;
- xvii. Operational Stage site signage; and
- xviii. All ancillary apparatus and site development works above and below ground, including soft and hard landscaping.

The applicant is seeking a ten-year planning permission. Current and future wind turbine generator (WTG) technology will ensure that the wind turbine model, chosen for the Proposed Project, will have an operational lifespan greater than the 35-year operational life that is being sought as part of the planning application.

Dr. Pamela Bartley of Hydro-G was commissioned to assess the risk to the quality and quantity of the Barnaderg Gortbeg GWS water sources. However, given that the Barnaderg Gortbeg GWS is intrinsically connected to the Uisce Eireann Mid Galway PWS both schemes are considered in this assessment.

The author of this report is an expert PWS water supply engineer with karst aquifer expertise who supervised water supply borehole drilling at the Barnaderg Gortbeg GWS site and within the compound of the nearby Mid Galway PWS. The variability in the karst of this area is phenomenal. The largest groundwater strike of my drilling supervision career was at Barnaderg GWS. Amongst the most mediocre karst conduit groundwater strikes of my career was at the nearby Mid Galway PWS WTP compound.

The proposal before An Coimisiún Pleanála in case PAX07.323761 concerns a network of haul roads, crane pads, construction pads, foundations and associated infiltration devices in the lands overlying the karst conduit groundwater system supplying water to the Group Water Scheme sources Barnaderg Gortbeg and Briarfield, the latter is not mentioned at all in the EIAR. In addition, the applicant proposes construction in the lands contributing groundwater and surface water to the Uisce Eireann Mid Galway PWS, which is a very large abstraction that is in the public record of EPA Abstraction Register in excess of that considered in the EIAR reported to An Coimisiún Pleanála. This has significance in the context of encroachment of a larger portion of the proposed development area into the zone of influence of the abstractions. The agents for this turbine project propose excessive and abnormally excessive loads and infrastructure in relatively close proximity to and in the same Groundwater Body (GWB) and the same catchment of the groundwater abstraction sources for Mid Galway PWS, Barnaderg Gortbeg GWS and Briarfield GWS.

The proposal before An Coimisiún Pleanála does acknowledge the fact that at the construction sites proposed for the 9 individual turbine footings (likely 23m diameter of concrete, likely in 30m diameter excavations) will require pumping of cement into deep foundations (5 to 10m depth) on lands that are connected to Mid Galway PWS and both the Barnaderg Gortbeg and Briarfield GWSs. The proposal before An Coimisiún Pleanála does acknowledge the hazard presented by the widespread evidence for surface karst (Appendix 8-2) and that those hazards might require pumping concrete into piled foundations beneath turbines AND beneath floating roads. However, the karst risk assessment is superficial and does not address the groundwater impact potential of karst in any way.

Part 3 of the European Union (Drinking Water) Regulations 2023 provides comprehensive instructions on Risk Assessment and obligations in respect to the catchments and controls for Public Water Supply Sources. The agents for the applicant have not exercised the legislative obligation considering the scale of PWS that could potentially be affected. The EPA Register of Abstractions is available to all members of the public and professionals in the assessment of risks posed to Public Water Sources. The EPA has published the register in a way that it is querriable by GWB name and its WFD Code. On the basis of the obligations set out in Part 3 of the European Union (Drinking Water) Regulations 2023, it is incumbent on applicants and planning authorities to complete detailed studies to complete Risk and Impact assessments in the context of PWS Abstractions.

In a karst conduit groundwater system such as this, risks posed include impacts on the quality of the water presented to the GWS for treatment before issue to their members and quantitative risks posed by potential interruption of water flow in conduits that could collapse or be filled with grout, as is one of the mitigation measures proposed by the applicant.

2.0 Groundwater Receiving Environment & PWS

The development area proposed for the construction site to enable turbines, roads, spoil heaps and underground cabling overlie the Clare Corrib Groundwater Body (WFD Code IE_WE_G_0020). The GSI data and maps server map groundwater characteristics as follows:

- Groundwater Flow Regime 'Karstic (KA)'.
- Aquifer type = Regionally Important Conduit Karstified Aquifer.
- Groundwater Flow Path Velocities (GSI, 2004) mapped in the East to West flow domain, which is the direction of flow applicable to this application and within the application area = 100m to 400m per hour in some cases. This means that groundwater flow velocities are 2.4 to 9.6 km per day. The GSI (2004) GWB Descriptor Sheet for the GWB is presented as Appendix A to this report.

No defensible assessment of groundwater flow systems has been submitted to An Coimisiún Pleanála regarding the groundwater system beneath the areas proposed for excessively abnormal loads, including all haul roads, crane pads, foundations and turbine masts. A Geotechnical Karst Risk Assessment (GDG, 2025) in "support of the application". However, that Geotechnical Karst Risk Assessment was completed by geologists and not hydrogeologists. This is evident in their opening quote from Drew (2018) in which Drew's "simple" definition of karst is presented in favour of the very next sentence in Drew's (2018) Karst of Ireland textbook, which defines a "more sophisticated and hydrogeologically orientated definition of what is meant by karst", as follows:

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"An integrated mass transfer system in soluble rocks with a permeability structure dominated by conduits dissolved from the rock and organised to facilitate the circulation of fluids."

The Geotechnical Karst Risk Assessment (GDG, 2025), in "support of the application", fails to convey the connection between the widespread evidence of surface expressions of karst on the proposed project's landscape with the known conduit system conveying large volumes of groundwater in the immediate vicinity of the PWS sources and two GWS sources.

Over 10,000 m³/d of groundwater is abstracted for public consumption each day in the vicinity of the proposed development. The Source Protection Report for the Mid Galway PWS scheme (EPA, 2012) is presented as Appendix B to this report. Whilst the karst conduit system is well described in EPA (2012), and each of the GWSs are also documented and evaluated, An Coimisiún Pleanála is advised that the Mid Galway report did not have a focus on the actual application area's subterranean Karst systems. Therefore, the level of detail is not available for the applicant's proposed development area. EPA (2012) is provided as an example only of how much work and risk is involved in this hydrogeological setting. As stated, the applicant's agents approached the situation from a geotechnical rather than hydrogeological perspective.

Subterranean conduits are the mechanism of that groundwater flow system. This is not acknowledged by the geotechnical engineers, who by their nature are interested in solid geology and not conduit groundwater systems. The many 'potential turloughs' and dolines mapped by the wind industry expert service provider, GDG (2025), are not explained as links to the underlying groundwater conduit system. Only one turbine location was surveyed in

the Geotechnical survey reported in the GDG (2025) report on karst. The method applied is not the method that those searching for groundwater conveying karst conduits seek. The preferred method is EM.

Turloughs are a groundwater feature. Turloughs are surface expressions of groundwater moving from the conduit groundwater flow system upwards, often in vertical shafts, to ground level in ephemeral lakes. The proposed construction area is between Horseleap Lough, Summerville Lough and Levally Lough. An underground conduit groundwater flow system connects those Loughs. This is documented in EPA (2012), which is Appendix B to this report. Never have excessive and abnormally excessive loads been applied to the landscape of east Galway and there are no site testing data presented for the applicant in which the shear loading capacity is demonstrated for the lands proposed for haul roads or the 9 crane pads and 9 turbine pads suggested.

3.0 The Clare Corrib Groundwater Body - Details relating to Sources of Water Schemes

The publically available EPA published register of abstractions, under the Abstraction & Impoundment Regulations, presents as follows:

- The Barnaderg Gortbeg GWS groundwater source is registered to supply 900 m³/d to the public from the Clare Corrib GWB. This water supply scheme was developed by the local community in 1970. There is no Plan B for the scheme. Uisce Eireann have not identified the adjacent Mid Galway Scheme as a scheme that has funding to expand. In any case, if the Barnaderg Gortbeg sources of water were impacted by the proposed development, so too would Mid Galway. The connectivity is documented in the EPA (2012) report appended here as Appendix B. The Barnaderg Gortbeg GWS manages 110 Km of pipe network distributing water to 1,500 connections and 940 Customers in the vicinity of the proposed development.
- The Briarfield and District Group Water Scheme Society Limited is registered to supply 91 m³/d to the public from the Clare Corrib GWB.
- The Uisce Eireann Mid Galway PWS is registered to supply 5,146 m³/d to the to the public from the ABBERT_030 river. An Coimisiún Pleanála is advised that all groundwater spring discharges are assigned as surface water system connectivity. Hence the Abbert River registered source. It is, however, a surface water system from which Uisce Eireann abstracts 5,146m³/d but the surface water is fed by groundwater springs. There is also a groundwater supply borehole at the site that assists in water treatment processes.

Groundwater and Surface Water are connected in this karst system. Hence the concern regarding the applicant's agent's presentation that:

"The topography of the Proposed Wind Farm site is undulating with gentle slopes typical of a low-lying raised bog setting with surrounding local hills. The elevation of the Proposed Wind Farm site ranges from approximately 65m OD (metres above Ordnance Datum) to 80m OD, with slopes falling to the north and southeast from a high point located centrally with the Proposed Wind Farm site which also coincides with a surface water catchment topographic divide between the Grange River to the north and the Abbert River to the south". & "The Proposed
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Wind Farm site is drained by several 1st order watercourses that emerge from the peatland areas. There is also a high density of man-made drainage associated with the peatland and grassland areas. The man-made drainage density is evident on the OSI 6", 25" mapping and aerial imagery" (Appendix 9-1 Flood Risk Assessment, EIAR 2025 Cooloo Wind Farm).

The potential for organic matter release from the bogs, during all phases of the project, to the drainage system has potential to react with the chlorination systems of the Water Treatment Plants (WTPs) and has potential to create Trihalomethanes.

The Drinking Water Regulations (2023) and the Groundwater Regulations (20120, as amended 2016) specify Parametric Values for chemicals and lubricants associated with the maintenance of Turbine blades and masts. No baseline information is presented in the EIAR for those parameters.

4.0 In appropriate Use of Information and Implications

Whilst the agents cite a 2012 Source Protection Zone report for the Mid Galway Scheme, the GSI and the EPA (2012) state very clearly that "Source Protection Zones are a land use planning tool which enables a more objective, geoscientific assessment of the risk to groundwater **quality** to be made". The emphasis is on **quality**: A Source Protection Zone is defined by a 100-day time of travel to the source and is designed to protect the source from microbial and viral contamination (DELG/EPA/GSI 1999). It is wholly inappropriate for wind farm applications to attempt to portray that their proposed development area does not wholly overlap a Source Protection Zone for a PWS or a GWS. Some of the Turbines proposed do overlap the mapped Source Protection Zone. However, ALL of the turbines proposed overlap the groundwater system feeding the Mid Galway and Barnaderg Gortbeg GWS sources. The connectivity to Briarfield GWS is also an issue.

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In this conduit karst groundwater setting the potential for collapse of surface karst into subterranean karst is high when the scale of the abnormal and excessively abnormal loads are considered. The issue here is that all groundwater in this GWB has the potential to flow to the Mid Galway PWS, Barnaderg Gortbeg GWS and Briarfield GWS. Even groundwater outside the 100-day time of travel Source protection Zone, that was mapped by the EPA and GSI (2012) for microbial and viral contamination, can travel to the sources for Mid Galway PWS, Barnaderg Gortbeg GWS and Briarfield GWS. Therefore, the issue of QUANTITATIVE IMPACT is more relevant and this has not been adequately assessed in the context of interruption of PWS in either the Water Chapter or the Geotechnical Risk Assessment.

Neither have the Biodiversity Assessments considered the potential impacts of the groundwater conduit system collapse, or deep peat slides, blocking the Poor Status drainage network, so well described and mapped in the Triturus (2025) Baseline Aquatic Survey (Appendix 6-3). An Coimisiún Pleanála is invited to include this in their brief to their own ecologist: What would be the effect on the Lough Corrib SAC and SPA to which the drainage system of the proposed development area is connected to?

Returning to water, the EPA (2012) was completed for a stated abstraction of 4,000 m³/d. In the intervening 13 years since the work was completed, the abstraction has increased to over 5,000 m³/d. For the operational 35 year lifespan proposed, the abstraction will increase again and again. Therefore, the mapped zones of contribution will increase farther into the turbine foundation areas. The same is true for the zone feeding Barnaderg Gortbeg GWS.

An Coimisiún Pleanála is invited to include this in their brief to their own hydrogeologist – how to forecast the increasing scale of impact into the future.

5.0 Business Focussed, Not People or Environment Focussed, Mitigation Measures Proposed

- The Mitigation Measures proposed in the Geotechnical Karst Risk Assessment provide valuable insight into the focus of the Environmental Impact Assessment completed by the agents for the wind industry. In the GDG (2025, Appendix 8-2 of the EIA), the 'Karst Risk Assessment' Appendix 1 presents all the potential risks to the client's infrastructural investments.
- There is no follow through regarding the required Mitigation required to provide an alternative source of water to 1000's of local homes (Mid Galway's 5,146 m³/d; Barnaderg Gortbeg's 900m³/d and Briarfield GWS's 91 m³/d).
- The potential scenarios of Hazard posed by the karst environment are correctly identified and listed in the GDG (2025) Appendix 1 Table in Appendix 8-2, as follows:
 - Rapid collapse of sinkhole/doline cavity
 - Subsidence of soils overlying suffusion or buried dolines
 - Cavities / Voids
 - Variable rockhead
 - Solutionally Weathered Rock
- The 'Risk Impact' entitled column of the Table in the GDG (2025) Appendix 1 of Appendix 8-2 of the EIA includes a strange mix of required construction efforts and in response to karst uncertainties, include as follows:
 - "Detailed ground investigation, mitigation through use of grouted piled foundations, or bridging cavities with concrete, or geogrid and coarse granular fill if appropriate". The ship will have sailed if permission is granted for a Wind Farm on speculative reasons that the mitigation is detailed ground investigation. In addition, suggesting grouting in this particular environment is not advised because large volumes of grout have the potential to clog conduits and stop groundwater flowing to the Mid Galway PWS, Barnaderg GWS and Briarfield GWS.
 - In relation to Access Roads in the bogs, which will have excessively abnormal loads placed over deeper bog than the applicant's agents have managed to push their probes through, the 'Risk Impact' of subsidence and piled foundations is not design according to the site investigations. The true response would have been a CONCLUSION THAT THE SELECTED AREA IS UNSUITABLE FOR THIS TYPE OF DEVELOPMENT. Sanctioning the placement of excessive and abnormally excessive loads over conduit karst supplying 1000's of homes with no water supply contingency is not advised in the interest in public health and safety.
- The Mitigation Measures proposed in Chapter 18 of the EIA propose surface water monitoring for a list of parameters that do not include the potential emissions from the materials that will arise from construction

and maintenance during operation (Table 9-8 of the Water Chapter is referred to in Table 18-1 Mitigation Measures, specifically MM3).

- The Mitigation Measures proposed in Chapter 18 of the EIA do not present Mitigation for Interruption of Public Water Supply. A simple email request to 'Data Requests' at Uisce Eireann will result in sharing of maps for the entire area of interest: the Grid Connection, the haul routes and the construction area. The potential for construction of the Grid Connection to intersect the water supply mains is high. No Mitigation Measures are proposed. The same applies to the water mains distribution network for the GWSs.
- There are many issues with the Mitigation Measures Proposed. However, most significantly, there is no Mitigation Measure proposed in relation to the potential for Human Health Impact on the people who receive groundwater and groundwater fed Surface Water from the three local PWS and GWS sources in the immediate vicinity of the proposed development area. As previously outline by Hydro-G and as published by the GSI in their description of the groundwater flow mechanism in the Clare Corrib GWB. Relative to the PWS and GWS abstraction source locations, the proposed haul roads, construction pads, crane pads and turbine erection sites are within the 9km published groundwater flow path length (GSI, 2004). There are no Mitigation Measures proposed for true risks to the source waters for public and GWS supply relating to issues, as follows:
 - Increased turbidity in the karst conduit or surface water system. Increased turbidity has the potential to affect the disinfection process in the WTPs and thereby compromises the sterility and safety of the water supplied to the public. There is no information presented by the applicant for baseline turbidity in surface waters or groundwaters of the area.
 - Increased Dissolved Organic Carbon in groundwater or surface waters. Construction in peatlands has the potential to exacerbate release of Dissolved Organic Carbon and this constituent is a driver on increased Trihalomethane formation potential in water supplied to the public after the statutory obligation of chlorination prior to discharge to the water mains. No Silt buster will remove DISSOLVED organic carbon in waters discharging from the site. There is no information presented by the applicant for baseline Dissolved Organic Carbon in surface waters or groundwaters of the area.
 - There is no information presented by the applicant for baseline lubricants and oils that will be in each hub and supplemented in the lifetime of the development, no information on hydrocarbon baseline, no details for the baseline surface water and groundwater constituents relatable to the proposed surface finishes of the coated turbines or those constituents that will be used in the cleaning of the turbine infrastructure.

Without baseline data, how can environmental compliance and public health impacts be policed in the lifetime of the proposed project?

6.0 Hydrogeological Impact Assessment Components

For all hydrogeological assessments, it is best practice to apply the Source > Pathway > Receptor Model of assessment of potential impact.

6.1 Sources

The potential sources of impact in any construction project of this nature, and indeed applicable to the Cooloo Wind Farm's proposal for Co. Galway, includes as follows:

- Water runoff from the construction site hardstandings and crane pads,
- Dewatering of trenches and excavations for foundations,
- Rainfall runoff on the peat, earth and rock extracted to enable each foundation base to be constructed.
- Cement being transported in trucks along the recently constructed haul roads,
- Cement being pumped from cement trucks,
- The transport and storage of steel reinforcement bars and rafts for the concrete foundations to each turbine, specified as 4-5m below ground level.
- Wastewater arisings from the people involved in the construction activities.
- Operational replacement of hub lubricants and hydrocarbons.
- Operational use of cleaning materials and de-icers.

The typical scale of a Turbine base pad construction area is presented as Plate A. Note that the turbine rotor lengths dictate some site dimensions. Turning distances for the unusually long trucks is also a constraint dictating the dimensions required to accommodate safe working areas. There will be the equivalent of c. 4 domestic resident sites area for each turbine ($4 \times 0.5 \text{ acre} = 2 \text{ acres} = \text{c. } 1 \text{ ha}$ of excavation for each of the 8 turbines). This presents silt and runoff burden that presents a threat to the Mid Galway PWS and GWSs nearby.

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Plate A Turbine base construction pads (9 no. proposed). Note the scale of each of the three rotors relative to the construction workers.

As is shown in the DWGS for the application, there will be extensive areas of Spoil Management and water management treatment systems adjacent to each of the proposed 9 turbines, the proposed substation construction site and along all trench excavation routes. All water management will be by Infiltration into the epikarst of the underlying Clare Corrib Groundwater Body and the Regionally Important Karst aquifer feeding Lough Corrib and multiple GWS BHs: refer to Drainage Drawings and BH Logs.

6.2 Pathway

In this karst limestone aquifer type, although mapped as Conduit karst, the epikarst plays the dominant role in conveyance of the abundant rainfall to surface water systems. This is known and understood by all hydrogeologists.

