Establishment of Groundwater Source Protection Zones

Mid-Galway Public Water Supply Scheme

Rev. A

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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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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 m^3/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**.

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 m^3/d but abstraction records indicate this can range with demand from 2,500 to 5,500 m^3/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 m^3/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 m^3/d) in early September 2010 to approximately 4,000 l/s (345,600 m^3/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 m^3/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 m^3/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.

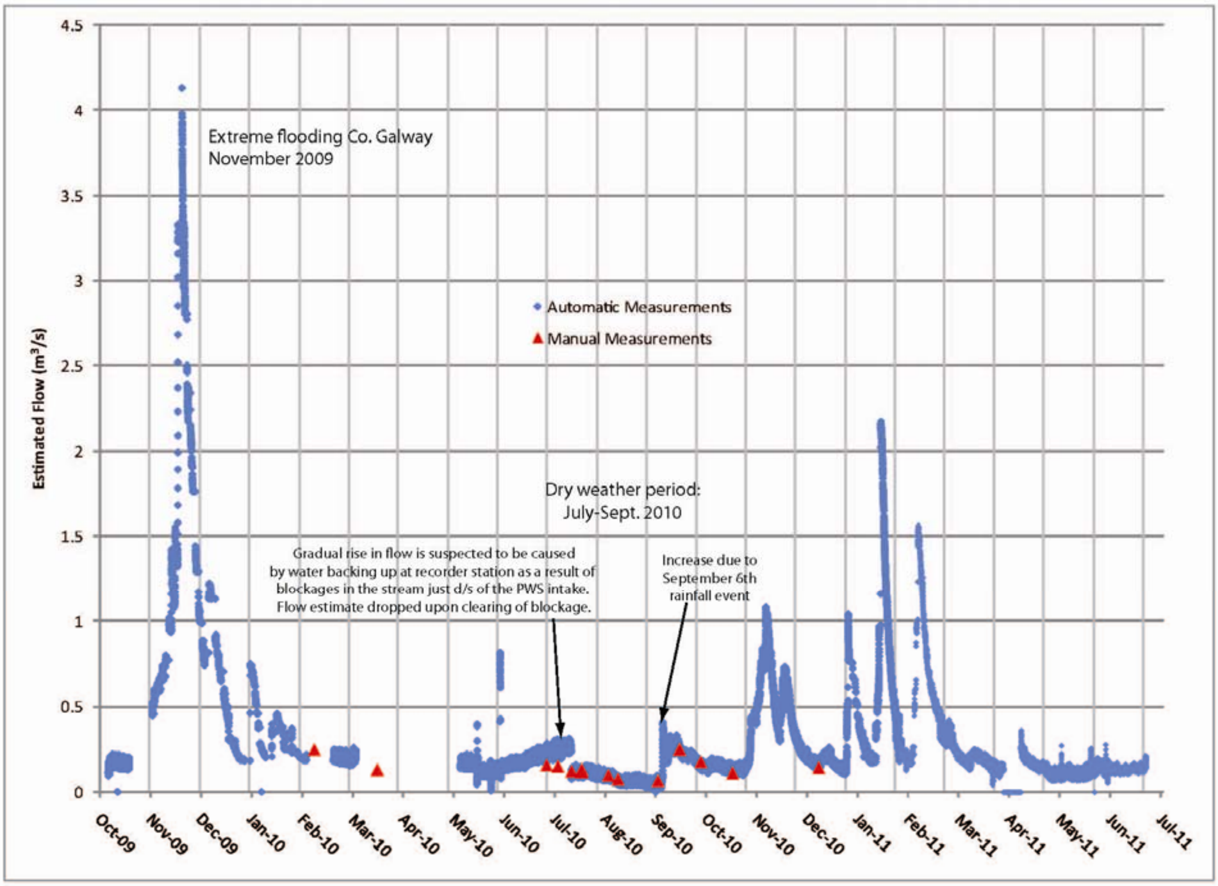


Figure 2: Estimated (Measured) Flow in the Derreen Stream October 2009 – July 2011

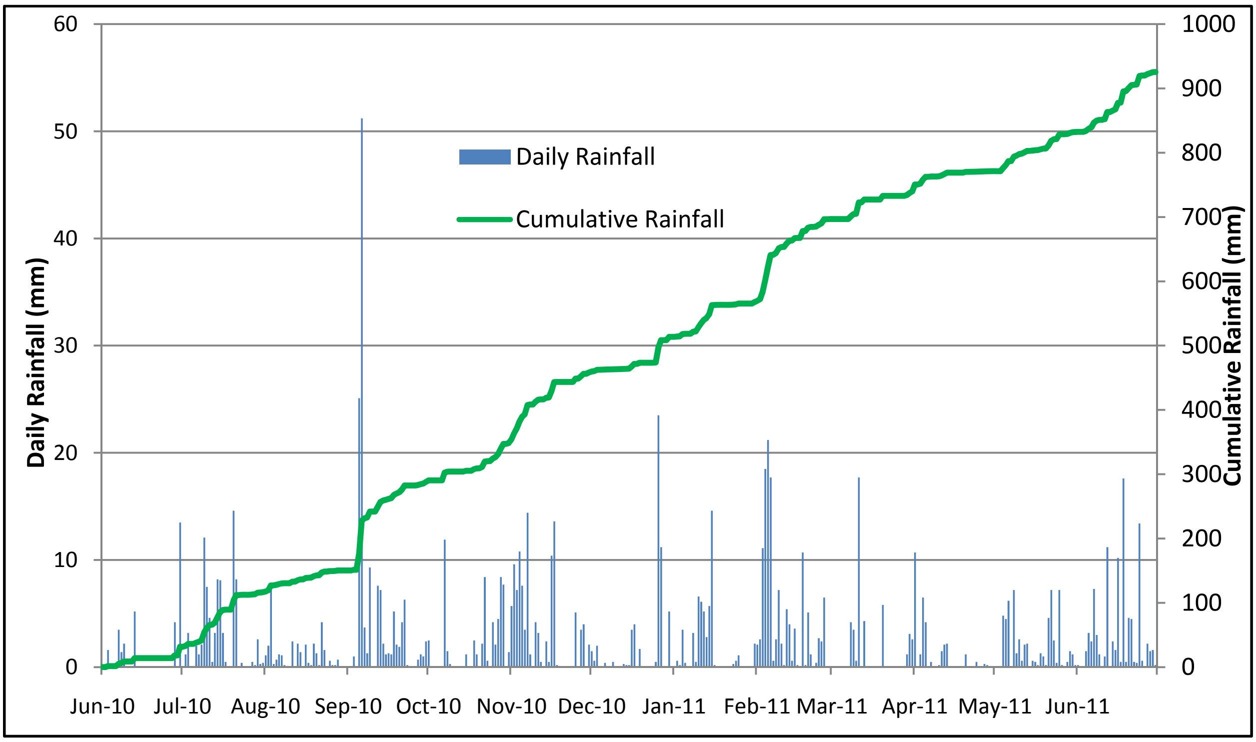


Figure 3: Daily and Cumulative Rainfall at Glenamaddy, June 2010 to July 2011

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 m^3/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 m^3/d) on August 5, 2010 and 2,623 l/s (226,627 m^3/d) on January 17, 2011. The latter includes an estimated contribution of 200 l/s (17,280 m^3/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 m^3/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 m^3/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.

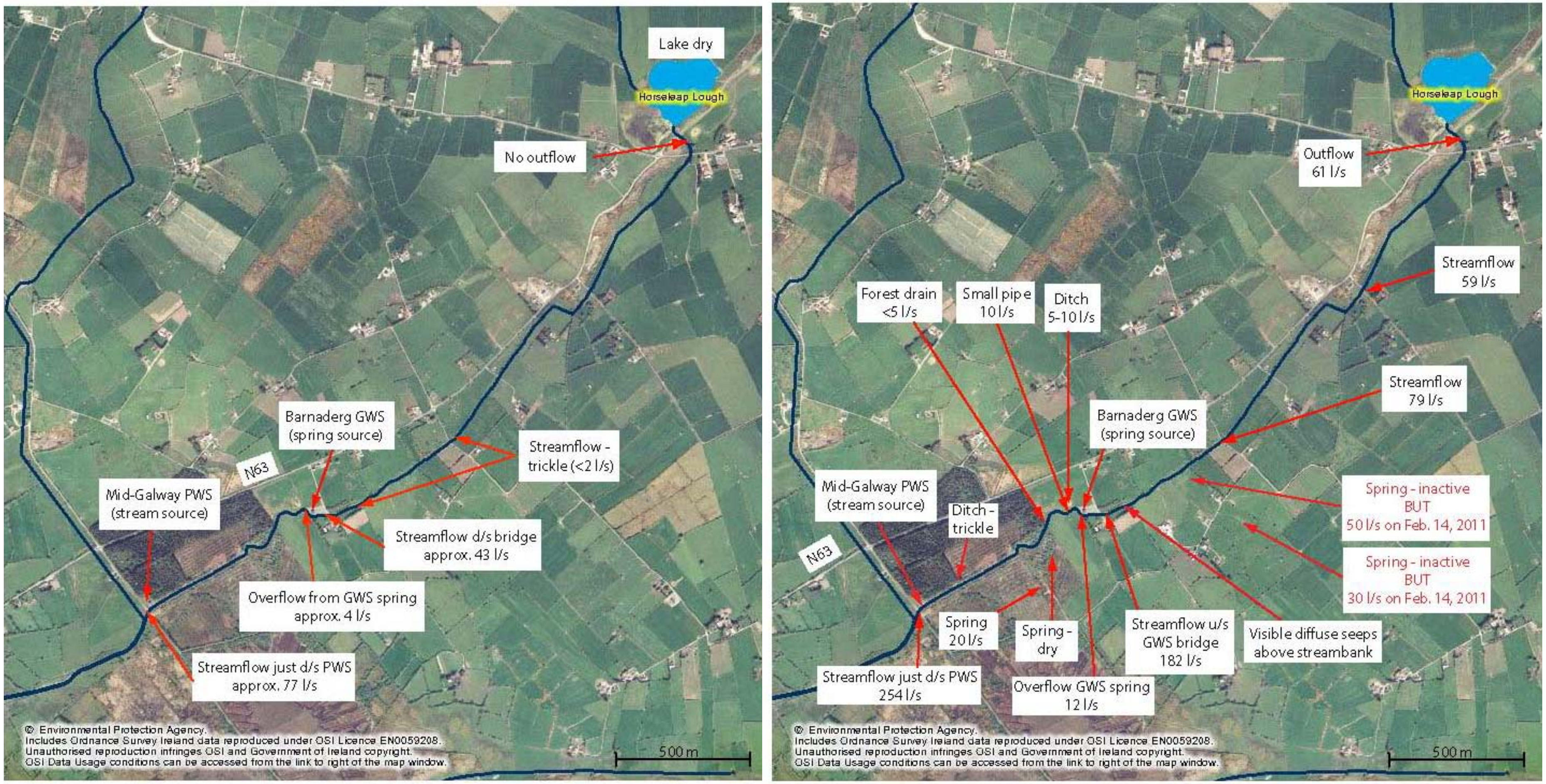
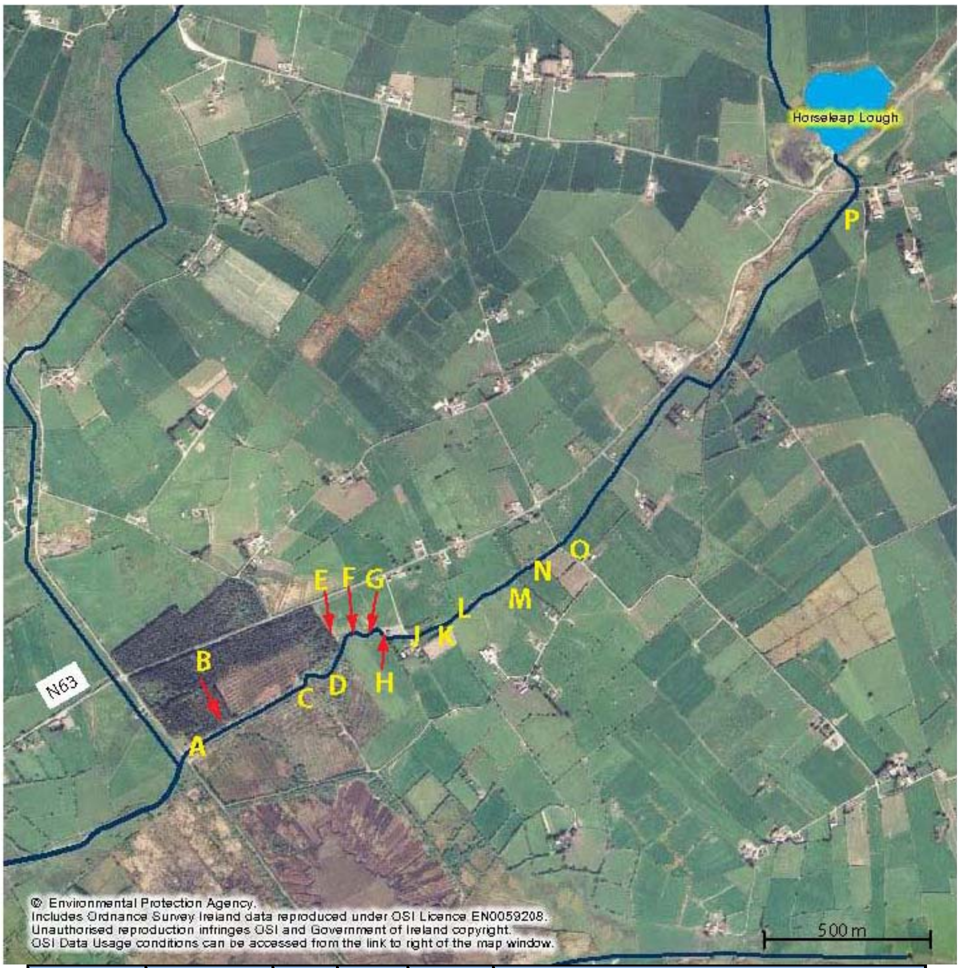