6.3 Receptors

The receptors within range of impact arising from the construction of the proposed windfarm, construction pads, hardcore standings, roads and infiltration drains include, as follows:

1. Mid Galway PWS
2. Barnaderg Gortbeg GWS
3. Briarfield GWS
4. Lough Corrib SAC and SPA

7.0 Building on Bogs over Conduit Karst – Hydrological Impact and Carbon Sequestration

There is a reason that the bogs of the proposed development area are there: poorly drained depressions in low permeability glacial till are ultimately filled with peat. The clay underlying the bogs is essential to their sustainability, cutaway or not. Integrity of the clay containment is essential to any restoration or rewetting. Turbine foundations, even on the margins of bogs, will destroy that integrity with all the implications for biodiversity/carbon storage. Even if not designated legally, they are Groundwater Dependent Terrestrial Ecosystems (WFD) and worthy of protection as listed habitats (which include 'degraded bog'). In Annex III of the parent EIA DIRECTIVE (2011/92/EU) on the assessment of the effects of certain public and private projects on the environment, Annex III clearly states that: "The environmental sensitivity of geographical areas likely to be affected by projects must be considered, having regard, in particular, to:

- (a) the existing land use;
- (b) the relative abundance, quality and regenerative capacity of natural resources in the area;
- (c) the absorption capacity of the natural environment, paying particular attention to the following areas:
 - (i) wetlands;
 - (vi) areas in which the environmental quality standards laid down in Union legislation have already been exceeded;"

Attention is drawn here to the legal obligation to consider "the absorption capacity of the natural environment". A significant portion of the land on which the turbines are proposed are bogs (wetlands of a sort). Professor Paul Johnston of Trinity College Dublin is on government record in stating that "Beyond all scientific doubt, building turbines in peat will negatively affect biodiversity and increase carbon loss from this habitat through the required drainage, foundations and infrastructure. Damage arising from construction releases more carbon from the

peatland. The long-term sustainable approach is the restoration of bog wetlands. A strategy of restoration, rather than any construction whatsoever, will provide a reduction in carbon emissions from the peatland in perpetuity. The societal benefits will be better water quality, reduction in flood events, a reversal of biodiversity loss and more opportunities for people to connect with nature resulting in better physical/mental health outcomes, as recognised in the Climate Action Plan, a derivative of the Paris Agreement. Moreover, since 1987, Ireland has been a signatory of the international Ramsar convention which provides for the protection and promotion of wetlands including peatlands. The case that windfarms in peatlands are incompatible with these requirements is rarely even considered appropriately in EIARs. The existing and growing resistance to terrestrial windfarms due to their environmental impact is frequently justified and exacerbated by inadequate EIARs which result in extra delays and costs as well as in poor planning decisions. This conflict between the requirements of environmental legislation and the need for increased wind power is unsustainable. When it comes to protecting our environment and its increasingly important ecosystem services on which the human race depends”.

Moreover, streams are the headwaters of the Clare River and hence supply sources for the Corrib SAC. All tributary streams to the Corrib are salmonid. Hence a windfarm in the headwaters of the catchment represents a risk to that water supply and ecology, especially in quality, notwithstanding the same tributaries are ancillary to an arterial drainage scheme. However, under Nature Restoration, such arterial drainage is itself under review for rehabilitation to more natural conditions (OPW) – building turbines should not be allowed to impede this restoration. The generic drainage system depicted in the report for draining roads and hardstands is unlikely to work since the low permeability soils will accelerate this drainage into the existing network – soil infiltration is likely to be poor, but no field assessment was made. Moreover, the proposed system with ‘silt traps’ is unlikely to work in detaining colloidal solids which, themselves carry Dissolved Organic Carbon (DOC) arising from the extensive excavations/roads on site, as well as from windfarm enhanced drainage from the peatbogs. Such losses conflict with the role of wind farms as climate mitigation devices.

8.0 Maladaptation

Maladaptation refers to actions or strategies that, while intended to address the challenges posed by climate change, inadvertently exacerbate the problem, or create new vulnerabilities. This can occur when adaptation measures are poorly planned, misaligned with the local conditions, or fail to account for long-term consequences.

The Ireland National Adaptation Framework – National Adaptation Plan 2025 (NAP 2024) states as follows:

- p.42, "Avoiding Maladaptation: Ensure that adaptation actions do not inadvertently create new vulnerabilities or exacerbate existing ones."
- "Consideration of Climate Mitigation: Ensure that climate mitigation outcomes are considered alongside adaptation planning where appropriate."
- p. 47, As part of its annual review, the CCAC also considers developments made in terms of supporting a just transition in terms of both mitigation and adaptation – noting in its 2023 review the need to accelerate the integration of the just transition principles across all mitigation and adaptation policy development and implementation".

9.0 Discussion – Safe Drinking Water Supply – A Human Right

In response to Mr. John McGuinness' PQ 103 question in the Oireachtas on the 5th of November 2024, Mr. Eamon Ryan admitted that Ireland's onshore Wind Targets were not tested using geospatial techniques ([Wind Energy Generation – Tuesday, 5 Nov 2024 – Parliamentary Questions \(33rd Dáil\) – Houses of the Oireachtas & https://www.oireachtas.ie/en/debates/question/2024-11-05/103/#pq_103](#)). The fact that Mr. Eamon Ryan admitted that they did not use geospatial techniques means that the government has not proven that their targets are logistically feasible given the constraints presented by Conservation Objective sites, the nature of groundwater as a source of supply in rural Ireland and the nature of housing development. Instead, wind energy targets were chosen by the then government based on modelling emissions and power systems. Therefore, Mr. Ryan's team decided that they wanted a certain emission reduction and set their target to that desire, regardless of any consideration of constraints posed by threats to Ireland's rivers, aquifers, water supply water to rural communities, Conservation Objective Natura 2000 sites and their endangered or protected species and habitats, nor were Housing Density nor Human Health implications considered in the selection of the onshore wind targets. It is for that reason that the results of the Strategic Environmental Assessment on Renewable targets cannot be published or defended by the Government.

The case before An Coimisiún Pleanála is a proposed High Risk & High Hazard development in the vicinity of groundwater and surface water supplying the Barnaderg Gortbeg GWS's groundwater spring and borehole abstraction locations. In the absence of any information being presented to An Bord Pleanála in relation to surface water and groundwater concentrations of those chemicals and lubricants associated with the maintenance of turbine masts and blades, as specified in the Drinking Water Regulations (2023) and Groundwater Regulations (2010, as amended 2016) it would seem that an EIA by An Coimisiún Pleanála is not possible. All of the parameters presented in Appendix 9-2 and 9-3 of the Water Chapter are chemicals associated with agricultural and domestic wastewater impacts. Therefore, the baseline quality of the waters has not been established in the area for groundwater and surface water turbidity (a parameter that will affect safety of supply), oils, lubricants and other chemicals that will be used to maintain, operate and repair the hubs and the coatings on the mast and blades of each turbine. Given that the groundwater of the proposed development area is connected to the Mid Galway and Barnaderg Gortbeg GWS sources, a baseline chemical analysis of parameters is required for the chemical constituents of relevance to the operation of the proposed development. Then, when the baseline is presented and the potential loadings are applied, An Coimisiún Pleanála must make a determination on the basis of whether the future chemical concentrations are acceptable in the context of environmental and public health impacts.

Notwithstanding potential water quality impacts, quantitative impact potential has not been acknowledged in any way by the applicant's agents. The hazards posed by subsidence in karst or collapse of caves has been listed. But the only impact considered is how the turbines might be affected.

Overall, the information presented by the applicant is lacking and there are gross omissions of factual information with respect to the Mid Galway PWS, Barnaderg Gortbeg GWS, Briarfield GWS and Lough Corrib SAC, SPA and Galway City's and Tuam's and environs' source of PWS. The proposal presents a construction period of up to 2 years if there are no delays caused by accidents or unfavourable weather. The lands proposed by the applicant are within
An Coimisiún Pleanála PAX07.323761

the EPA WFD catchment of, and Zone of Contribution to, Lough Corrib: the PWS supply for water to Galway City, Tuam and north east Galway. The multinational and educationally driven economy of Galway city and Tuam is wholly reliant on Lough Corrib as its source of PWS. The proposed development area is also in the groundwater system feeding the nearby Mid Galway PWS and Barnaderg Gortbeg GWS. The applicant's agents have incorrectly used a land use planning map for microbial time of travel and a volume of water abstraction that is 13 years out of date.

With respect to An Coimisiún Pleanála's obligations under s15(1) of the Climate Act is to address "the climate emergency", the rights of the public to have safe water delivered to their homes and farms is a Human Right. As stated by Mr. Justice Humpries in the Coolglass Judgment: 15(1), like any other domestic provision, must be interpreted consistently with EU and European Convention on Human Rights ("ECHR") law.

10.0 Recommendation

It is recommended that An Coimisiún Pleanála refuse permission to the said development for the reason that the proposal presents a risk to public health by the pathway of groundwater abstracted for the purposes of Public Water Supply at the Mid Galway source(s), the Barnaderg Gortbeg GWS and Briarfield GWS. The rights of the public to have safe water delivered to their homes and farms is a Human Right that must be maintained.

Pamela Bartley

Signed: _____

Date: 20th November 2025

Dr. Pamela Bartley BEng, MSc, PhD

Appendix A GSI (2004) GWB Description Sheet

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		<p>Groundwater flow directions and gradients: Overall, flow directions are to the southwest, with all groundwater discharging to L. Corrib. Although, there are six surface water catchments within the GWB, a <i>key</i> aspect is that groundwater can flow across the surface water divides and beneath surface water channels, as evidenced by the tracer test data. Examples of this key property are listed as follows:</p> <ol style="list-style-type: none"> 1) water that sinks at Ballyglumin Cave emerges at Aucloggeen Spring, which crosses two surface water catchments. 2) water sinking along an losing stretch of the River Clare reemerges as the headwater of the Black River. 3) recent tracing tests in the Ballinlough area of Roscommon indicate a link across the Shannon RBD into the Western RBD, from Coolcam (Roscommon) to Meeltraun (Mayo). 4) water along an losing stretch of the Sinking River flows about 10 km underground to join the River Clare. <p>Drew (1976 (a)) suggests that groundwater flow is concentrated along the axes of shallow synclines. Gradients are variable, irregular due to the uneven distribution of transmissivity and are in the order of 0.01-0.002 (Drew and Daly, 1993; Daly, 1985)).</p>																					
	Thickness	The Dinantian Pure Bedded Limestones are generally over 100 m thick. Most groundwater flows in an epikarstic layer a couple of metres thick and in a zone of interconnected solutionally-enlarged fissures and conduits that extends approximately 30 m below this. Deeper inflows can occur in areas associated with faults or dolomitisation.																					
Overlying Strata	Lithologies	Till is the dominant subsoil type, covering approximately 65% of the GWB. Cutover Peat comprises 23% of the area, sand/gravel covers approximately 3% and alluvium 2%. A full breakdown of the subsoil lithology is given in Table 1. A large proportion of the sand/gravel forms a random hummocky topography, although long sinuous, braided ridges of sand/gravel (eskers) have also been deposited especially in the east. A small portion of the north eastern area of the GWB around Cloonfad is described under the Roscommon Groundwater Protection Scheme (Lee and Daly, 2003) The till in this area is described as "SILT" (BS 5930), and is classed as "Moderate" permeability. There are also areas of "clayey" till, often underlying areas of raised bog (Drew and Daly, 1993). The thin till cover over much of the west part of the area is generally free draining (Daly, 1985).																					
	Thickness	East of a line linking Athenry – Tuam – Dunmore, the subsoil is "generally thicker" (Daly, 1985; Drew and Daly, 1993). This is supported by the occurrence of rock at or near surface, which is generally restricted to the western and southwestern part of the GWB. Analysis of the available depth to bedrock borehole data is limited as most of the data are clustered in three main areas: western, northeastern and central (area around Tuam) parts of the GWB. Nevertheless the data show a <i>general</i> increase in subsoil thickness in an easterly direction: average depth to bedrock increases from 4 m to 9 m from the west to east. In addition, there are instances of depth to bedrock greater than 20 m around Dunmore (northeast of GWB). However, there are also pockets of deeper till in the southwestern part of the GWB.																					
	% area aquifer near surface	50% of the GWB to the west of the line Athenry – Tuam – Dunmore is only covered by shallow till. 4% of the total GWB area has rock at or near surface.																					
	Vulnerability	The vulnerability for a small portion of the north eastern area of the GWB around the area of Cloonfad is described in the County Roscommon Groundwater Protection Scheme (Lee and Daly, 2003). In this area the vulnerability classification is variable dependent on the depth to bedrock. For the rest of the area. <i>[Information to be added at a later date]</i>																					
Recharge	Main recharge mechanisms	Both point and diffuse recharge occur in this GWB. Diffuse recharge occurs over the GWB via rainfall percolating through the permeable subsoil. Despite the presence of peat and till, point recharge to the underlying aquifer occurs by means of swallow holes and collapse features/dolines. Dolines have been recorded even in areas of thick peat deposits (Hickey et al, 2002). Point recharge occurs via many small sinks that are present in the low permeability till areas where the subsoil is breached. Recharge also occurs along 'losing' sections of streams. There are well defined stretches of the River Clare, Sinking River and Abbert River that are losing (Daly, 1985; Drew and Daly, 1993).																					
	Est. recharge rates	<i>[Information to be added at a later date]</i>																					
Discharge	Large springs and large known abstractions (m³/d)	<table border="0"> <tr> <td>Large Springs:</td> <td>Corrandulla GWS (6764 m³/d)</td> <td>Kilbannon GWS (5995 m³/d),</td> </tr> <tr> <td></td> <td>Mullacultra GWS (3270 m³/d)</td> <td>Barnaderg Group Scheme (5000 m³/d),</td> </tr> <tr> <td></td> <td>Ballyhaunis WSS (12000 m³/d)</td> <td>Tobernanny,</td> </tr> <tr> <td></td> <td>Gortgarrow</td> <td>Lettera</td> </tr> <tr> <td>Large known borehole abstractions:</td> <td></td> <td></td> </tr> <tr> <td></td> <td>Gallagh GWS (523 m³/d)</td> <td>Rusheens Tuam GWS (114 m³/d)</td> </tr> <tr> <td></td> <td>Roadstone Ltd (227 m³/d)</td> <td>Belclare (114 m³/d).</td> </tr> </table> <p><i>[Information to be added to and checked]</i></p>	Large Springs:	Corrandulla GWS (6764 m ³ /d)	Kilbannon GWS (5995 m ³ /d),		Mullacultra GWS (3270 m ³ /d)	Barnaderg Group Scheme (5000 m ³ /d),		Ballyhaunis WSS (12000 m ³ /d)	Tobernanny,		Gortgarrow	Lettera	Large known borehole abstractions:				Gallagh GWS (523 m ³ /d)	Rusheens Tuam GWS (114 m ³ /d)		Roadstone Ltd (227 m ³ /d)	Belclare (114 m ³ /d).
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	Gallagh GWS (523 m ³ /d)	Rusheens Tuam GWS (114 m ³ /d)																					
	Roadstone Ltd (227 m ³ /d)	Belclare (114 m ³ /d).																					
Main discharge mechanisms	The main groundwater discharges are to the streams, rivers and large springs found within the body. The large springs at Kilcoona, Bunatober and Aucloggeen and others issue from the bottom of a limestone scarp that is thought to represent an ancient shoreline of L. Corrib. Further these springs are likely to represent overflow springs and deeper groundwater flow discharges to outlets beneath the present day L. Corrib (Drew, 1993). In winter groundwater will fill the turloughs found in the area and partly discharge via the artificial channels that were installed to alleviate flooding.																						

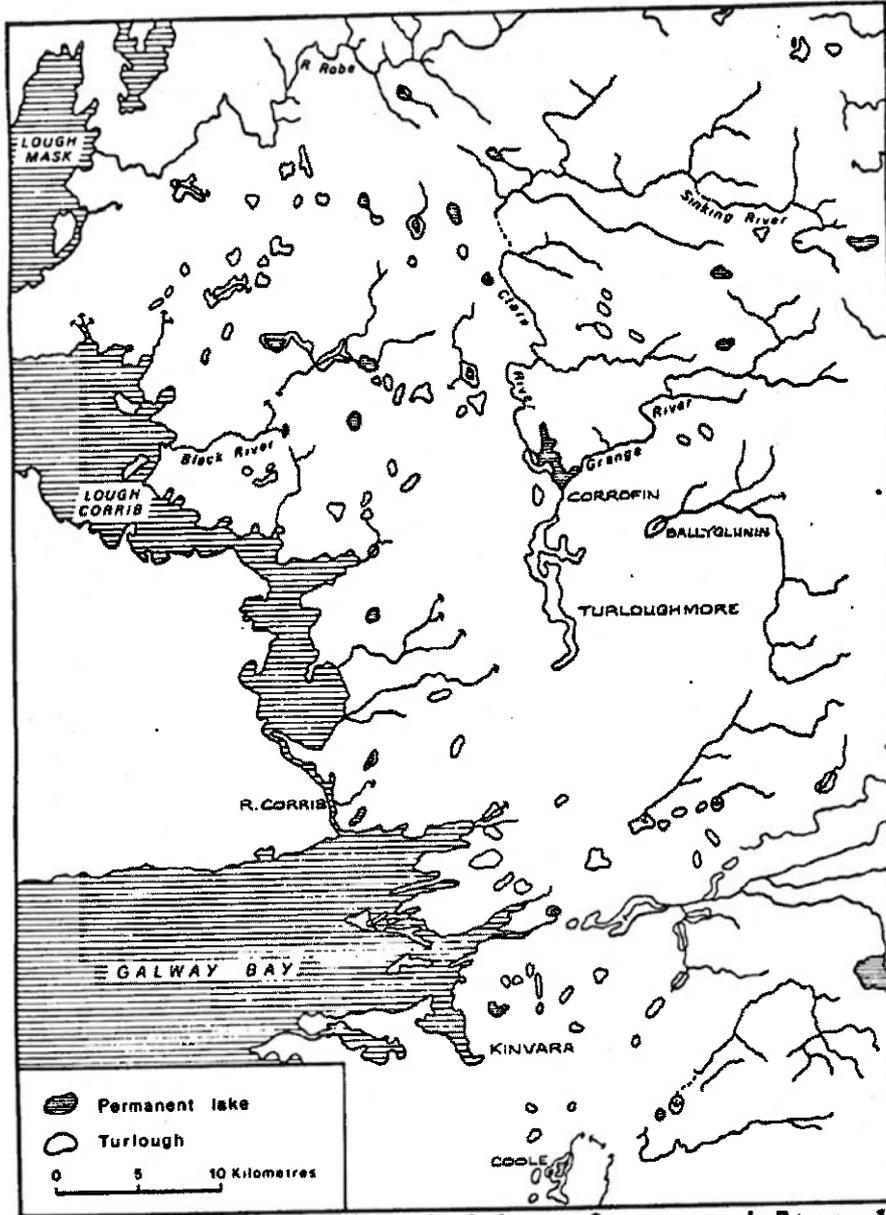
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Hydrochemical Signature	The groundwater has a calcium bicarbonate signature. Two groundwater provinces are suggested by Drew and Daly (1993). Firstly, there is a shallow groundwater component that is characterised by high suspended solids and relatively low electrical conductivities (300-400 $\mu\text{S}/\text{cm}$). Springs that are fed by this component typically have a "flashy" throughput and often cease to flow during prolonged drought. Secondly, there is a deeper groundwater component that is characterised by relatively non-turbid groundwater with higher electrical conductivities (>450 $\mu\text{S}/\text{cm}$). Springs fed by this deeper component often have smoother hydrographs where there is a gradual change in discharge. Several large springs comprise both flow components, examples are Lettera, Tobernanny and Bunatober springs.
Groundwater Flow Paths	These rocks are generally devoid of intergranular permeability. Groundwater flows through fissures, faults, joints and bedding planes. In pure bedded limestones these openings are enlarged by karstification which significantly enhances the permeability of the rock. Karstification can be accentuated along structural features such as fold axes and faults. Groundwater flow through karst areas is extremely complex and difficult to predict. As flow pathways are often determined by discrete conduits, actual flow directions will not necessarily be perpendicular to the assumed water table contours, as shown by several tracing studies (Drew and Daly, 1993). The tracer tests show that groundwater can flow across surface water catchment divides and beneath surface water channels. Flow velocities can be rapid and variable, both spatially and temporally. Rapid groundwater flow velocities indicate that a large proportion of groundwater flow occurs in enlarged conduit systems. Groundwater flow in highly permeable karstified limestones is of a regional scale. Flow path lengths can be up to a several kilometres, for example 9.6 km from Ballyglunin Cave to Auclogheen Spring. Overall, groundwater flow will be towards the River Clare and L. Corrib, but the highly karstified nature of the bedrock means that locally groundwater flow directions can be highly variable.
Groundwater & Surface water interactions	The area is drained by the River Clare and its tributaries, however the present day drainage network has been changed significantly by arterial drainage that took place early in the nineteenth century. Figures 1 and 2 show the pre/post arterial drainage network. According to Coxon and Drew (1983), much of the current stream network is a storm runoff system that is inactive during summer months. Thus, prior to drainage, streams sank underground via the turloughs present in the GWB. Many of the streams have well defined losing stretches where they lose water to the underground system (Daly, 1985). There is a high degree of interconnection between groundwater and surface water in karstified limestone areas such as in this GWB. Even though large areas of peat and tills overlie the body, collapse features in these areas provide a direct connection between the surface and the groundwater systems. The close interaction between surface water and groundwater in karstified aquifers is reflected in their closely linked water quality. Any contamination of surface water is rapidly transported into the groundwater system, and vice versa. Furthermore, there are a number of terrestrial ecosystems within this GWB with varying dependence on groundwater.