Figure 4: Flow Contributions to Derreen Stream on September 3rd and 16th, 2010



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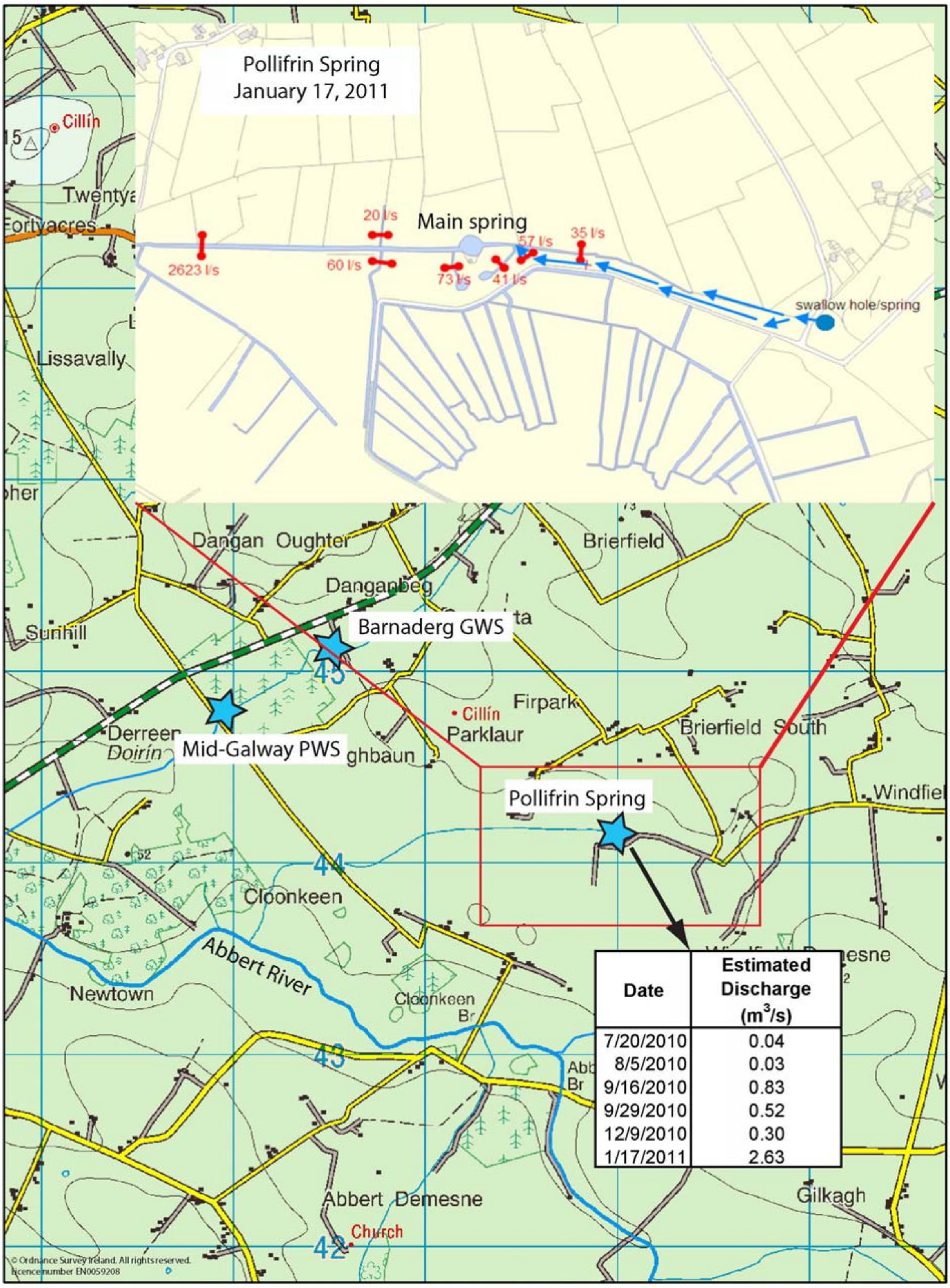
Location	Flow m³/s	EC	Ph	Temp	Description
A	0.3316	703	7	10.5	Main channel, just u/s of Mid-Galway PWS
B	0.0363	693	7.12	10.2	Inflow (ditch)
C	0.0858	709	6.76	10.2	Spring contribution
D	0.0158	708	6.94	10.2	Spring contribution
E	0.0055	790	7.46	9.7	Inflow (ditch)
F	0.007	728	7.09	10.2	Inflow from covered spring via pipe
G	0.0023	712	7.06	9.2	Spring
H	0.006	708	6.81	10.2	Overflow from spring at Barnaderg 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



Date	Estimated Discharge (m^3/s)
7/20/2010	0.04
8/5/2010	0.03
9/16/2010	0.83
9/29/2010	0.52
12/9/2010	0.30
1/17/2011	2.63

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).

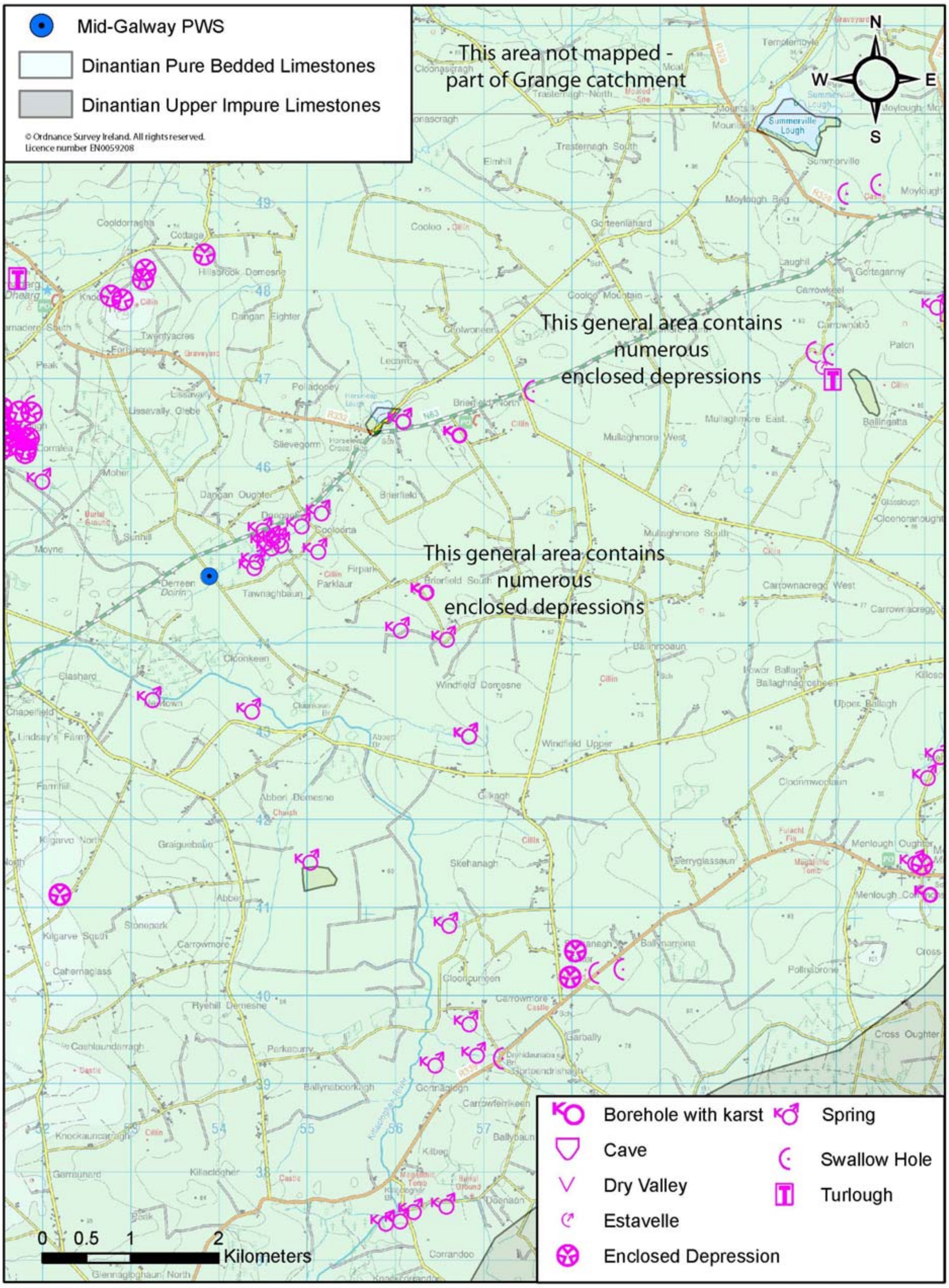


Figure 7: Bedrock/Rock Unit and Karst Features Map

In addition, there is evidence of kart 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 m^3/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.