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Conceptual model	<ul style="list-style-type: none"> • The north, south and west groundwater divides of this GWB are topographic highs that coincide with surface water catchment boundaries. It is bounded to the east by Lough Corrib. • The topography is undulating with ground elevations ranging from 10-160 mAOD. A large proportion of the body is overlain by till, which thickens in an easterly direction. • The area is principally drained by the River Clare and its tributaries, however the present day drainage network has been changed significantly by arterial drainage that took place early in the nineteenth century. Much of the current stream network is a storm runoff system and is inactive during summer months. Prior to artificial drainage, streams sank underground via a few turlough sinks in the GWB. • Within the GWB, surface water catchments are often bypassed by groundwater flowing beneath surface water channels and across surface water catchment divides. • A large number of karst features occur within the body. These include turloughs, caves, dolines, swallow holes and springs. • The GWB is composed primarily of high transmissivity karstified limestone (Rk^c). Transmissivity and well yields are variable. Storage in the GWB is low. • Groundwater flows through a network of solutionally enlarged bedding planes, fissures and conduits. • Rapid groundwater flow velocities have been recorded through groundwater tracing. The tracing indicates an anisotropy in the transmissivity, with faster groundwater flow velocities and higher transmissivity in an E-W direction, which may be linked to shallow E-W trending synclinal axes and steeper E-W hydraulic gradients. • Recharge in this GWB occurs via losing streams, point and diffuse mechanisms. Despite the presence of peat and till, point recharge to the underlying aquifer occurs by means of swallow holes and collapse features/dolines. • The groundwater in this body is generally unconfined but may become locally confined beneath thick, low permeability subsoil. Most of the groundwater flow occurs in the upper epikarstic layer and in a zone of interconnected solutionally enlarge bedding planes and fissures, generally extending to a depth of 30 m. • In general, the degree of interconnection in karstic systems is high and they support regional scale flow systems. Flow paths have been measured up to 10 kilometres in length. • Some areas in this GWB are of extreme vulnerability due to the thin nature of the subsoil, as well as the frequency of karst features, allowing point recharge. Groundwater storage in karstified bedrock is low and the potential for contaminant attenuation in such aquifers is limited. • The main discharges are to the rivers, large springs and L. Corrib. In winter groundwater discharges to the many turloughs and transmitted via the artificial channels that were installed to alleviate flooding. • There is a high degree of interaction between surface water and groundwater in this GWB. There are a number of terrestrial ecosystems within this GWB which have varying dependence on groundwater. • There are potentially two groundwater provinces within the GWB but this is uncertain. The groundwater has a calcium bicarbonate signature.
Attachments	Figures 1, 2, 3, 4 and 5.
Instrumentation	<p>Stream gauges: 30002, 30003, 30004, 30006, 30007, 30010, 30011, 30012, 30013, 30014, 30015, 30020, 30022, 30023, 30024, 30025, 30026, 30029, 30030, 30032, 30040, 30045, 30053, 30055, 30071, 30101, 30103.</p> <p>EPA Water Level Monitoring boreholes: Lackagh, GAL287, Tuam (Coca Cola), GAL291, Shrule, MAY085</p> <p>EPA Representative Monitoring points:</p>
Information Sources	<p>Daly, D. (1995) <i>A report on the Flooding in the Glenamaddy area</i>. Groundwater Section Report File 2.2.7. 34pp.</p> <p>Daly, D. (1992) <i>A report on the Flooding in the Claregalway area</i>. Groundwater Section Report File 2.2.7. 12pp.</p> <p>Daly, D. (1985) <i>Groundwater in County Galway with particular reference to its Protection from Pollution</i>. Geological Survey of Ireland report for Galway County Council. 98pp.</p> <p>Drew D.P. and Daly D. (1993) <i>Groundwater and Karstification in Mid-Galway, South Mayo and North Clare</i>. A Joint Report: Department of Geography, Trinity College Dublin and Groundwater Section, Geological Survey of Ireland. Geological Survey of Ireland Report Series 93/3 (Groundwater), 86 pp</p> <p>Drew, D.P. (1973a) <i>Hydrogeology of the north Co. Galway – south Co. Mayo lowland karst area, Western Ireland</i>. International Speleology 1973, III, Sub –section Ca.</p> <p>Drew, D.P. (1973b). <i>Ballyglunin core Co. Galway and the hydrology of the surrounding area</i>. Irish Geography Vol. 6, No. 5. pp 610-617.</p> <p>Doak, M. (1995) <i>The Vulnerability to Pollution and Hydrochemical Variation of Eleven Springs (Catchments) in the Karst Lowlands of the West of Ireland</i>. Unpublished M.Sc. thesis, Sligo Regional Technical College.</p> <p>Hickey, C., Lee, M., Drew, D., Meehan, R. and Daly D. (2002) <i>Lowland Karst of North Roscommon and Westmeath</i>. International Association of Hydrogeologists Irish Group. Karst Field Trip October 2002. Unpublished IAH Report.</p> <p>Lee, M. & Daly D. (2003) <i>County Roscommon Groundwater Protection Scheme</i>. Main Report. Roscommon County Council & Geological Survey of Ireland, 54pp.</p> <p>Hickey, C., Lee, M., Drew, D., Meehan, R. and Daly D. (2002) <i>Lowland Karst of North Roscommon and Westmeath</i>. International Association of Hydrogeologists Irish Group. Karst Field Trip October 2002. Unpublished IAH Report.</p>
Disclaimer	Note that all calculation and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae.

Figure 1 Pre Arterial Drainage.



[copied from Coxon and Drew, 1983]

Figure 2 Post Arterial Drainage



(copied from Coxen and Drew, 1983)

Figure 3 Histogram of Karst features in Clare-Corrib GWB

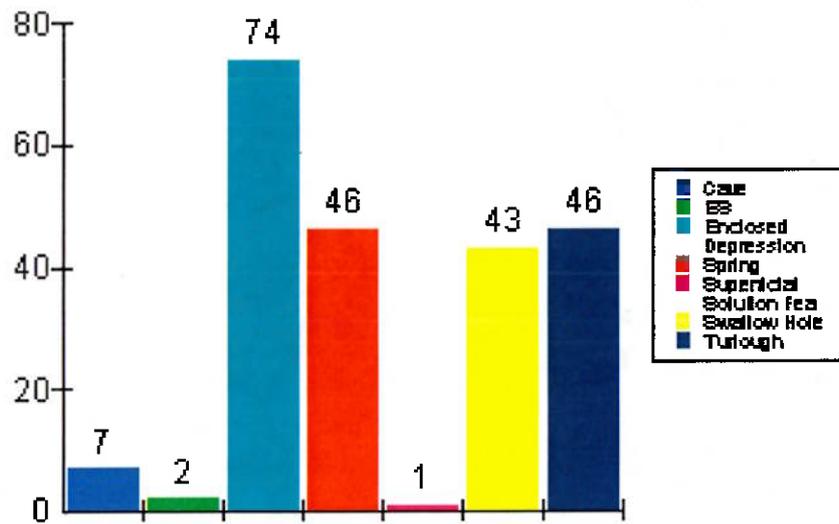


Figure 4 Histogram of Well Yields in Clare-Corrib GWB

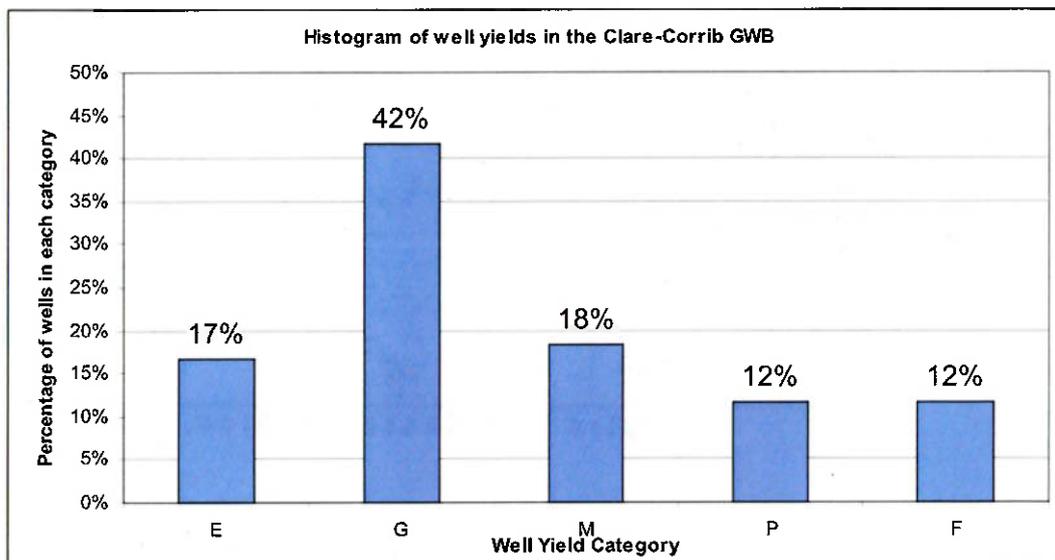
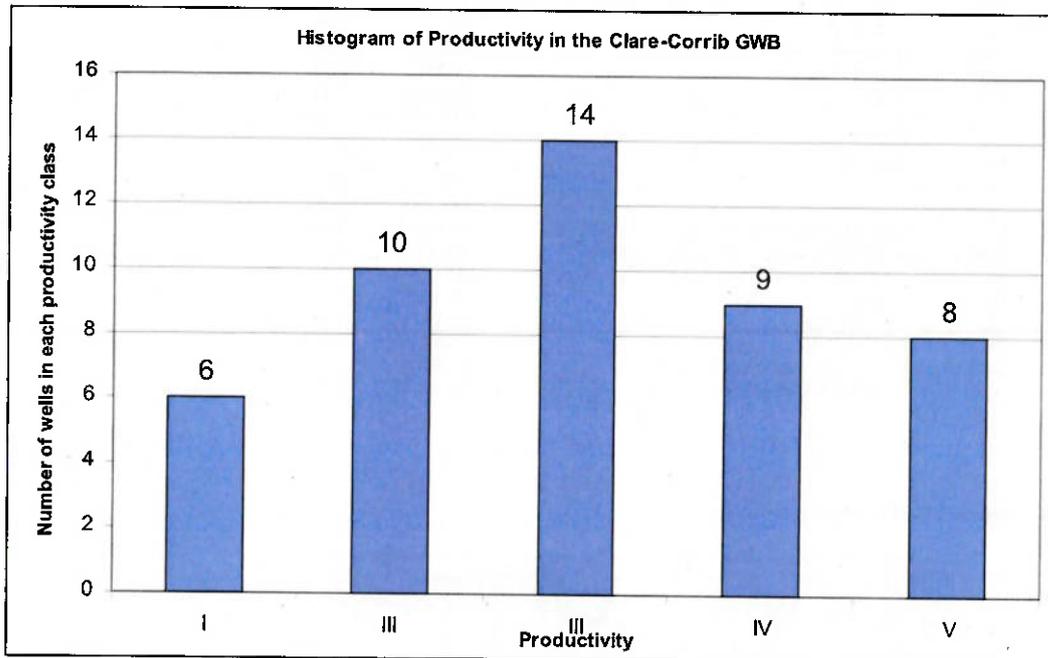


Figure 5 Histogram of Well Productivities in Clare-Corrib GWB



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List of Rock units in Clare-Corrib GWB

Unit Name	Code	Description	Rock Unit
Ardnasillagh Formation	AS	Dark cherty limestone, thin shale	Dinantian Pure Bedded Limestones
Aughnanure Oolite Formation	AU	Cross-bedded massive oolitic limestone	Dinantian Pure Bedded Limestones
Ballysteen Formation	BA	Dark muddy limestone, shale	Dinantian Lower Impure Limestones
Boyle Sandstone Formation	BO	Sandstone, siltstone, black mudstone	Dinantian Mixed Sandstones, Shales and Limestones
Cloonfad Felsite	CfFa	Felsite	Granites & other Igneous Intrusive rocks
Cong Canal Formation	NL	Medium to thick-bedded pure limestone	Dinantian Pure Bedded Limestones
Cong Limestone Formation	CO	Thick-bedded pure limestone	Dinantian Pure Bedded Limestones
Coranellistrum Formation	CT	Medium to thick-bedded pure limestone	Dinantian Pure Bedded Limestones
Illeaunagappul Formation	IL	Limestone, thin shale partings	Dinantian Pure Bedded Limestones
Kilbryan Limestone Formation	KL	Dark nodular calcarenite & shale	Dinantian Lower Impure Limestones
Knockmaa Formation	KA	Thick-bedded pure limestone	Dinantian Pure Bedded Limestones
Lucan Formation	LU	Dark limestone & shale (Calp")	Dinantian Upper Impure Limestones
Oakport Limestone Formation	OK	Pale grey massive limestone	Dinantian Pure Bedded Limestones
Oldchapel Limestone Formation	OC	Dark fine limestone & calcareous shale	Dinantian Pure Bedded Limestones
Owenriff Member	OUor	Dark limestone with thin shales	Dinantian Lower Impure Limestones
Two Mile Ditch Member	KATm	Thick-bedded limestone, clay wayboards	Dinantian Pure Bedded Limestones
Visean Limestones (undifferentiated)	VIS	Undifferentiated limestone	Dinantian Pure Bedded Limestones
Waulsortian Limestones	WA	Massive unbedded lime-mudstone	Dinantian Pure Unbedded Limestones

**Appendix B Establishment of Groundwater Source Protection Zones
Mid-Galway Public Water Supply Scheme (May 2012)**



Establishment of Groundwater Source Protection Zones

Mid-Galway Public Water Supply Scheme

Rev. A

May 2012

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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 Source Protection Zone also provides an area in which to focus further investigation and is an area where protective measures can be introduced to maintain or improve the quality of groundwater.

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

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



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APPENDICES

Appendix A: Photographs

Appendix B: Mapped Karst Features

Appendix C: Subsoil Logs – window sampling (2010)

Appendix D: Tracer Test Results

1 Introduction

Groundwater Source Protection Zones (SPZ) have been delineated for the Mid-Galway public water supply scheme according to the principles and methodologies set out in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999) and in the GSI/EPA/IGI Training course on Groundwater SPZ Delineation.

The Mid-Galway Public Water Scheme (PWS) is sourced from an unnamed stream in the townland of Derreen, Co. Galway. In 2010 and 2011, the PWS pumped and distributed an estimated 4,000 m³/d on average to households connected to the scheme.

The objectives of this report are as follows:

- To outline the principal hydrogeological characteristics of the area surrounding the PWS.
- To delineate source protection zones for the sources of water to the PWS.
- To assist the Environmental Protection Agency and Galway County Council in protecting the water supply from contamination.

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

The maps produced are based largely on the readily available information in the area, a field walkover survey, water level monitoring during normal pumping operations, 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 authors wish to acknowledge the contributions made by the caretakers of water supply facilities at the Mid-Galway PWS, the Barnaderg group water scheme (GWS), and the Brierfield GWS.

2 Methodology

The methodology applied to delineate the SPZ consisted of data collection, desk studies, site visits, field mapping of geological exposures, mapping of geomorphology and karst features, well audits, water level recording, flow measurements, tracer testing, as well as subsequent data analysis and interpretation. The work was carried out between June 2010 and October 2011.

3 Location, Site Description and Spring Protection

As shown in **Figure 1**, the Mid-Galway PWS is located approximately 4 km to the northeast of Abbey village and 3.5 km south of Barnaderg village. The source of the water for the PWS is an unnamed stream which flows south from Horseleap Lough to the Abbert River. For ease of reference, this stream is referenced as the Derreen stream, named after the townland that the PWS is located in and which provides water to the PWS. Derreen stream is intermittent in its upper reaches between the Barnaderg GWS and Horseleap Lough.

The PWS is contained within a fenced-in area that holds a new (2011) reservoir, treatment facility, and pumphouse. The water is filtered and disinfected at source prior to distribution. Photographs of the PWS and general points of interest are included in **Appendix A**.



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Figure 1: Location Map with Points of Interest

4 Summary of Sources

Table 1 provides a summary of the PWS. The average quantity of water abstracted and distributed in 2010/2011 was 4,000 m³/d but abstraction records indicate this can range with demand from 2,500 to 5,500 m³/d.

Table 1: Source Details

	Mid-Galway PWS
Reporting Code	IE_WE_G_225_07_003
Groundwater Body	Clare-Corrib (IE_WE_G_0020)
Grid reference	153928E, 244679N
Townland	Derreen
Source type	Surface water (originating mainly as groundwater)
Owner	Galway County Council
Elevation (Ground Level - GPS)	54 mOD
Average daily abstraction (m ³ /d):	4,000
Estimated median discharge (m ³ /d)*	19,000

Note:

* - Estimated from EPA flow records for the measurement period between October 2009 through June 2011.

The PWS sources its water from an intake on an unnamed stream which flows between Horseleap Lough (see **Figure 1**) and the Abbert River. The stream's flow has been monitored by the EPA since October 2009 when an automatic flow recorder (a Time of Flight ultrasonic device) was installed by the bridge approximately 20 m downstream of the PWS intake. As such, the device records flows which are influenced by the abstractions from the PWS. A second, smaller abstraction also takes place at the Barnaderg GWS, located approximately 700 m upstream of the PWS (see **Figure 1**). Until late 2011, the GWS sourced its water from a spring which contributes overflow to the Derreen stream. The GWS presently produces water from a new well drilled less than 100 m from the spring, drawing on the same groundwater that otherwise discharges naturally to the spring. The total average abstraction from the GWS in 2010-2011 was approximately 900 - 1,000 m³/d.

Estimated flows are shown in **Figure 2** for the period between October 2009 and June 2011. There are data gaps, particularly in the first few months of operation, however, the estimated flow ranged from 30 l/s (2,590 m³/d) in early September 2010 to approximately 4,000 l/s (345,600 m³/d) during the flood events of November 2009. The flow records are characterised by dry- and wet-weather extremes. In order to reduce potential skewing of flow statistics by extreme events, median flows have been defined rather than arithmetic averages. For the measurement period referenced above, the median flow is 168 l/s (14,515 m³/d). This increases to 225 l/s when abstractions from the PWS and the Barnaderg GWS are added. When only daily maxima values are used (i.e. by removing potential streamflow reductions from abstractions), the median flow becomes 220 l/s (19,000 m³/d), and the bi-weighted mean is very similar, at 214 l/s. A value of 220 l/s is, therefore, considered a more representative flow to be used for purposes of delineating zones of contribution to the PWS. It is represented primarily by groundwater discharges into the stream from: a) individual springs; and b) diffuse seepages along the stream bed and bedding planes on adjacent stream banks. Surface water contributions only become important at much higher flows, and originate as runoff in ditches, overflow from Horseleap Lough, as well as overflow from a topographic depression just east of Horseleap (which joins the outflow from the lake near the Horseleap Bridge).