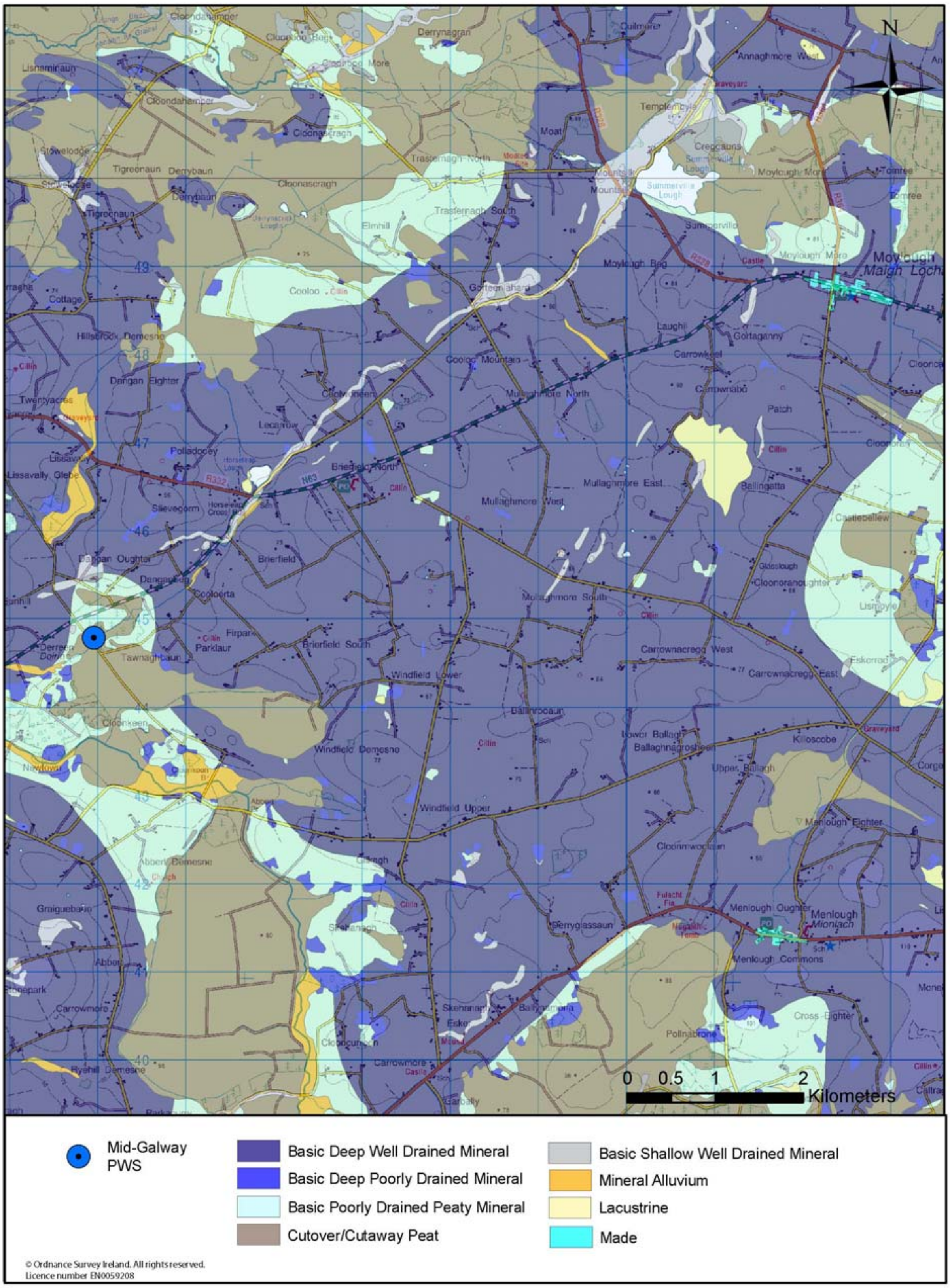


Figure 8: Soils Map

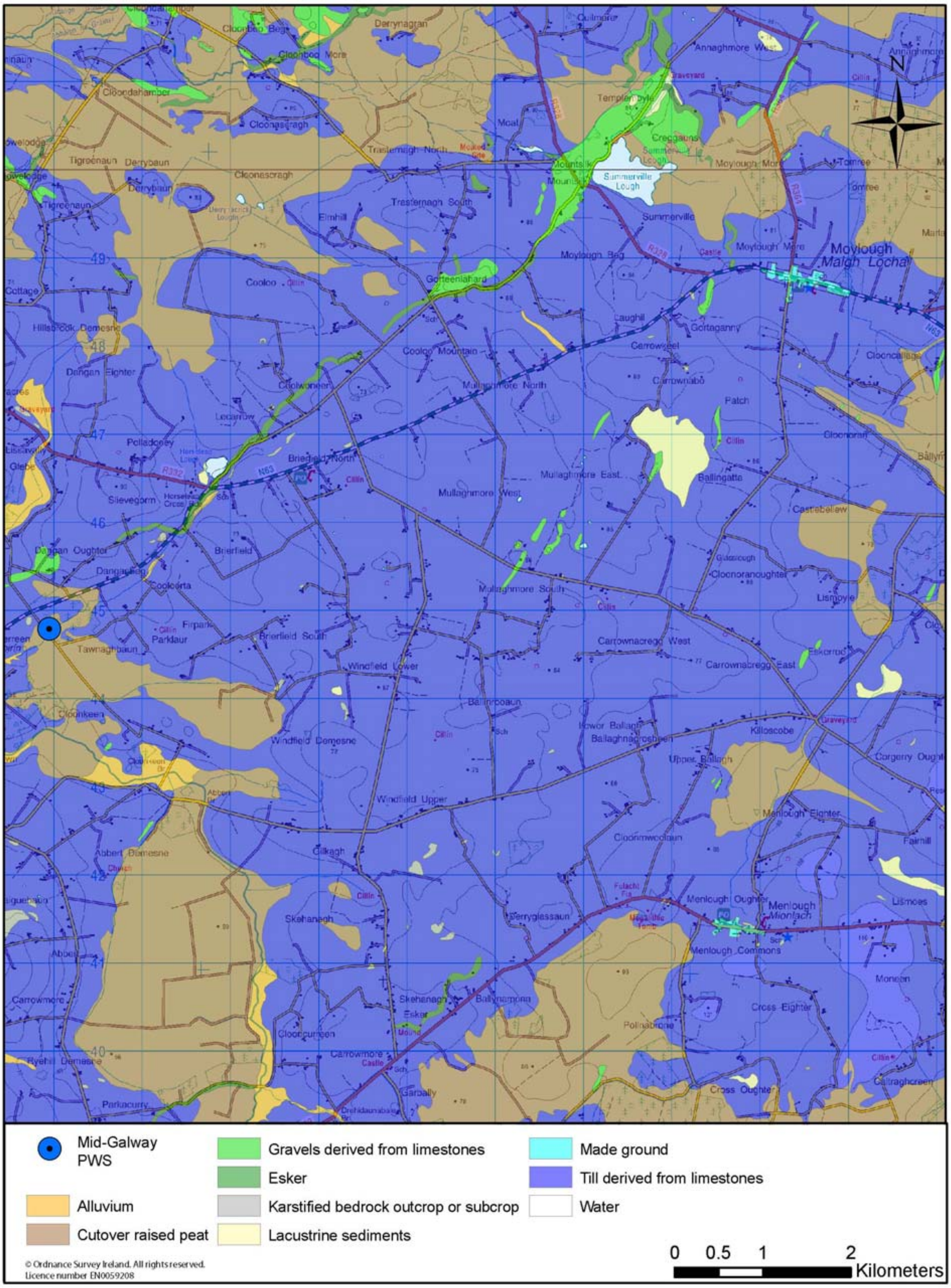


Figure 9: Subsoils Map

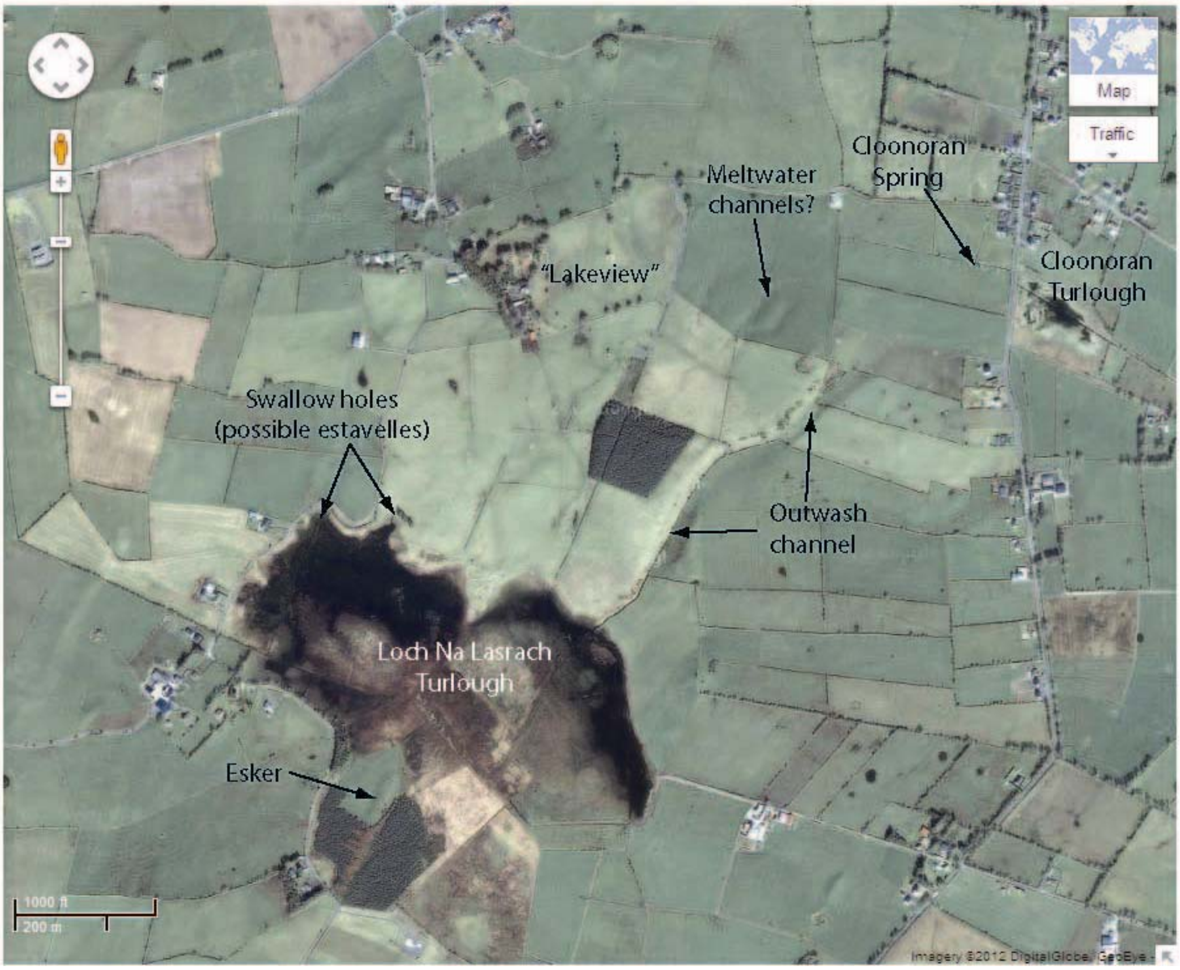


Figure 10: Outwash Channel from Loch Na Lasrach

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.

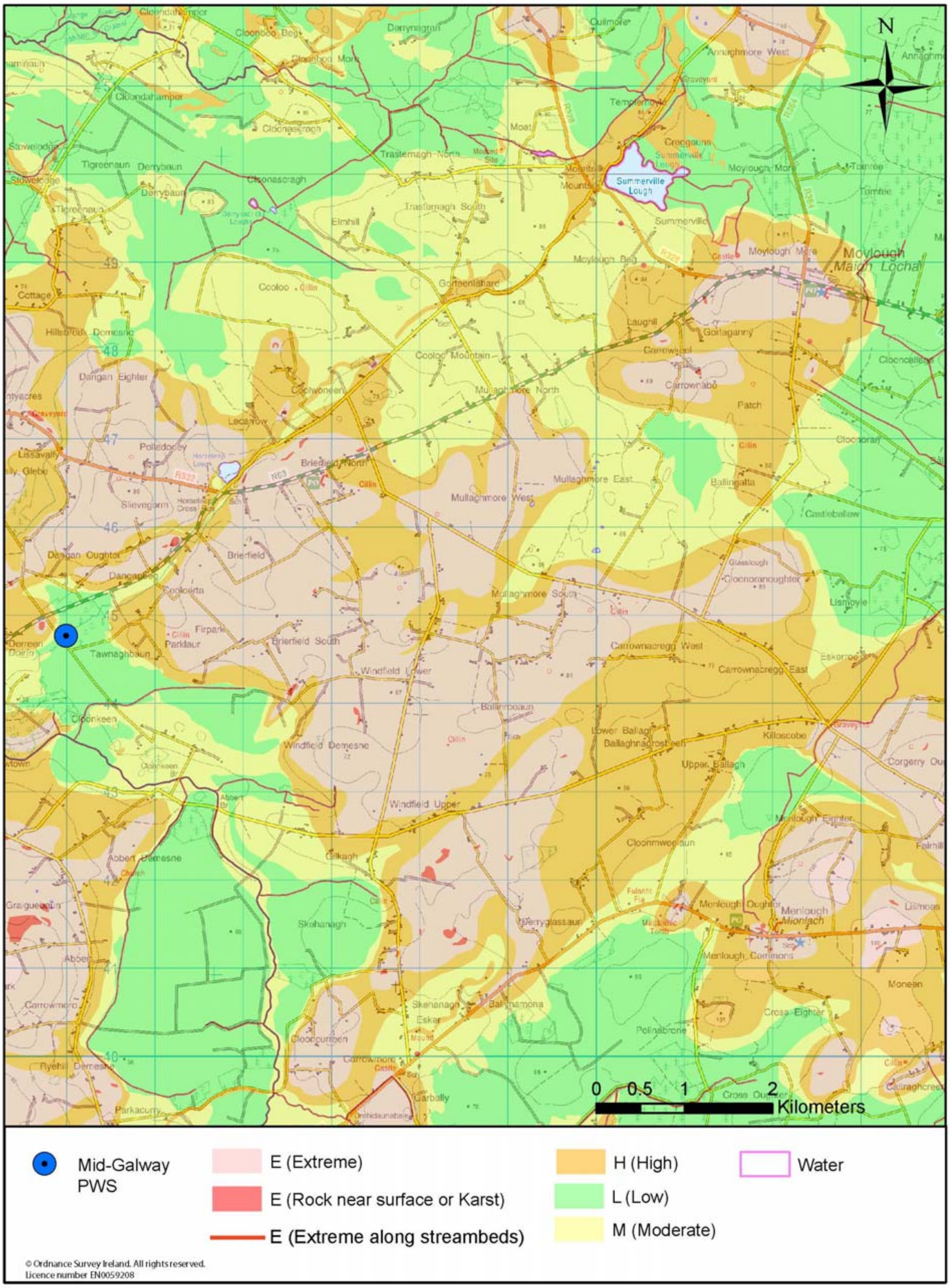


Figure 11: Groundwater Vulnerability Map