A rare opportunity was afforded in early September 2010 to observe a sudden hydraulic 'transformation' of the hydrological system in response to a single, individual storm event. As indicated in **Figure 3**, 51 mm rainfall event was recorded on September 6th at a nearby rainfall station at Glenamaddy, less than 20 km to the north-northeast of the PWS.

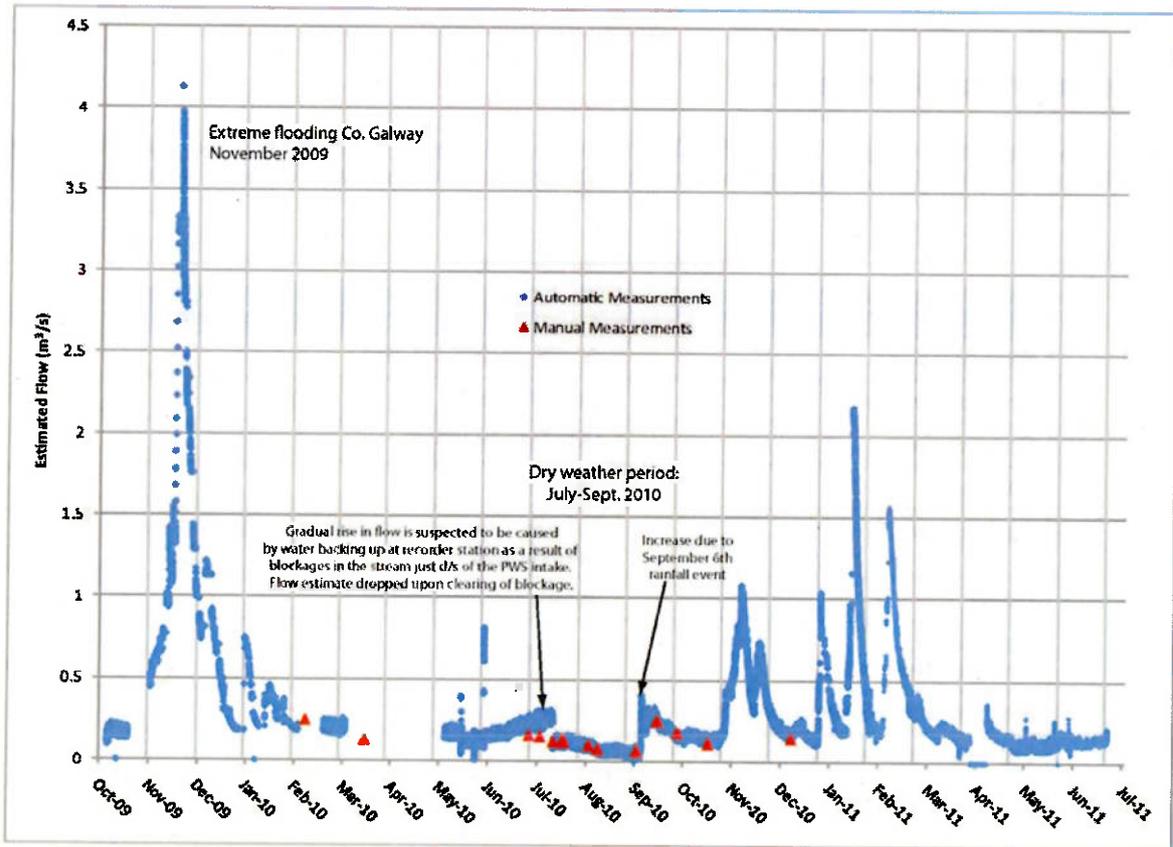


Figure 2: Estimated (Measured) Flow in the Derreen Stream October 2009 – July 2011

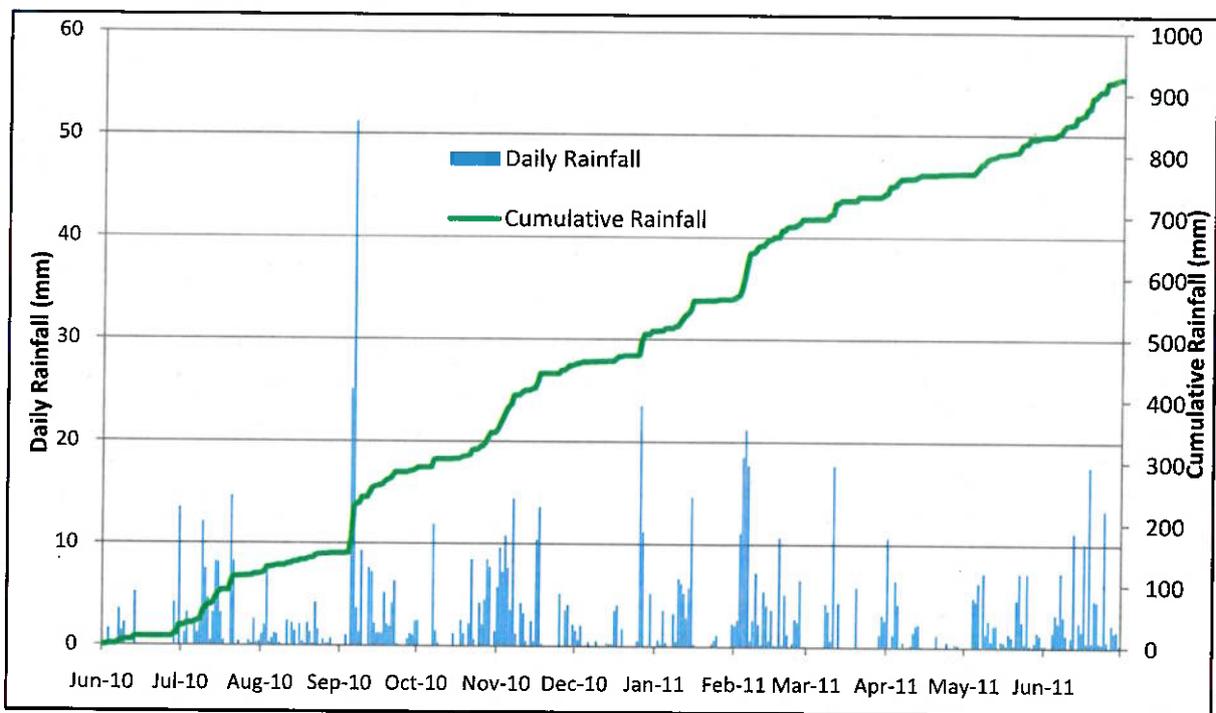


Figure 3: Daily and Cumulative Rainfall at Glenamaddy, June 2010 to July 2011

The hydrological changes that resulted are summarized in **Figure 4** along the Derreen stream, where manual flow measurements of individual discharge points and streamflow were made on September 3rd (the end of the extended dry weather period) and September 16th (post-September 6th storm event). The September 16th measurements are consistent with similar measurements by the EPA in March 2008, which are reproduced in **Figure 5**, although spring discharges and inflows from ditches in the wooded area near the PWS were much larger on March 6th, 2008 presumably because antecedent ground conditions were more saturated.

General observations from site visits on different dates testify to a dynamic groundwater flow system where individual discharge points appear and disappear as a function of the hydrological conditions that preceded or existed on the dates of measurement/visit. These types of springs are typically known as 'overflow' springs, and typically point to the presence of a complex system of underground conduits. As noted by the red text in **Figure 4**, two additional springs were active on February 14, 2011 on the east bank of the Derreen stream. These springs appeared after heavy rainfall events in January and early February 2011, whereby water levels built up over time before reaching ground surface at these locations (note, 3-4 metres above stream level). Their combined measured discharges were approximately 80 l/s (10% of the total measured flow in the Derreen stream on that day).

The area between Horseleap Lough and the PWS undoubtedly represents an important groundwater discharge area. It occupies a relatively low topographic position adjacent to the Abbert River and, indeed, the Abbert River may be acting as a hydraulic boundary to groundwater flow. This, however, has not yet been conclusively demonstrated. Drew (1973) identified a shallow conduit system that passes beneath and across the Abbert River at Ballyglunin, approximately 7.5 km to the southwest of the PWS. A similar situation could exist closer to the Mid-Galway PWS.

The groundwater discharges associated with the Derreen stream are small compared to the Pollifrin Spring, shown in **Figure 6**, which is located approximately 2.2 km to the east-southeast of the PWS. It consists of three discrete but connected discharge points, and is by far the largest of all discharges in the study area. Pollifrin is a source of water for the Brierfield GWS, with an average daily abstraction of 100 m³/d. Given its location and based on results of dye tracer testing (see Section 8), Pollifrin is considered to be part of the same hydrogeological system that supplies water to the Mid-Galway PWS and the Barnaderg GWS. Unfortunately, there are no historical flow records from Pollifrin. Manual spot measurements of the outflow channel that carries water to the Abbert River yielded a range of flows between 30 l/s (2,592 m³/d) on August 5, 2010 and 2,623 l/s (226,627 m³/d) on January 17, 2011. The latter includes an estimated contribution of 200 l/s (17,280 m³/d) from surface runoff (i.e. inflow from ditches). The Pollifrin spring appears to be subject to the same extreme behaviour as the Derreen stream. From the few measurements that exist, the median flow (discharge) is estimated at 411 l/s (35,510 m³/d). Combined with the records from the PWS, the total median discharge for the entire groundwater discharge system is estimated to be 631 l/s (54,518 m³/d).

4.1 Topography, Surface Hydrology, Landuse

The PWS is situated approximately 54 mOD at the edge of a forested area which is surrounded by agricultural (pasture) land. Topography rises gently in an east-northeasterly direction to elevations of approximately 80-90 mOD in the vicinity of Moylough (see **Figure 1**). The roughly triangular area between the PWS, Moylough and Menlough (to the south of Moylough) forms a gently rolling limestone 'plateau' which is generally devoid of surface drainage features but incorporates numerous small enclosed depressions that pond rainwater following high intensity or long duration rainfall events. The general study area is demarcated by limestone hills at Oakwood (160 mOD, near Abbeyknockmoy, south of the Abbert River), Knock (115 mOD, near Barnaderg village), and Mountbernard (125 mOD, some 11 km east of Monivea village).

The PWS is located in the Western River Basin District, within the Clare River catchment. Regional drainage is to the west-southwest, towards the Clare River. Local drainage, including the Derreen Stream, is towards the Abbert River which in turn flows into the Clare River. Other significant surface water features within the study area are Horseleap Lough to the east-northeast of the PWS and Summerville Lough to the west of Moylough. Whereas the Abbert River is a regional drainage feature, the two loughs are local features with small catchment areas.

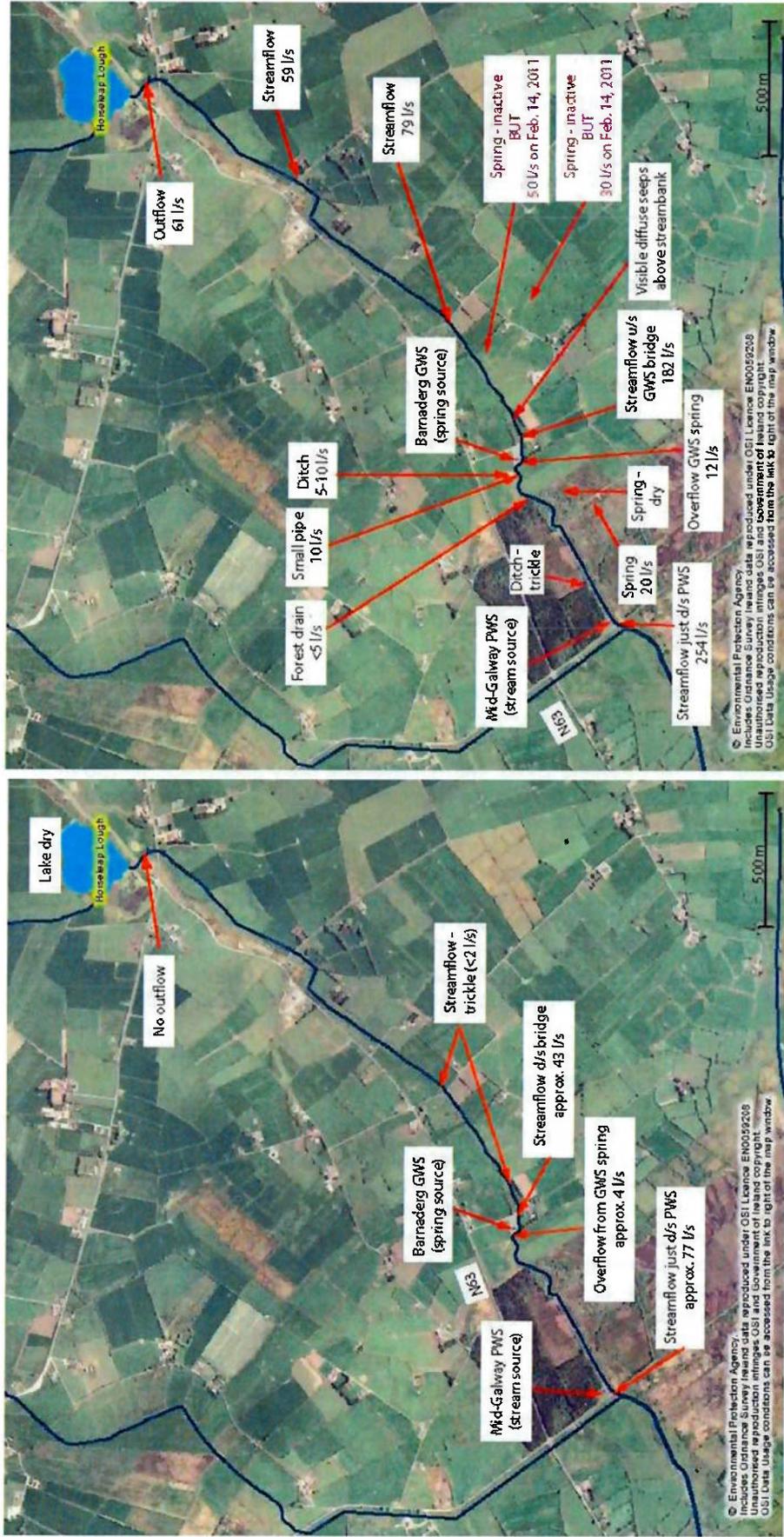
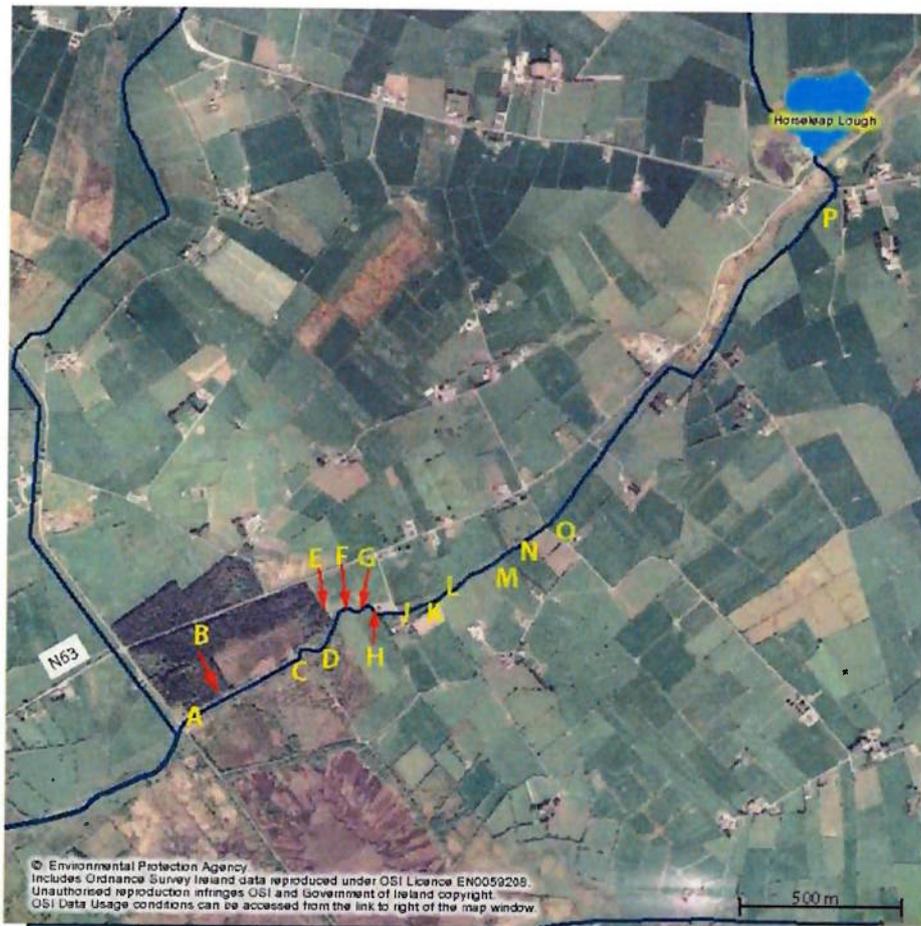


Figure 4: Flow Contributions to Derreen Stream on September 3rd and 16th, 2010



Location	Flow m ³ /s	EC	Ph	Temp	Description
A	0.3316	703	7	10.5	Main channel, just u/s of Mid-Galway PWS
B	0.0363	693	7.12	10.2	Inflow (ditch)
C	0.0858	709	6.76	10.2	Spring contribution
D	0.0158	708	6.94	10.2	Spring contribution
E	0.0055	790	7.46	9.7	Inflow (ditch)
F	0.007	728	7.09	10.2	Inflow from covered spring via pipe
G	0.0023	712	7.06	9.2	Spring
H	0.006	708	6.81	10.2	Overflow from spring at Bamaderg GWS
J	0.188	715	6.82	9.9	Main channel
K	0.0866	708	6.76	10.1	Diffuse discharges from the stream bank
L	0.1014	700	7.26	9.6	Main channel
M	--				Spring, no flow
N	0.035	680	7.03	9.4	Seep via ditch
O	0.057	661	7.51	9.1	Main channel
P	0.0368	604	8.15	8.6	Outflow from Horseleap Lough

Figure 5: Flow Contributions to Derreen Stream on March 6, 2008

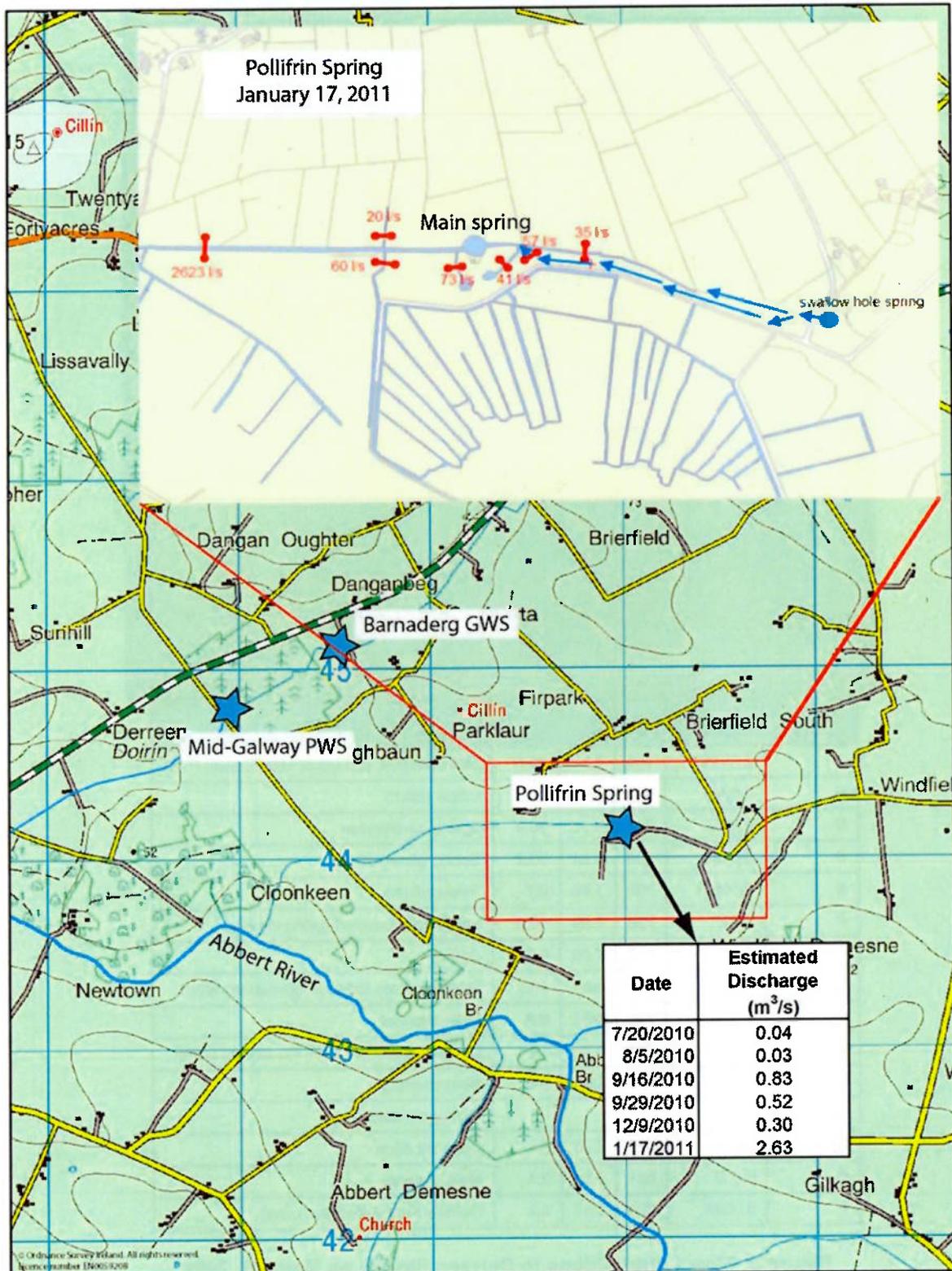


Figure 6: Spot Measurements of Discharges from Pollifrin Spring

5 Hydrometeorology

Establishing groundwater source protection zones requires an understanding of general hydrometeorological patterns across the area of interest. The information presented below was obtained from Met Éireann.

Annual Average Rainfall: 1,057 mm. The contoured map of rainfall data in Ireland (Met Éireann website, data averaged from 1961–1990) shows that the source is located between the 1,000 mm and the 1,200 mm average annual rainfall isohyets. The closest meteorological (rainfall) station is at Glenamaddy (Gortnagier) approximately 15 km away to the north, with a 30-year average annual rainfall of 1,057 mm. For the study period between June 2010 and June 2011 (see **Figure 3**), the total rainfall was 850 mm.

Annual evapotranspiration losses: 450 mm. Potential evapotranspiration (P.E.) is estimated to be 475 mm/yr (based on data from Met Éireann). Actual evapotranspiration (A.E.) is estimated as 95% of P.E., to allow for seasonal soil moisture deficits.

Annual Average Effective Rainfall: 607 mm. The annual average effective rainfall is calculated by subtracting actual evapotranspiration (450 mm) from rainfall (1,057 mm). The 30-year average potential recharge to groundwater is therefore 607 mm/year.

Reference is made to Section 9 on recharge which estimates the proportion of effective rainfall that enters the groundwater system.

6 Geology

This section outlines the relevant characteristics of the geology of the immediate study area. It provides a framework for the assessment of groundwater flow and source protection zones. The geological information is based on:

- Geology of South Mayo. Bedrock Geology 1:100,000 Map series, Sheet 11, Geological Survey of Ireland (McConnell et al, 2002);
- Geology of Longford-Roscommon. Bedrock Geology 1:100,000 Map series, Sheet 12, Geological Survey of Ireland (Morris et al, 2003);
- Field mapping of bedrock outcrops, karst features, and Quaternary deposits;
- Discussions with Markus Pracht of the bedrock section of the Geological Survey of Ireland.

6.1 Bedrock

As indicated in **Figure 7**, the bedrock in the entire study area has been mapped by the GSI as Dinantian Pure Bedded Limestone. Outcrops of bedrock are generally scarce, but consist of pale grey, thin bedded (<1 m) limestones that are nearly horizontally bedded.

6.2 Karst Features

Important karst features have been mapped (see **Figure 7** and **Appendix B**) during walkover surveys. Besides the springs highlighted between Horseleap Lough and the PWS, the most significant karst features within the study area include two turloughs (Cloonoran and Loch Na Lasrach, both near Moylough), active swallow holes (e.g. Moylough Castle, Loch Na Lasrach and Ballynamona), as well as the large spring(s) at Pollifrin. Within the elevated limestone plateau that was referenced in Section 4, there are literally dozens of enclosed depressions (too many to map individually as part of this project).

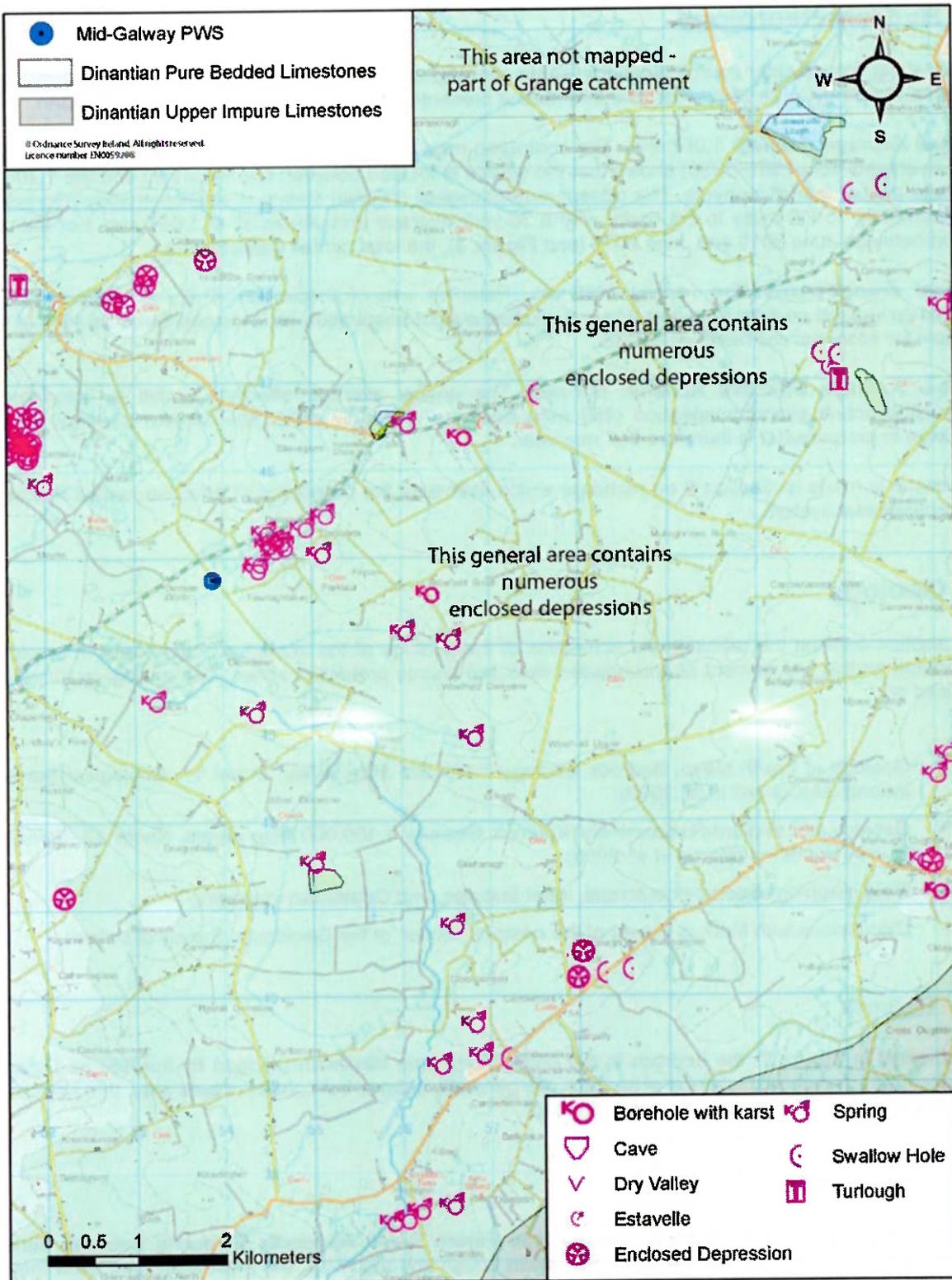


Figure 7: Bedrock/Rock Unit and Karst Features Map

In addition, there is evidence of karst conduits in at least three boreholes, including the well that was drilled adjacent to the Barnaderg GWS spring (Hydro-G, 2011). Until the autumn of 2011, the GWS abstracted an estimated 1,000 m³/d from the Barnaderg spring which now overflows into the Derreen stream. The new well drilled in 2011 has since become the primary source of water for the GWS. The borehole is approximately 53 m deep. Drilling was stopped when a major conduit was encountered which produced 'sufficient' quantities of water to meet the demands of the GWS. During air-lifting and test pumping of the borehole, an immediate response was observed in the water levels and overflow at the GWS spring source, proving a direct connection between the spring and the deeper conduit intersected by the borehole (Bartley, 2011). Whether or not the deeper conduit is the principal 'feeder' to the Barnaderg spring is not known. Similar instantaneous water level changes were also noted in a disused borehole approximately 150 m to the west of the new borehole, suggesting the presence of a deeper conduit system in the PWS discharge area generally.

6.3 Depth to Bedrock

Soils are thin (<3 m) across much of the study area but depth to bedrock increases along eskers and moraine ridges (see below) as well as within the peat areas of Horseleap Lough, Summerville Lough, Loch Na Lasrach and the Abbert River, as well as small, internal drainages within the limestone plateau area (where water ponds and partly recharges the underlying aquifer). At the new borehole at the Barnaderg GWS, till and alluvial sediments were found to be nearly 10 m thick, and is presumably associated with the linear NE-SW trending esker at Horseleap Lough.

6.4 Soil and Subsoil Geology

Mapped soils within the study area, see **Figure 8**, include deep, well drained mineral soils (BminDW) across much of the study area with pockets of shallow peaty soils surrounding the previously referenced loughs and peat areas. Shallow, well drained mineral soils (BminSW) are associated with linear esker deposits, whilst lacustrine soils (clays/marl) are associated with the Loch Na Lasrach turlough.

Mapped subsoils, see **Figure 9**, consist primarily of glacial limestone-derived till (TLs) and cutover peat (cut). Other subsoil types mapped in the study area include linear esker deposits stretching from the PWS to Summerville Lough, re-worked gravel deposits derived from the limestone till, and lacustrine clays at the Loch Na Lasrach turlough. Subsoil permeability, as mapped by Teagasc, is 'moderate' across the limestone till areas, 'high' along the esker deposits, and 'low' in the pockets of peat and lacustrine clays. Window sampling was carried out at the eastern end of Summerville Lough to examine the nature of subsoils adjacent to the peat area that drains to the swallow hole at Moylough Castle. The logs of 9 shallow (<5 m deep) boreholes are reproduced in **Appendix C**, and indicate a range of subsoil grades and layering of peat, clay, silt, sand and gravel. The peat is believed to be relatively thin. In addition to surface drainage from the peat towards the swallow hole, it is also possible that subsurface drainage takes place via sandy deposits.

During field mapping of karst features, an interesting subsoil feature was noted at the northern end of the Loch Na Lasrach turlough. As indicated on **Figure 10**, a drainage channel has been partly excavated by local residents in an attempt to alleviate flooding in the turlough, whereby the flood water would drain north towards the low-lying area near Cloonoran Turlough. The dug channel takes advantage of a natural, linear depression which, according to local residents, is filled with 'sandy material'. Exposures at the base of the main meltwater channel indicate the presence of well drained, permeable till. On the basis of the local geomorphology, the natural, linear depression is interpreted to be a glacial outwash channel. It is flanked to the east by a parallel high moraine ridge and aligns with N-S trending deposits to the south of the turlough. There are three other, but more subtle, parallel outwash channels between Loch Na Lasrach and Lakeview that also extend to the north. Observations of relative elevations suggest that the main outwash channel is in direct hydraulic communication with the Loch Na Lasrach turlough, certainly when water levels are high.

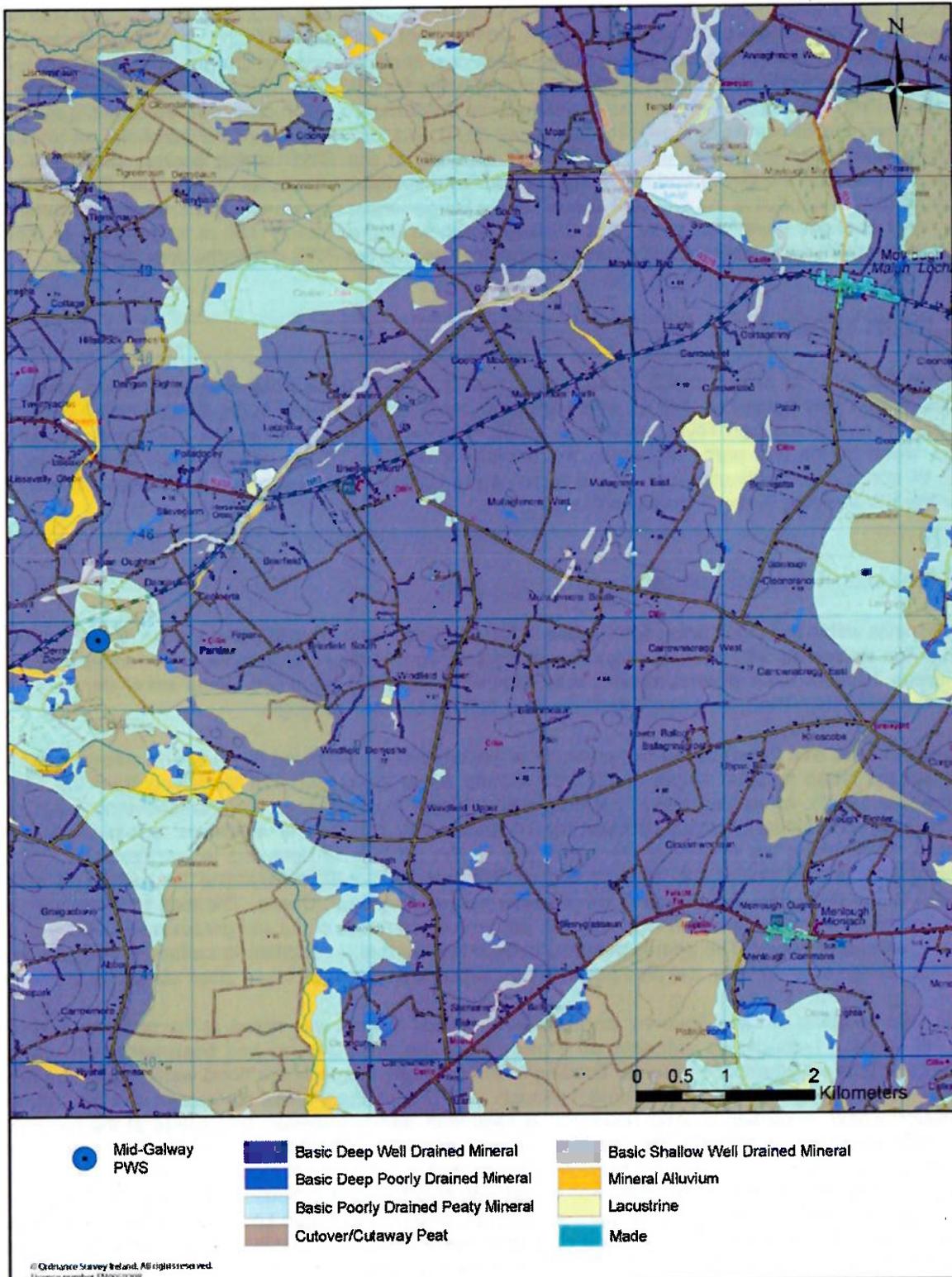


Figure 8: Soils Map

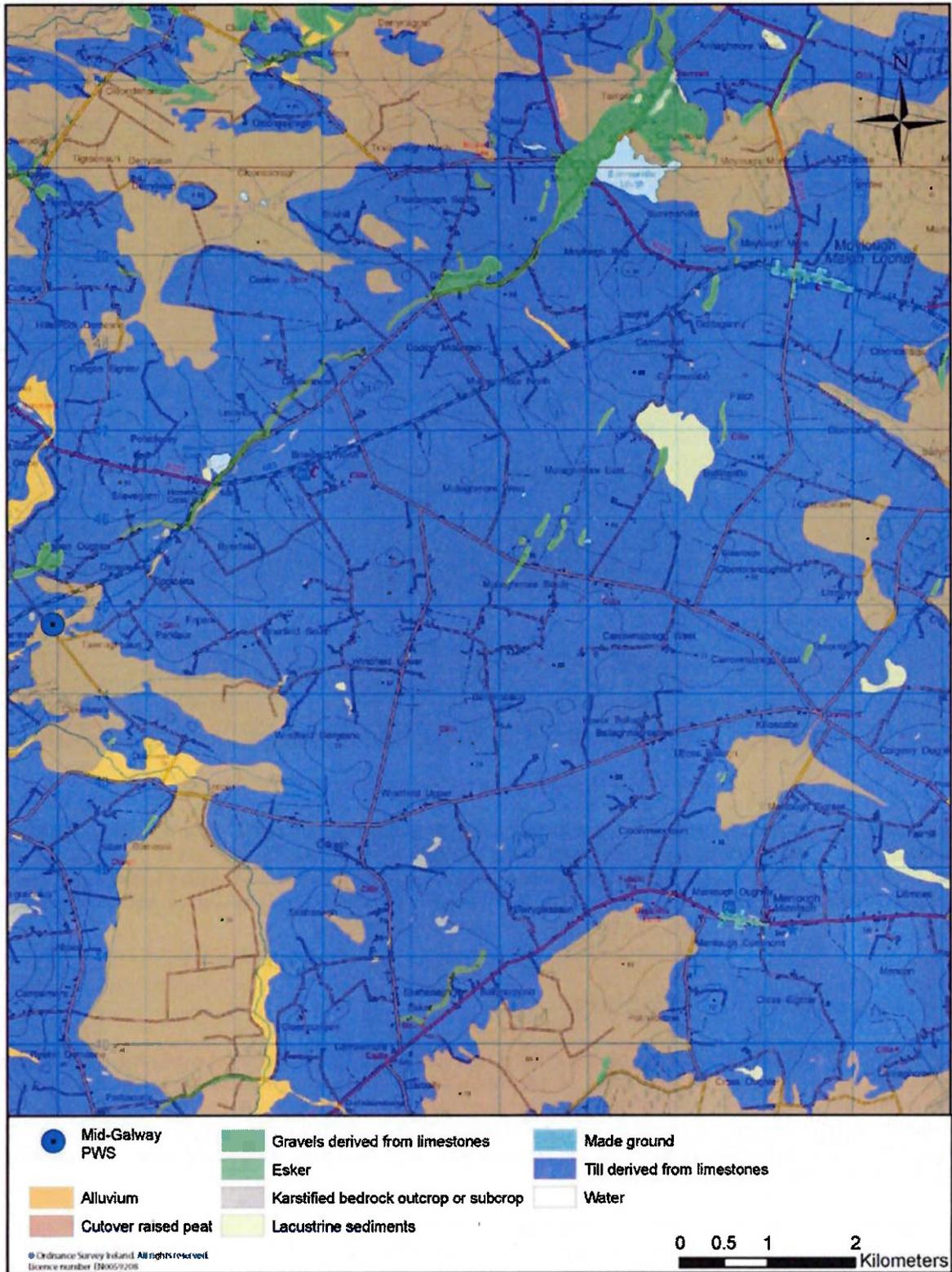


Figure 9: Subsoils Map



Figure 10: Outwash Channel from Loch Na Lasrach

This implies that some water escapes from the turlough as shallow groundwater in a northerly direction via the outwash deposits. The meltwater channel curves to the northeast towards the spring that supplies water to the Cloonoran turlough to the south of Moylough, which in turn overflows and drains further east towards Mountbellew, and ultimately to the Suck River. This implies that Loch Na Lasrach is part of the western headwaters of the Suck River and, by inference, also the Shannon River.