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.

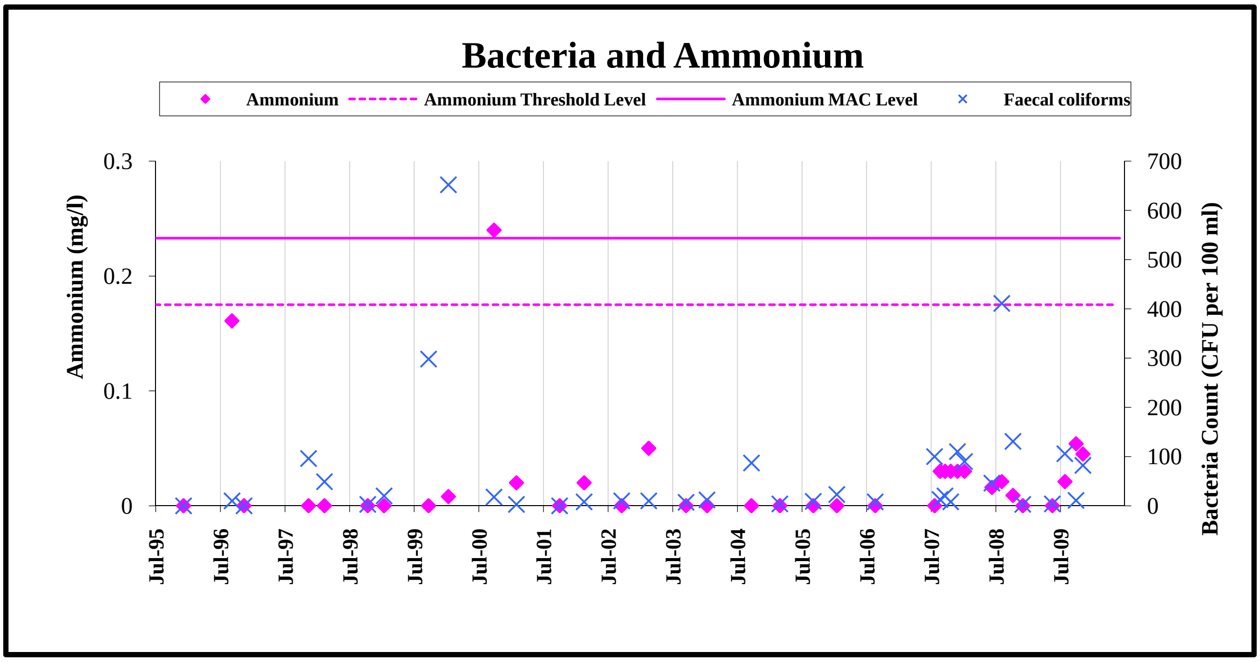
The established southwest and westerly groundwater flow components to the Mid-Galway PWS contrast with the demonstrated north-northeasterly flow gradients associated with the Mountbellew PWS (CDM 2011) and Caltra GWS (CDM 2012a).