7 Groundwater Vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target', which in the case of the Mid-Galway PWS is the limestone aquifer. As such, vulnerability relates primarily to the permeability and thickness of subsoil. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes document (DELG/EPA/GSI, 1999) and in the draft GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination (Fitzsimons et al, 2003).

A groundwater vulnerability map for County Galway has been developed by the GSI. As shown in **Figure 11**, vulnerability is mapped as 'extreme' and 'high' within most of the study area, 'moderate' where subsoils are thick (e.g. esker ridges), and 'low' where peat and lacustrine clays are present. In the immediate vicinity of the PWS, vulnerability is mapped as 'moderate' and 'low' on account of peaty subsoils and greater depths to bedrock.

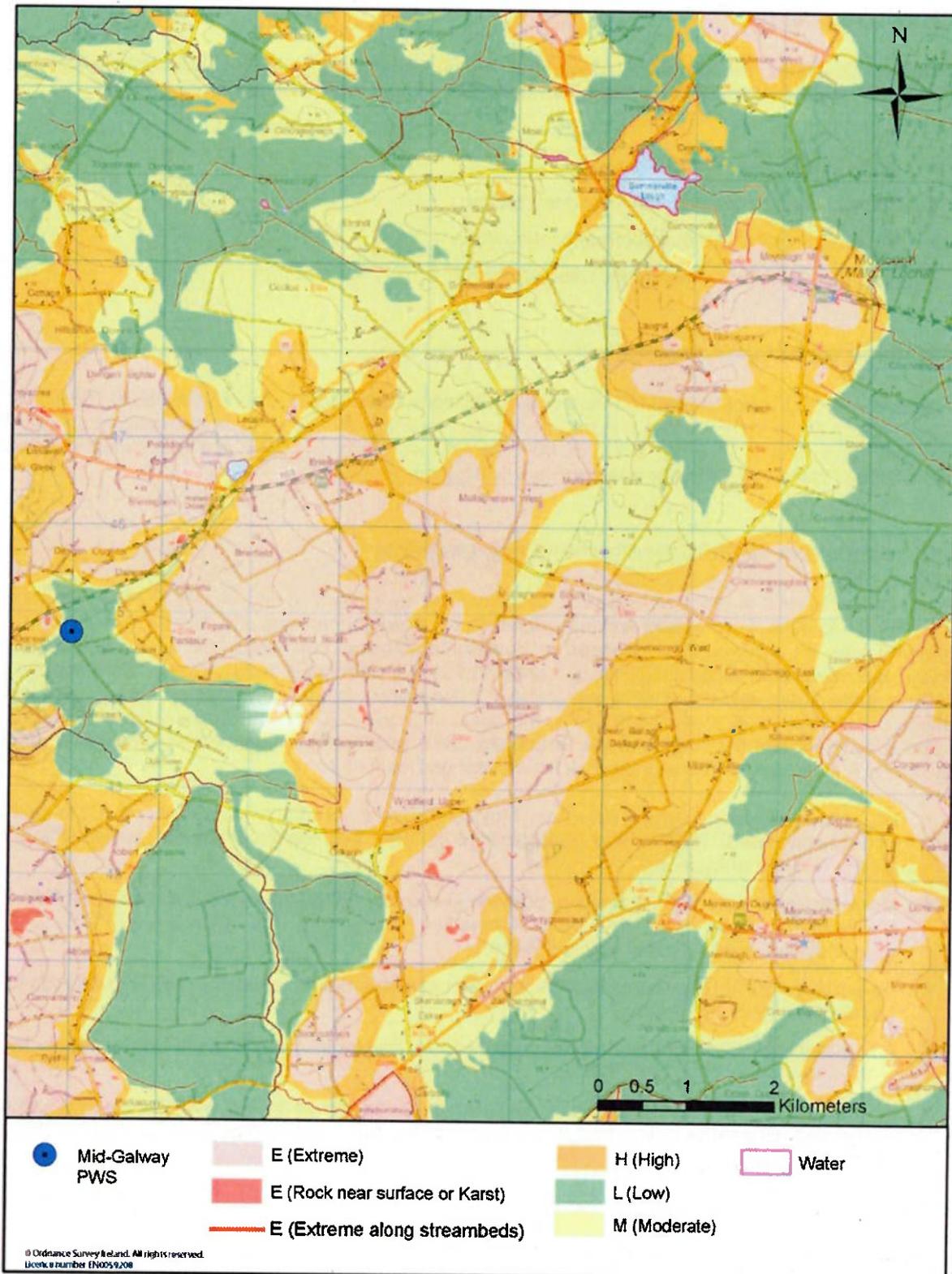


Figure 11: Groundwater Vulnerability Map

8 Hydrogeology

This section describes the current understanding of the hydrogeology of the study area of the PWS. Hydrogeological and hydrochemical information was obtained from the following sources:

- GSI and EPA websites and databases;
- County Council Staff and drinking water returns;
- Met Eireann rainfall and evapotranspiration data;
- Field mapping, tracer testing and measurements.

8.1 Groundwater Body and Status

The main spring that supplies the PWS is located within the Clare-Corrib groundwater body (GWB) which has been classified by the EPA as being of "Poor" status (due to elevated phosphorus concentrations). The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the Water Framework Directive website: www.wfdireland.ie/maps.html.

8.2 Groundwater levels, flow directions and gradients

The limestone bedrock in the area is karstic as evidenced by general spring characteristics and mapped karst features. As such, fissures and conduits dictate flow patterns, directions and rates. These flows vary in space and time as a function of changes in hydrometeorological conditions. General topographic and drainage considerations suggest that groundwater flow is from northeast to southwest. To establish flow directions, travel times, and zones of contribution(s), 7 dye tracer tests were conducted from 7 dye injection locations between June 2010 and April 2011, and again in October 2011, specifically targeting detection in the Derreen stream and the springs at the Barnaderg GWS and Pollifrin. Summarised in **Appendix D**, five tests were positively traced to one or more of these locations, as follows:

- An actively draining swallow hole near Moylough Castle was traced to Barnaderg GWS and the Mid-Galway PWS. Pollifrin was not sampled for this test, hence, it is not known if the dye discharged at this location.
- Using tankered water for dye flushing purpose, a recently (2009) opened surface collapse feature at Mullaghmore North was traced to Barnaderg GWS and the Mid-Galway-PWS, with a suspected/marginal detection also at Pollifrin.
- An actively draining swallow hole at the Loc Na Lasrach turlough resulted in confirmed traces to the Mid-Galway PWS and Pollifrin.
- Using tankered water for dye flushing purposes, a doline located at Windfield Demesne was traced to the Mid-Galway PWS and Pollifrin.
- An actively draining swallow hole at Ballynamena was traced to the Mid-Galway PWS, with a suspected/marginal detection also at the spring at the Barnaderg GWS. The dye was not detected at Pollifrin.

Two traces did not yield any results, i.e. the dyes were not detected in any of the sampling locations. These traces were injected in an active swallow hole at Carrowmanagh, approximately 3 km to the northwest of the PWS, and a doline at Annaghmore, approximately 3 km north of Moylough village. One test, from the active swallow hole at Ballynamena, was repeated in October 2011 due to inconclusive results during a first attempt in April 2011.

It should be pointed out that detections of dye at the Mid-Galway PWS are attributed to the sampling that was carried out along the Derreen stream, both at selected upgradient springs and diffuse seepages as well

as by the PWS itself. Results point to a complex flow system with contributions to the Mid-Galway PWS from both proximal and distal locations to the northeast, east, and southeast. The results further demonstrate that the general area that incorporates the PWS, the Barnaderg GWS, and the Pollifrin spring can be considered part of the same groundwater flow system (see Figure 1 and also Section 9).

With evidence of flow from the Loch Na Lasrach turlough to the Mid-Galway PWS (and Pollifrin), it is concluded that the turlough is part of the ZOC of the PWS which drains to the Abbert River which in turn flows into the Clare River. In Section 6.4, it was demonstrated that the turlough also contributes to the Suck River catchment. By inference, the turlough is situated at the natural groundwater divide between the Shannon and Western River Basins.

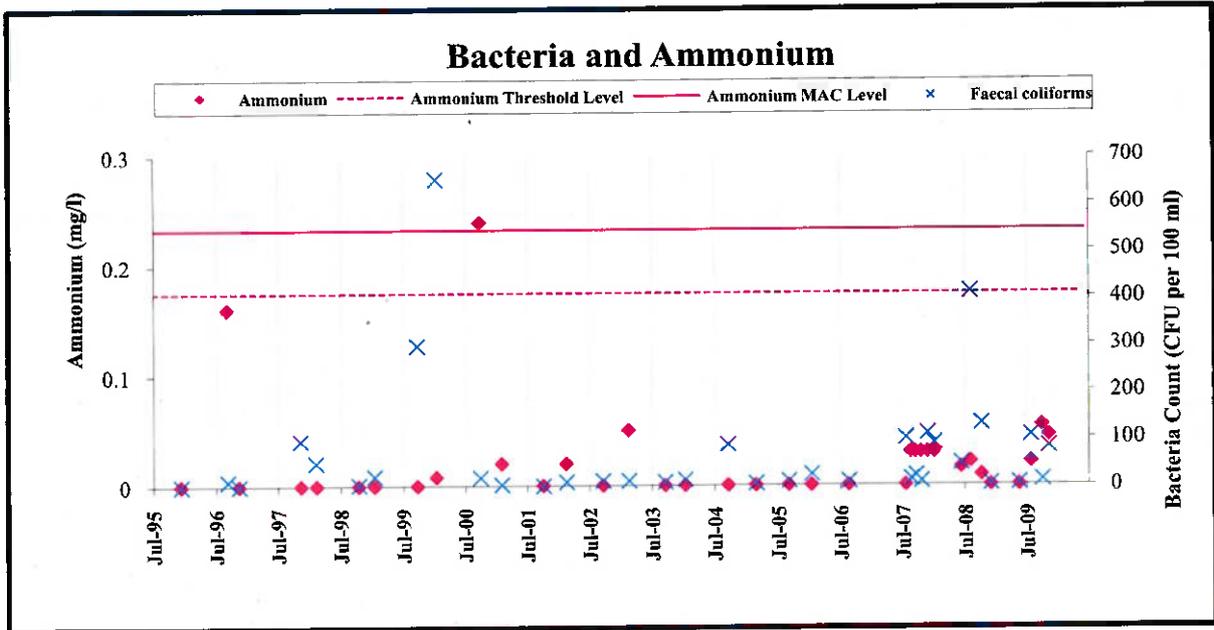
The established southwest and westerly groundwater flow components to the Mid-Galway PWS contrast with the demonstrated north-northeasterly flow gradients associated with the Mountbellew PWS (CDM 2011) and Caltra GWS (CDM 2012a).

8.3 Hydrochemistry and Water Quality

The Mid-Galway PWS was monitored by the EPA annually between 1995 and 1998, semi-annually between 1995 and 2006, and has been monitored quarterly from 2006 to present. The PWS was included in the EPA operational chemical network in late-2006. The sample point is in the pump house, prior to treatment. Existing laboratory results have been compared to these thresholds or standards: EU Drinking Water Council Directive 98/83/EC Maximum Admissible Concentrations (MAC); the European Communities Environmental Objectives (Groundwater) Regulations 2010, which were recently adopted in Ireland under S.I. No. 9 of 2010.

The water quality data are summarised graphically in **Figures 12 to 15**, representing up to 36 samples in total (until the end of 2009), and results are highlighted as follows:

- The water is hard (average 352 mg/l CaCO₃). Field conductivity ranges between 559 and 825 µS/cm with an average of 721 µS/cm. The average field pH is 7.1 and the hydrochemical signature of the water is calcium bicarbonate.
- Faecal coliforms are detected periodically with gross contamination (>100 CFU per 100 ml) on 7 occasions in the available dataset, tending to occur in late summer.
- There has been only one exceedance of EPA's status Threshold Value of 0.175 mg/l for ammonium. The general apparent absence of ammonium pre-2007 reflects the use of different detection limits, at 0.008 and 0.03 mg/l. EPA's analytical protocols have changed with the introduction of the Water Framework Directive related monitoring programme at the end of 2006, whereby detection limits were generally lowered for many substances (ammonium detection limit is 0.007).
- Concentrations of nitrate (as NO₃) range from 3 mg/l to 29 mg/l with a mean of 14 mg/l, and with a possible downward concentration trend in the past 3-4 years. These values are well below the groundwater quality standard of 50 mg/l and the EPA status Threshold Value of 37.5 mg/l for "Good" chemical status.
- Chloride concentrations range from 10 mg/l to 26 mg/l with a mean of 20 mg/l. which is below EPA's status Threshold Value of 24 mg/L for "Good" chemical status. Like nitrate, chloride concentrations appear to show a decreasing trend in the past 3 years or so.



Note- the zero concentrations of ammonium shown pre-2007 reflect the use of higher detection limits compared to post-2006 data.

Figure 12: Bacteria Counts and Ammonium Concentrations

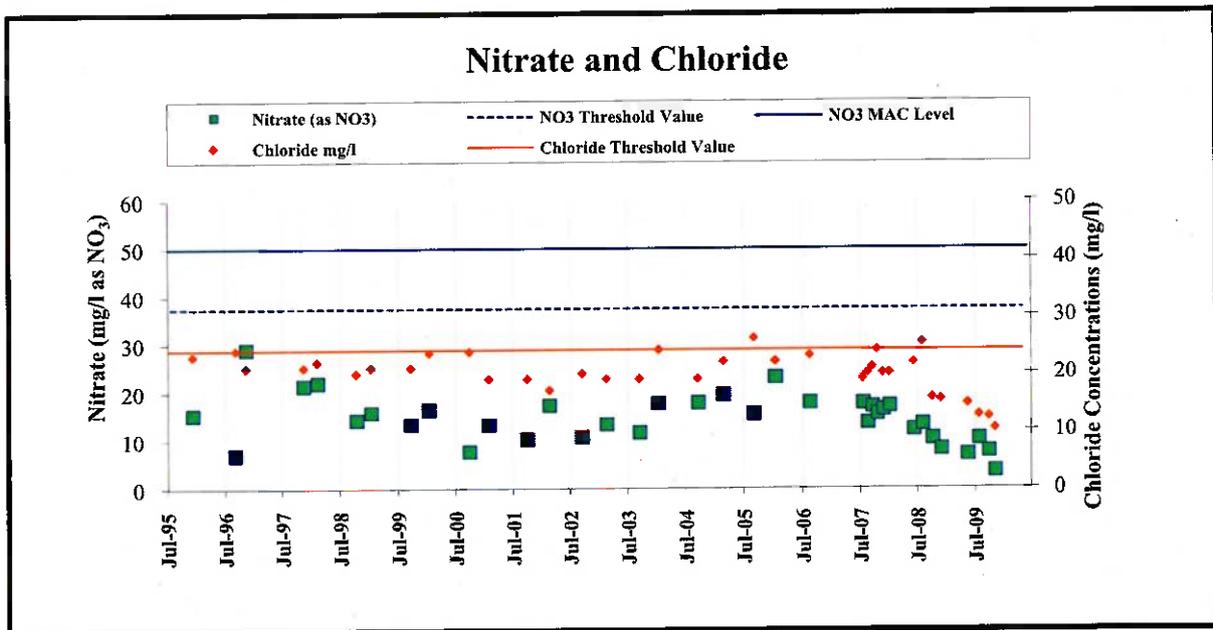
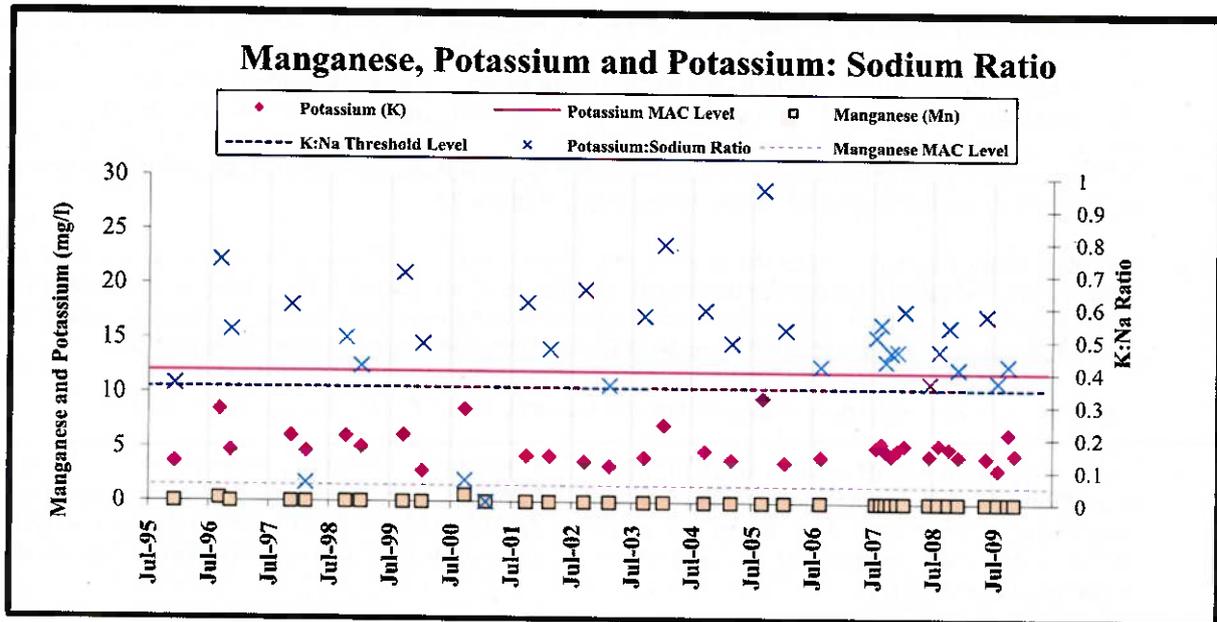
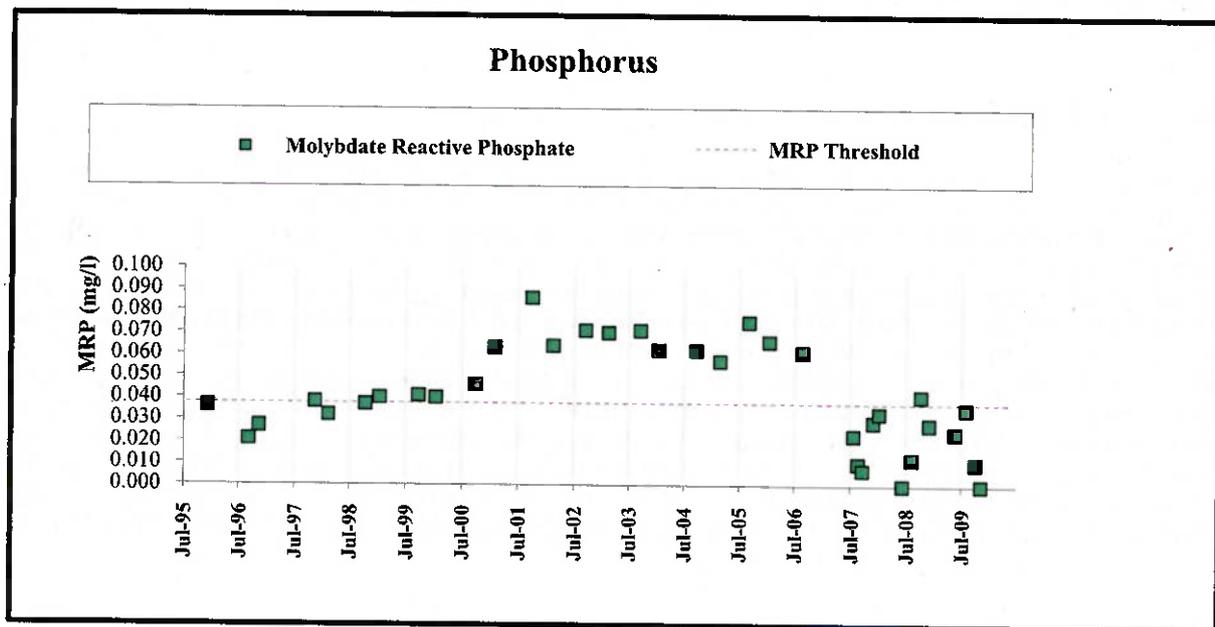


Figure 13: Nitrate and Chloride Concentrations



Note - zero concentrations of Mn implies it was not detected above its detection limit.