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 $CaCO_3$). 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 NO_3) 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

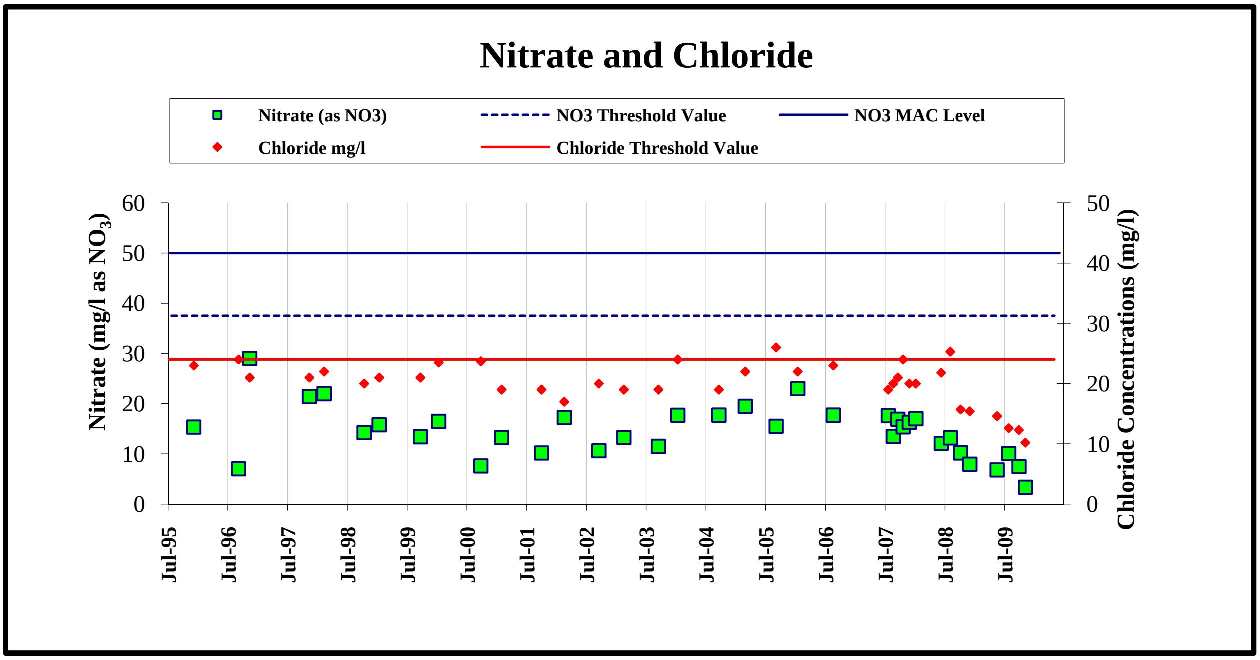
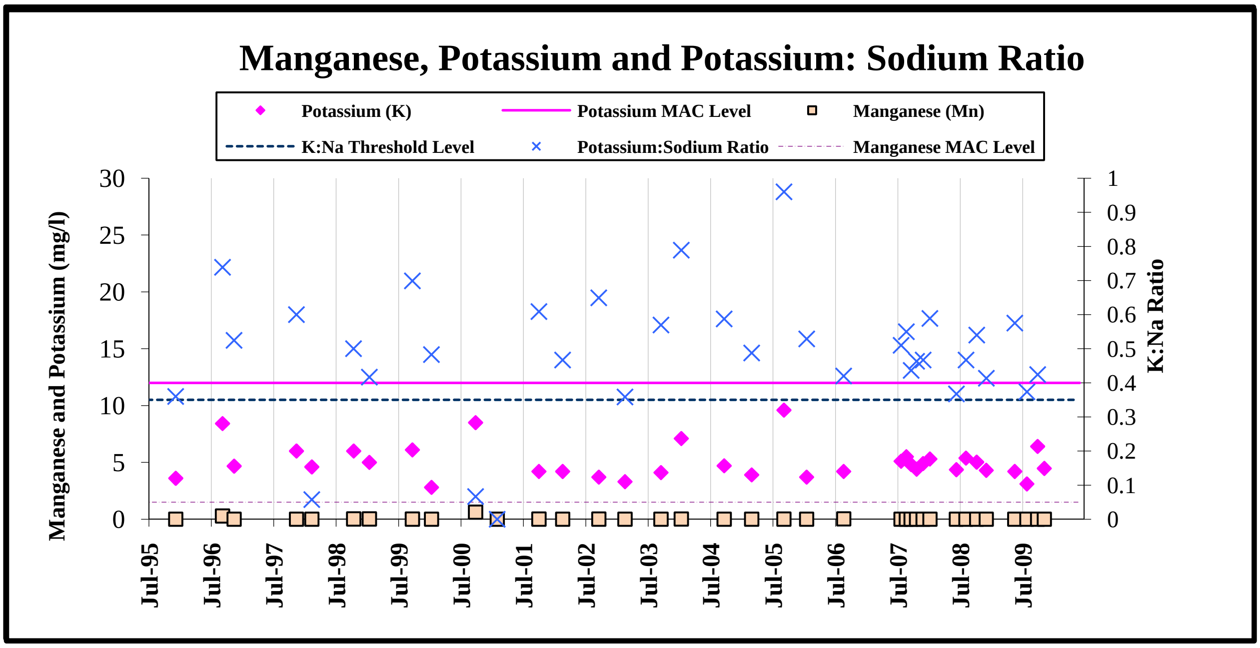
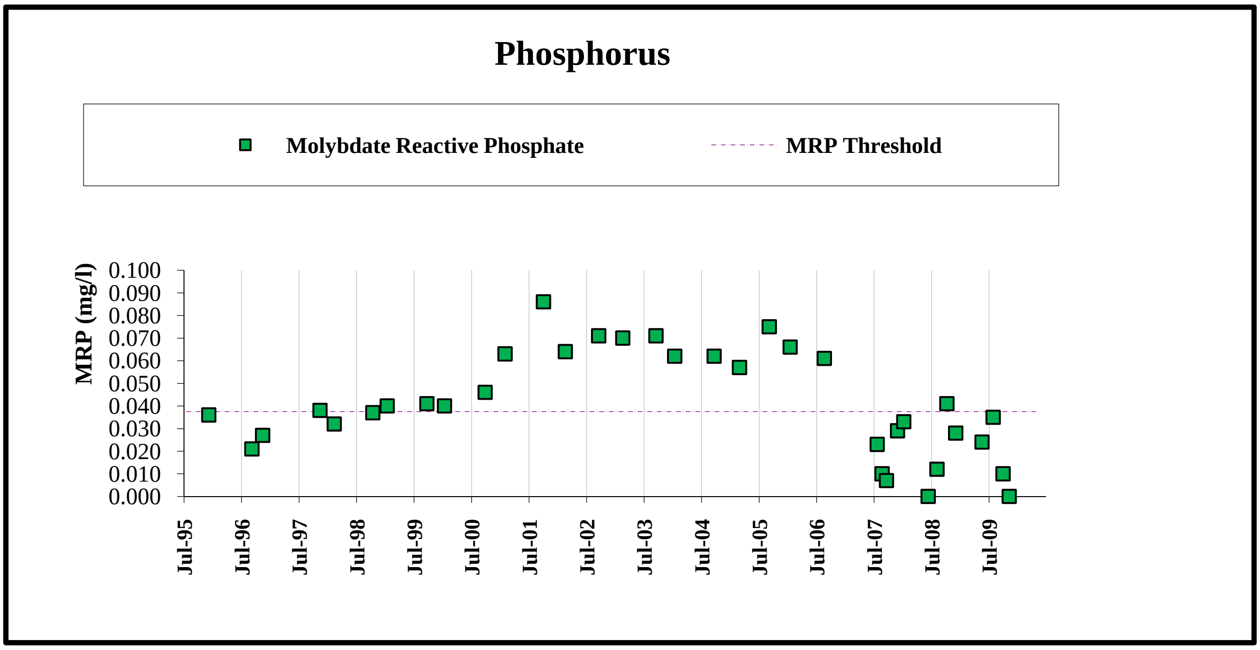