Figure 14: Manganese and Potassium Concentrations and K/Na Ratios



Note - zero concentrations of MRP implies it was not detected above its detection limit.

Figure 15: MRP Concentrations

- The range of reported concentrations of Molybdate Reactive Phosphate (MRP), or orthophosphate, is between non-detect (<0.009 mg/l) and 0.875 mg/l. The latter value occurred in October 2007 and stands out from the rest of the data (therefore, not included in the graph below). Excluding the single high value, the average MRP concentration over the reporting period was 0.064 mg/l (as P), which is above the EPA status Threshold Value for "Good" groundwater status of 0.035 mg/l P. Between 2000 and 2006, concentrations generally exceeded the threshold, and since 2006, there has been a marked improvement in related concentrations (see **Figure 15**).
- Sulphate, magnesium and calcium concentrations are within normal ranges. The potassium/sodium ratio is high, frequently exceeding its threshold value of 0.35, possibly on account of generally low concentrations of sodium. There have been several exceedances of relevant threshold values for iron, particularly in the period 2000 through 2006, and may be indicative of organic pollution.
- The concentrations of all other trace metals are low and/ or below laboratory detection limits.
- There have been two detections each of MCPA and mecoprop (active ingredients in herbicides) in post-2006 samples, but the detections were below drinking water standards. The concentrations of all organic compounds to date are below respective laboratory limits of detection, with the exception of one unconfirmed detection of total petroleum hydrocarbons of 60 µg/l in 2009, above the drinking water standard of 10 µg/L.

In summary, groundwater quality at the PWS shows elevated MRP concentrations and is periodically impacted from bacteriological contamination. A water quality improvement has occurred since 2006/2007, with a decrease in concentrations of parameters that are indicative of organic waste sources (e.g. nitrate, K/Na ratio, iron, manganese, chloride). The precise cause for the improvement is not known, however, a general decrease in nitrate and phosphate concentrations in the years 2007-2009 has been referenced nationally (EPA, 2010) and may be linked to above average rainfall (and recharge) conditions in the wet years of 2008 and 2009.

8.4 Aquifer Characteristics

The presence of karst features within the study area provides evidence for karstification of the limestone aquifer that supplies groundwater to the Mid-Galway PWS. The established links between dye injection points and the downgradient springs are characteristic of the regional aquifer system that stretches across much of County Galway and which gives rise to numerous springs used for public water supply. This limestone aquifer has been classified by the GSI as an *Rkc* aquifer – a *regionally important karstic aquifer, dominated by conduit flow*. Flow rates of between 750 m/d and 1,500 m/d through the karst system have been established from the tracer tests at Moylough Castle and Loch Na Lasrach. The tests were carried out under very different hydrological conditions (dry and wet, respectively), which may account for the difference in measured flow rates. The associated flow gradients are 0.002 and 0.004, respectively. There are few locations where the limestone is exposed, so it is difficult to judge the degree to which the epikarst is present and/or developed. The epikarst is the upper, more fractured and weathered zone in karstified rocks. It is particularly important to groundwater recharge estimation, as it determines the distribution of recharge, specifically diffuse recharge, and can be visualised as a perched aquifer system channelling infiltrating water to points of entry into the deeper groundwater flow system.

9 Zone of Contribution

The Zone of Contribution (ZOC) of a natural spring or other discharge point (e.g. abstraction borehole) is the hydrogeological catchment area(s) of the source that is required to support the natural discharge or abstraction from long-term recharge. As such, the size of the ZOC is controlled by the total discharge (outflow) at the source and groundwater recharge (inflow) to the source. The *shape* of the ZOC is controlled by groundwater flow patterns and gradients, as well as subsoil and aquifer permeabilities. As each of these elements is subject to some uncertainty, ZOC delineation typically involves water balance calculations (see Section 9.3) and conceptualising the groundwater flow system, as described below.

9.1 Conceptual Model

Illustrations of the conceptual hydrogeological model of the groundwater flow system associated with the Mid-Galway PWS are provided in **Figures 16 and 17**. Groundwater discharges from a karstified limestone aquifer where flow is concentrated in conduits that converge and discharge in the area between the PWS, Barnaderg GWS, and the Pollifrin spring. Established flow directions are from higher ground to the northeast, east and southeast. The presence of springs on both sides of the Abbert River suggests that the river may act as a hydraulic barrier. However, this has not been conclusively demonstrated. Evidence of deeper conduits in the area of the Barnaderg GWS would indicate that conduits may be able to transport groundwater past and possibly beneath the Abbert River, similar to the situation described at Ballyglunin by Drew (1973).

Point recharge to the karstified limestone aquifer occurs at swallow holes and enclosed depressions, some of which have been used to trace dye materials to the PWS. Although swallow holes have the same hydrological function of draining water into the aquifer, the mapped swallow holes in the study area occur in very different physical settings:

- Swallow holes near Moylough Castle drain a large peat bog near Summerville Lake. There are drainage channels directly connected to the lake. Gradients are very shallow, but the peat area and the lake drain to the swallow holes near the castle, for most of the year (flows into the swallow holes ranging from 'dry' to 20 l/s were measured as part of this study);
- Swallow holes at the Loch Na Lasrach turlough drain surface water when turlough levels recede. During rainfall events, the turlough collects surface runoff from surrounding land, including 5-10 m high moraine ridges. The surface catchment of the turlough is small compared to the quantity of water that is held in the turlough. It also occupies high ground, at an elevation of approximately 80 mOD. Local residents have indicated that the swallow holes at the northern end of the turlough periodically supply water into the turlough, whereby the swallow holes would serve as estavelles. Unfortunately, this has not been possible to confirm or witness directly during this study. Given the high elevation of the turlough compared to surrounding land, the only feasible 'driver' for this situation (i.e. topography) would be groundwater inflow from the north.
- Swallow holes at Ballynamona drain a small, unnamed stream which originates on higher peaty, forested ground (flow into the swallow hole ranging from 5-20 l/s were measured as part of this study). The inflowing stream fluctuates significantly with rainfall, and loses water along its path before reaching the swallow hole, thus recharging the aquifer along the way.

Diffuse recharge occurs across the broader 'limestone plateau' indicated on **Figure 16**. The plateau (70-90 m OD) is devoid of surface drainage features, which may be explained by 'efficient' recharge of rainwater. A significant area of the plateau is covered by thin subsoils (generally <3 m) which would result in high and efficient diffuse recharge into the underlying limestone aquifer, especially where the epikarst is well developed. The plateau occupies a roughly triangular area between the PWS, Moylough village, and Ballynamona. Lower recharge rates and quantities are expected where subsoils are thicker and/or of lower permeability, such as the areas near Summerville Lough and Loch Na Lasrach. The topography in these areas are dominated by gently undulating hills of shallow till resting on karstified bedrock, with eskers and ice marginal moraines deposited occasionally as 5-10 m high linear ridges. Esker and moraine ridges are not believed to bear any relationship to groundwater flow directions in the underlying limestone aquifer. They do, however, influence recharge patterns, whereby runoff from the ridges collects in numerous small internal drainage basins, where the ponded water infiltrates slowly to the limestone aquifer. The lowest groundwater recharge rates within the study area would be associated with the peat areas. However, as indicated previously, surface water associated with peat areas also drains to individual, mapped swallow holes near Summerville Lough, Loch Na Lasrach, and Ballynamona.

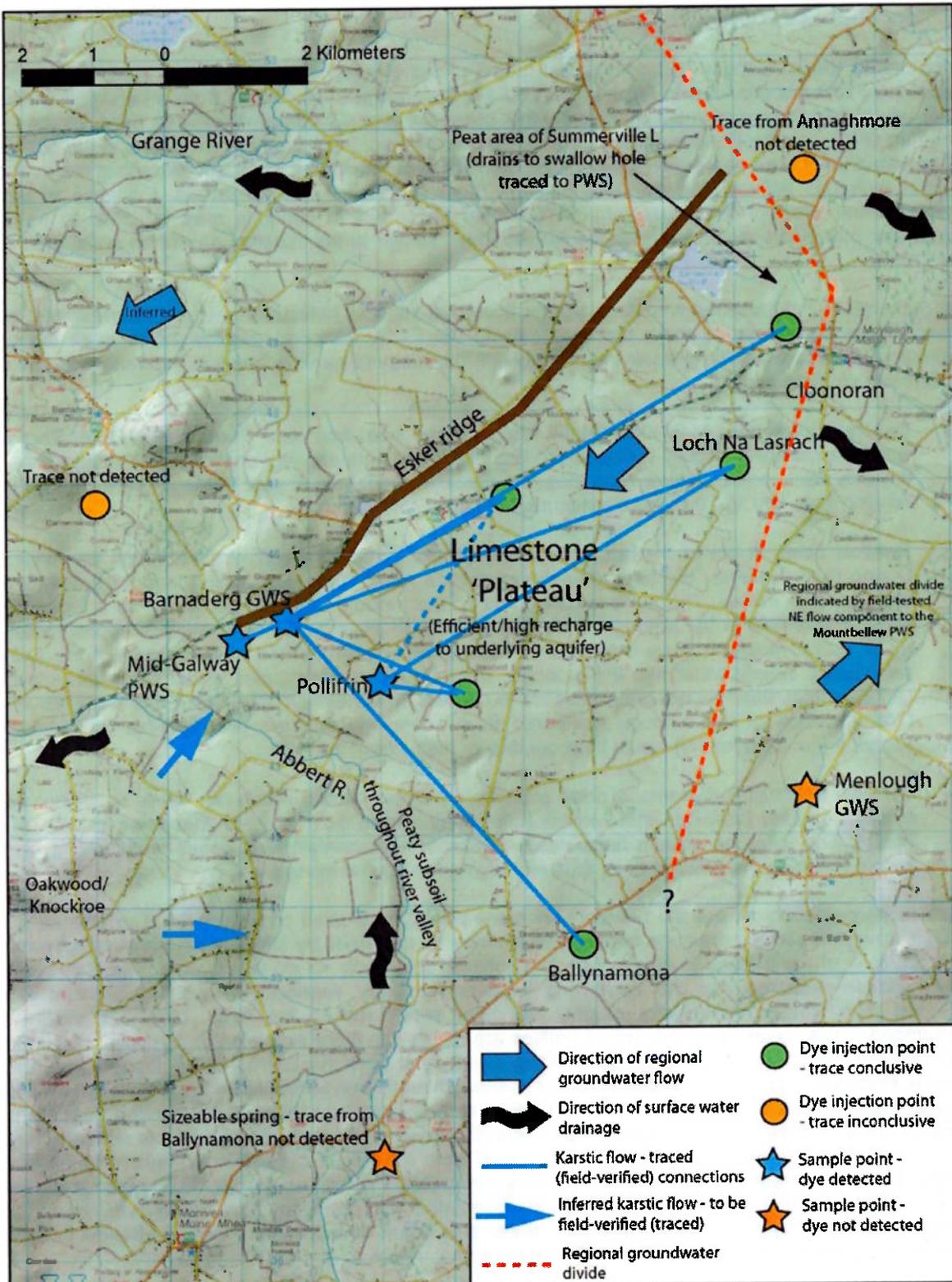


Figure 16: Conceptual model with results of tracing – plan map

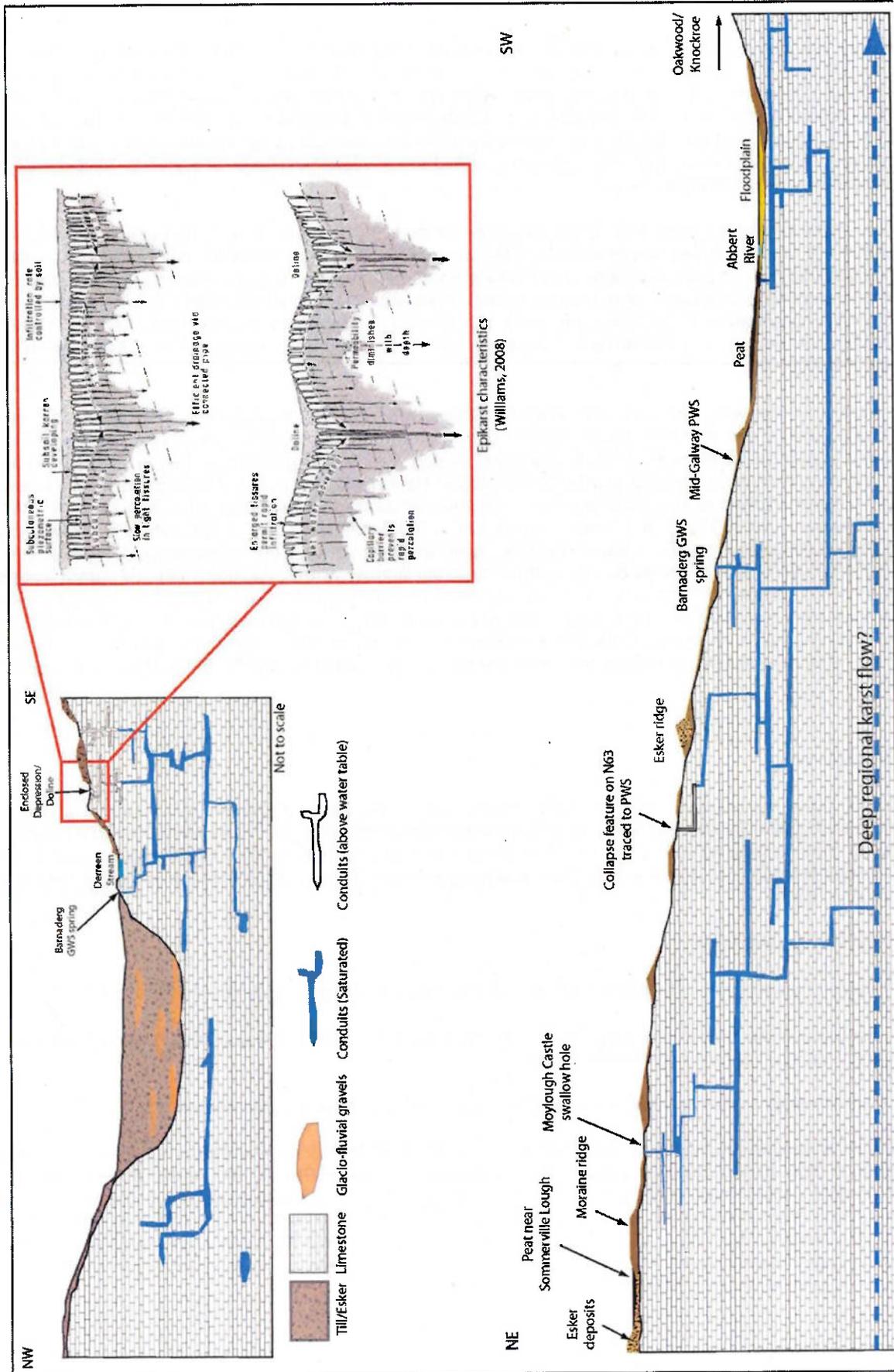


Figure 17: Conceptual model - cross-section

Groundwater discharges occur at springs and as diffuse seepages from shallow bedrock presumed to represent epikarst. A good example of the latter is observed just upstream of the bridge that crosses the Derreen stream adjacent to the Barnaderg GWS. Seepages occur from apparent bedding exposed 1-2 m above the stream water level. The epikarst is suspected to be a significant contributor to the extreme changes in discharges that are observed at the PWS and Pollifrin springs during rainfall events. The epikarst may be less developed or absent beneath some areas that are covered by thicker till deposits, as calcareous tills can buffer the pH of infiltrating water.

Below the epikarst, groundwater flow takes place in conduits at different 'levels' (depths/elevations), as evidenced in the recently drilled borehole at the Barnaderg GWS. These conduits fill and empty in time as a function of specific hydrological conditions. Their interactions and the water levels/pressures within them give rise to the time-varying discharge rates measured and observed at individual discharge points. The conduit flow system is characterized by high transmissivity, low storage, fast travel times, and little or no attenuation of pollutants aside from mixing and dilution. Flow rates up to 1,500 m/d were measured from the tracer tests described in Section 8.4.

Where sand and gravels deposits are present, these provide for groundwater storage which can drain/recharge to the underlying limestone aquifer during prolonged dry weather conditions, such as those experienced during the summer of 2010. A southwest to northeast trending esker system is visible from the PWS to Summerville Lough, roughly parallel to the N63 at Horseleap Lough. Sand and gravel deposits are, therefore, present above the limestone aquifer in the main groundwater discharge area between the PWS and the Barnaderg GWS. The drilled borehole adjacent to the Barnaderg GWS encountered approximately 10 m of till and esker-type deposits above bedrock, including a 4 m thick, permeable sand and gravel layer (Bartley, 2011). With such deposits overlying the limestone aquifer at this location, and with groundwater levels higher in bedrock, the hydraulic responses in the limestone aquifer at the Barnaderg GWS location would be expected to be buffered by the sand and gravel deposits. Such buffering effects are, however, not apparent and as a result, the precise discharge mechanism and setting of the limestone springs are not well understood. Potential discharge scenarios may involve rapidly varying depths to bedrock (i.e. subsoil 'windows').

9.2 Boundaries

Groundwater flows by gravity to the discharge points along the Derreen stream. All areas at a higher elevation than the Mid-Galway PWS are, therefore, potentially within the ZOC. The delineated ZOC, shown in **Figure 18**, was developed from a combination of tracer test results, topographic interpretations, and water balance considerations (see Section 9.3). Specifically, the shape of the ZOC is influenced by the following main considerations:

- Positive dye tracer lines;
- Inferred high rates of diffuse recharge across the limestone plateau (indicated in **Figure 16**);
- Presence of springs to the east of the limestone plateau, near Moylough and Menlough villages, which require their own contributing areas;
- Peat areas that drain to swallow holes which have been traced to the Mid-Galway PWS.

The **western boundary** in vicinity of the PWS is defined by surface drainage and groundwater discharges that contribute flow to the Derreen stream at and upstream of the PWS. To the north of the PWS, the western boundary extends along Slievegorm hill. A tracer test from an active swallow hole to the west of this hill did not result in a positive detection at the PWS and is therefore excluded from the ZOC. To the south of the PWS, the western boundary is defined by Pollifrin spring and broadly follows the margins of lower-permeability sediments along the Abbert River (which include peat and marl, i.e. low recharge). Until proven otherwise, it is inferred that the Abbert River is a hydraulic boundary.

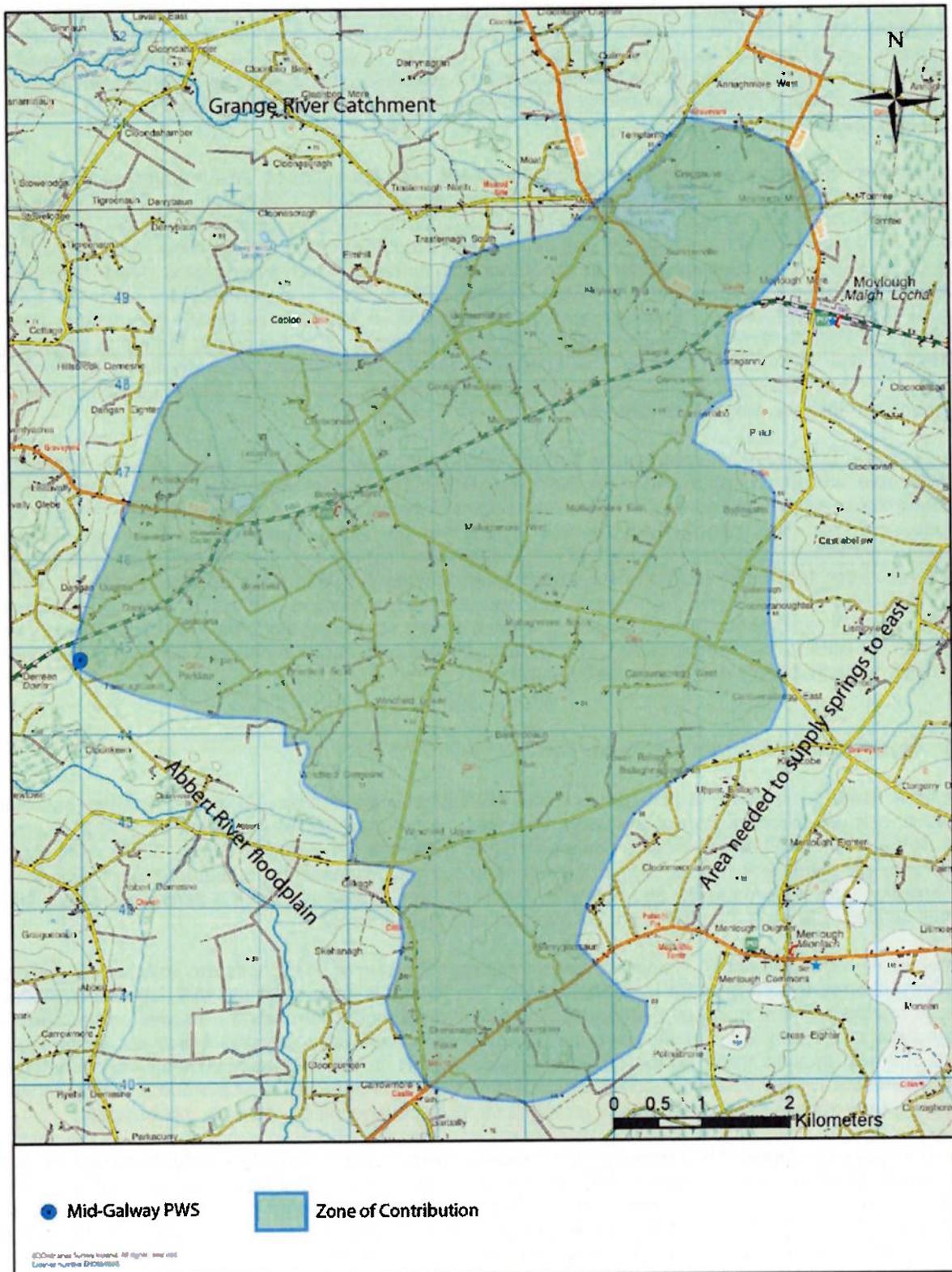


Figure 18: Estimated Zone of Contribution

The **northwestern boundary**, which extends past Summerville Lough, is constrained by several small springs that give rise to the headwaters of the Grange River. The boundary is, therefore, taken to be the topographic catchment divide of the Grange River. The ZOC incorporates the esker system between the PWS and Summerville Lough, as this is believed to be in hydraulic contact with the limestone and is oriented in the same structural direction (southwest to northeast) as the established tracer lines that run sub-parallel to the N63 (see **Figure 16**).

The **northern boundary** extends to a topographic divide near Annaghmore. At Annaghmore, dye injection into a free draining doline did not result in detections at any of the locations monitored, including the PWS. The **eastern boundary** is broadly constrained by consideration of the probable catchment areas for the springs at Cloonoran and Menlough, as well as the delineated ZOC of the Mountbellew PWS (CDM, 2011). The Cloonoran spring supplies water to the Cloonoran turlough which drains east. Menlough springs, including the spring that supplies water to the Menlough GWS, drain in a northerly direction. The swallow hole at Lismoes, just east of Menlough, was traced north to the Mountbellew PWS, from where drainage continues to Mountbellew and the Suck River. The inferred eastern ZOC boundary, therefore, represents a divide between groundwater flow to the southwest (in the Mid-Galway groundwater catchment) and northeast (in the Menlough/Mountbellew groundwater catchments), thus marking the divide also between the Western and Shannon River Basin districts.

The **southern boundary** incorporates the surface catchment of the stream that drains into the Ballynamona swallow hole, and which was traced to the Barnaderg GWS. This stream loses water along its course before reaching the swallow hole and so the surface catchment of the swallow hole is also inferred to be part of the groundwater catchment of the PWS (hence, included in the ZOC). Furthermore, there are numerous enclosed depressions/dolines in the area of Skehanagh and Winfield, between Ballynamona and the PWS, and it is inferred that these are part of a groundwater pathway between Ballynamona/Skehanagh and the PWS discharge area generally. The location of the **southwestern margin** of the ZOC (near Carrowmore) is constrained by the presence of several springs located further southwest along the Killaclogher River (which becomes the Abbert River further north). The largest of these springs was monitored during a dye tracer test from Ballynamona, but did not yield a positive detection.

9.3 Recharge and Water Balance

The term 'recharge' refers to the amount of water that infiltrates into the ground and replenishes an aquifer. As such, it is an important part of the water balance of a groundwater flow system. For the SPZ project, recharge is estimated using Guidance Document GW5 (Groundwater Working Group, 2005), from which a bulk recharge coefficient (R_c) is defined for an area that is described by combinations of groundwater vulnerability, subsoil permeability and soil type. The R_c is then applied against the annual average effective rainfall defined in Section 5 to derive annual average recharge (in mm/yr).

The estimation of a realistic R_c is important as it influences the size of the ZOC to the source and, therefore, the Outer Source Protection Area (see Section 10). The R_c that is defined for the Mid-Galway PWS area is directly related to the conceptual hydrogeological model presented in Section 9.1 as well as the boundary discussions in Section 9.2. For the 'extreme' groundwater vulnerability scenario which occurs throughout much of the study area, including the 'limestone plateau', an R_c of approximately 90% can be expected (i.e. 90% of effective rainfall infiltrates into the groundwater system). For the other vulnerability scenarios, which involve greater subsoil thicknesses and/or a range of subsoil permeabilities, lower R_c values apply.

The ZOC shown in **Figure 18** is based on the estimated median combined total discharge measured at the Mid-Galway PWS and Pollifrin spring of 631 l/s (54,518 m³/d). It has a total area of approximately 49.8 km² which, on the basis of general catchment characteristics, was derived from an area-weighted recharge coefficient (R_c) of 66%, as indicated below. Using the meteorological statistics in Section 5, the average annual recharge over the ZOC is estimated to be 402 mm/yr, as follows:

Average annual rainfall (R) (see Section 5)	1,057 mm
Estimated P.E. (see Section 5)	475 mm
Estimated A.E. (95% of P.E.)	450 mm
Effective rainfall (ER = R-AE)	607 mm
Potential recharge (equal to ER)	607 mm
Rc for 'extreme' vulnerability areas (41% of ZOC area)	90%
Rc for 'high' vulnerability areas (27% of ZOC area)	70%
Rc for 'moderate' vulnerability areas (24% of ZOC area)	40%
Rc for 'low' vulnerability areas (8% of ZOC area)	10%
Bulk recharge coefficient for ZOC	66%
Annual recharge rate	402 mm

It follows that the remaining 34% of the water balance is represented by surface runoff which is generated along the surface catchments of Horseleap Lough, Summerville Lough and Loch Na Lasrach. Some proportion of the runoff may recharge into the aquifer via swallow holes and/or collect in and recharge via numerous small, internal drainage basins within the limestone plateau.

As mentioned above, the defined ZOC reflects dye tracer test results as well as an area needed to support the representative discharge from the groundwater system, which is derived from a combination of the EPA gauging station near the Mid-Galway PWS and spot-measurements at Pollifrin. It does not reflect peak discharges. Estimates of the representativeness of spring discharges and stream flows using arithmetic means are likely to be inaccurate given the occurrence of extreme high discharges and flows. Hence, the median/bi-weighted flow value was used which gives less weight to extreme values in the dataset.

The positive dye traces provide important controls on the shape and extent of the ZOC. Despite these controls, there remain two primary areas of uncertainty that, on the basis of additional study, could yet influence the definition of the ZOC:

- a) the hydraulic interaction between the karstified aquifer and the Abbert River;
- b) the 'robustness' of the presently estimated median flow of the Pollifrin spring.

The Abbert River is potentially, but not yet conclusively demonstrated to be, a hydraulic boundary for southwesterly groundwater flow in the general study area. As a hydraulic boundary, it would help explain the emergence of springs and seepages on the eastern bank of the river. With the possibility of groundwater flow also from the Oakwood/Knockroe hill area (see Figure 1) towards the river (i.e. from the west), a hydraulic boundary at the river would also help to explain the presence of small springs on the western bank of the river. However, the possibility that flow crosses the river, either via a deep regional conduit system (to the southwest) or in the manner described at Ballyglunin (Drew, 1973) (e.g. to the northeast from Oakwood/Knockroe) cannot be ruled out. The former is difficult to ascertain without significant drilling and dye tracer testing. The latter can be tested, especially during low flow conditions, by injecting dye materials in dolines that have been mapped at Knockroe to see if they emerge at discharge points on the opposite side of the Abbert river (e.g. at Pollifrin). This was planned during the study described herein, but permission was not granted by landowners to access the required locations for dye injection purposes within the study period. In this regard, recommendations for additional work are included in Section 13.

As for the estimated median flow of the Pollifrin spring, additional measurements are needed to strengthen the flow statistics from this important discharge source. A median discharge of 411 l/s has been estimated on the basis of six measurements only, although they do include a broad range of values during dry and wet weather conditions, and the magnitude of the median flow is 'conceptually right' from observations made during field visits. If anything, the referenced median discharge is likely on the high end of the scale, which means the resulting ZOC is conservatively large. As stated in Section 13, flow measurements from Pollifrin should be made on a routine basis.

10 Source Protection Zones

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

The SO encompasses the entire ZOC to the PWS. The SI is defined by a 100-day time of travel to the source and is designed to protect the source from microbial and viral contamination (DELG/EPA/GSI 1999). Actual flow velocities ranging from 750-1,500 m/d have been demonstrated from dye tracer testing in the study area which means that, once pollutants enter the conduit system, they can reach the PWS within a few days from the distant parts of the ZOC. For this reason, the entire ZOC is defined as an SI. This is especially critical in the 'extreme' and 'high' vulnerability areas, and within the surface catchment areas of swallow holes.

The resulting groundwater Source Protection Zones are shown in **Figure 19**. Within the ZOC, the SI is designated as SI/Extreme (41%) SI/High (27%), SI/M (24%) and SI/L (8%).

11 Potential Pollution Sources

Potential sources of groundwater pollution within the ZOC are mainly associated with farmyards, landspreading of slurry, livestock grazing close to karst features such as swallow holes (especially), as well as onsite wastewater treatment systems (OSWTS). These are located and/or practiced throughout the ZOC. In addition, there are sand and gravel quarries along the esker deposits. There are no industrial or commercial activities that can be described as high risk activities.

12 Conclusions

The Mid-Galway PWS sources its water from the Derreen stream which represents a mix of groundwater and surface water. Several springs and streambank seepages contribute flow to the Derreen stream between the PWS and Horseleap Lough. The water that is discharged originates from both proximal and distal locations, including swallow holes as far away as Lough Na Lasrach and Moylough Castle. Groundwater flows through fissures, fractures and open conduits in a karstified limestone aquifer that facilitates very fast transport of water. Dyes have been traced from injection points up to 9 km from the PWS, at flow rates ranging from 750 m/d to 1,500 m/d.

The delineated ZOC extends to the northeast, east and southeast from the PWS. It incorporates the springs at Pollifrin and Barnaderg GWS, as both of these are part of the same groundwater flow system that supplies water to the PWS. The size of the ZOC has been estimated from water balance considerations and covers a total area of approximately 49.8 km². Its shape is influenced by dye tracer test results, primarily from injection points to the east-northeast. The ZOC of the PWS alone, i.e. excluding Pollifrin, is in reality a subset of the ZOC shown in **Figure 18**, but cannot be 'extracted' or parsed out with any degree of certainty unless a significant additional body of field work, notably flow measurements and dye tracer testing, was carried out. The hydraulic relationships between the springs would need to be examined in terms of their hydraulic responses to rainfall events, and roles as underflow or overflow springs.

Groundwater flow and ZOCs in karstified aquifers are difficult to predict at best, and will change in time with hydrometeorological conditions. Consequently, some uncertainty will always remain with ZOC delineation, including that presented in this report. Although the existing tracer tests provide good control points for the shape of the ZOC, there are areas of uncertainty that remain, notably the hydraulic influence of the Abbert River on groundwater discharges and the estimate of median discharge from the Pollifrin spring. Recommendations for additional work are included in Section 13.

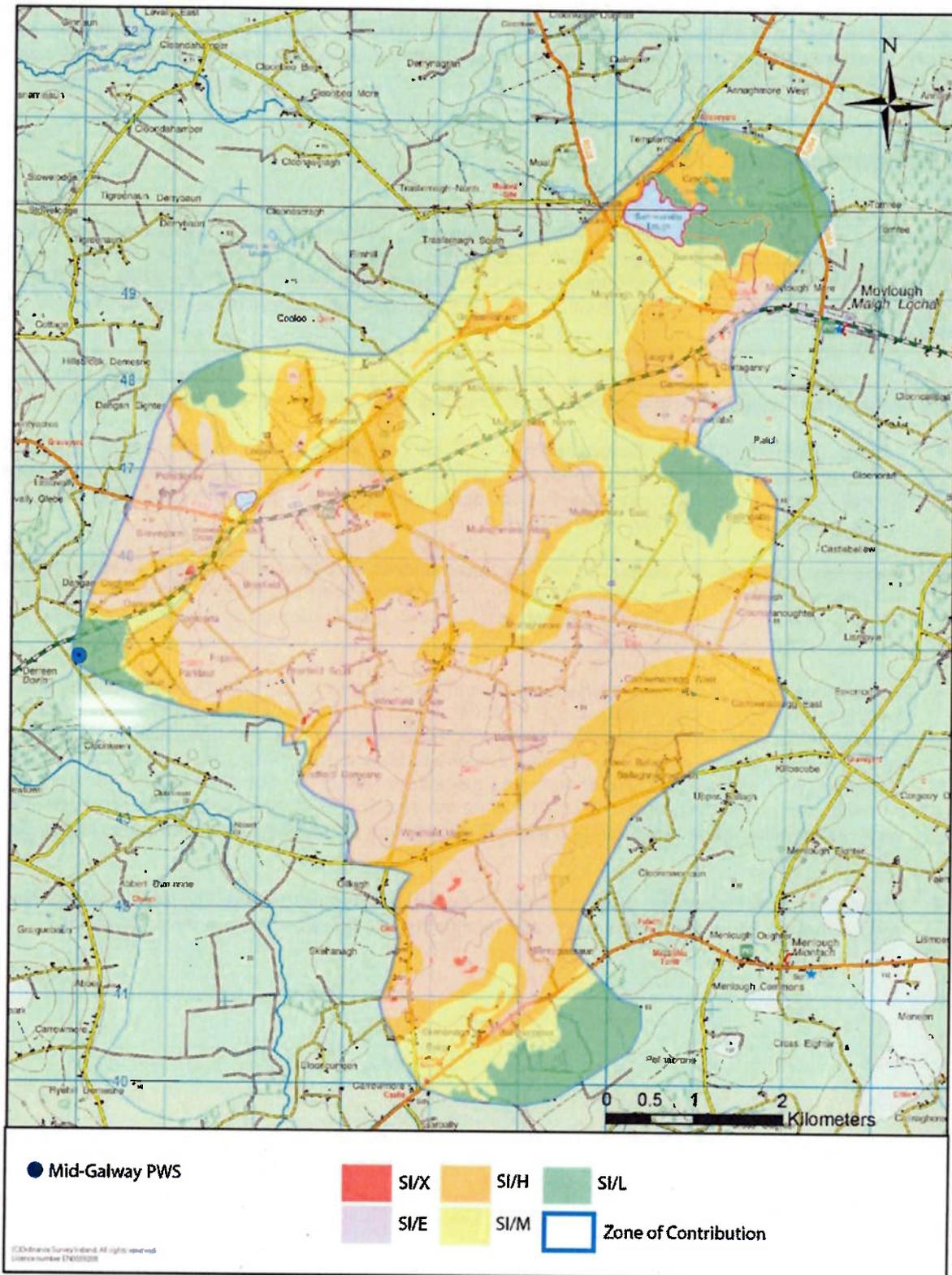


Figure 19: Source Protection Zones

Water quality data from the Mid-Galway PWS shows historical and periodic evidence of contamination by organic waste sources. The greatest risk of pollution appears to be associated with farmyards, landspreading of slurry, livestock grazing near point locations of groundwater recharge, and likely also private onsite wastewater treatment systems.

13 Recommendations

Given the vulnerability of the Mid-Galway PWS to contamination, good agricultural practice relating to landspreading and slurry storage should be followed within the delineated ZOC. Current landspreading and cattle grazing activities should be reviewed with local farmers in order to minimize the risk of impact on water quality. As the PWS pumps water that originates as both groundwater discharges and surface runoff into the Derreen stream, consideration must be taken in equal part to both, including surface catchments of streams and swallow holes.

Although the delineated ZOC of the PWS is considered to be reasonably well defined and conservatively large, additional field-based work is warranted to address technical questions that remain, specifically:

- Routine discharge (flow) measurements should be conducted at the Pollifrin spring (e.g. in the stream that flows from the spring to towards the Abbert River) – this is recommended to strengthen the estimated median discharge from the spring and, therefore, the general groundwater flow system that is associated with the Mid-Galway PWS;
- Tracer testing should be conducted from mapped dolines at Oakwood/Knockroe, to test whether or not groundwater from this largest hill in the entire study area could flow and discharge into the Derreen stream, i.e. by crossing the Abbert River and thereby testing the hydraulic function of the river as a potential hydraulic divide.
- The existing tracer test from Ballynamona should be repeated under lower flow conditions, and with a significantly large input (mass) of dye material, to verify the established positive trace to the Mid-Galway PWS. The existing positive trace, which interestingly was not detected at Pollifrin (even though it is located in direct line between Ballynamona and the PWS), raises questions about the connectivity between karst features in the southwestern part of the delineated ZOC. A new test with an expanded monitoring regime to include even the smallest of mapped springs, is recommended to verify the existing trace and provide additional information on potential other flowpaths in this part of the study area.
- Questions surrounding the swallow holes at Loch Na Lasrach as possible estavelles should be verified through additional observations and monitoring of inflows/outflows at these locations.

14 References

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APPENDIX A

Photographs

APPENDIX B

Mapped Karst Features

APPENDIX C

Subsoil Logs – window sampling (2010)

APPENDIX D

Tracer Test Results