Figure 13: Nitrate and Chloride Concentrations



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 looses 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.

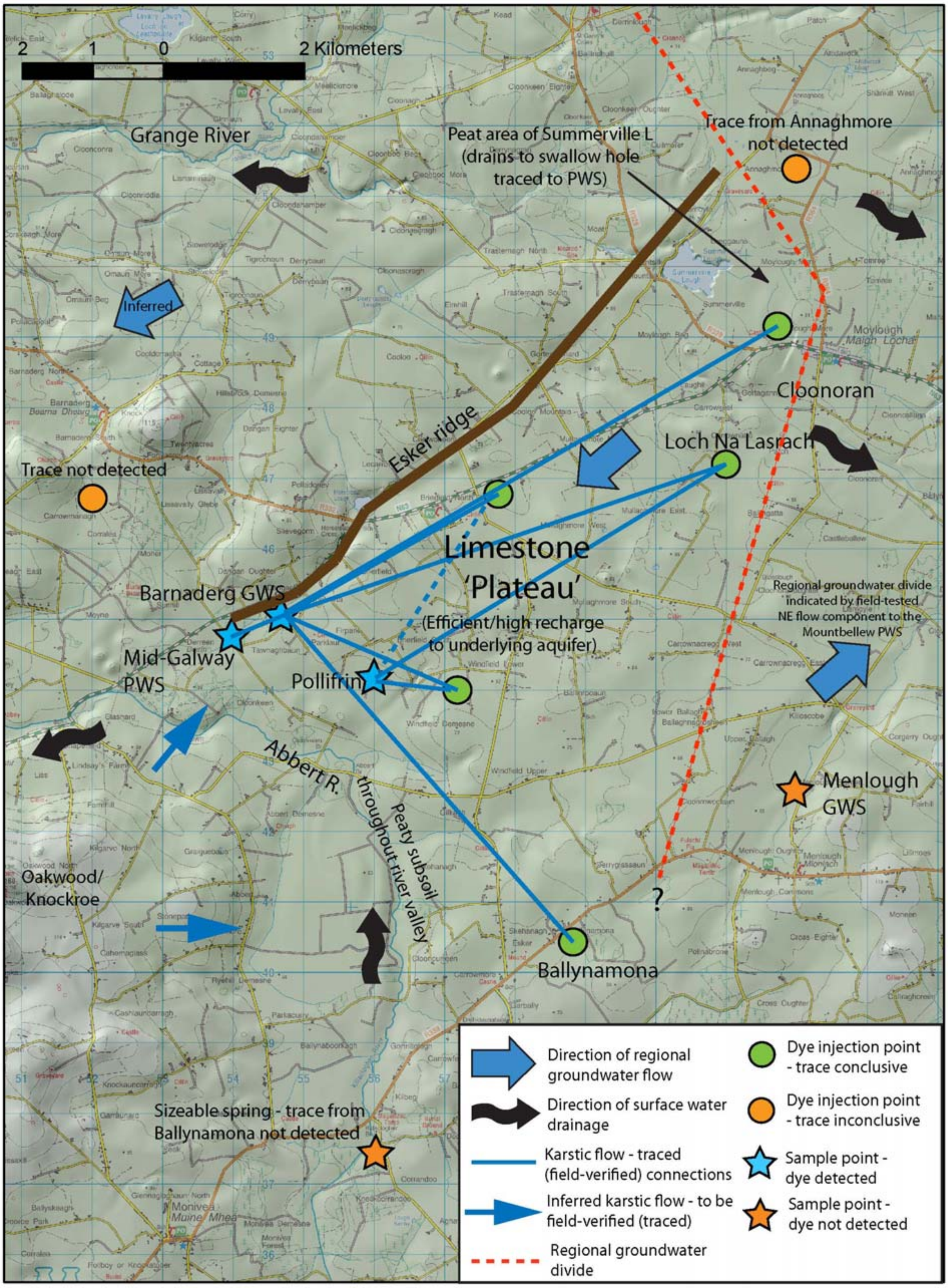


Figure 16: Conceptual model with results of tracing – plan map

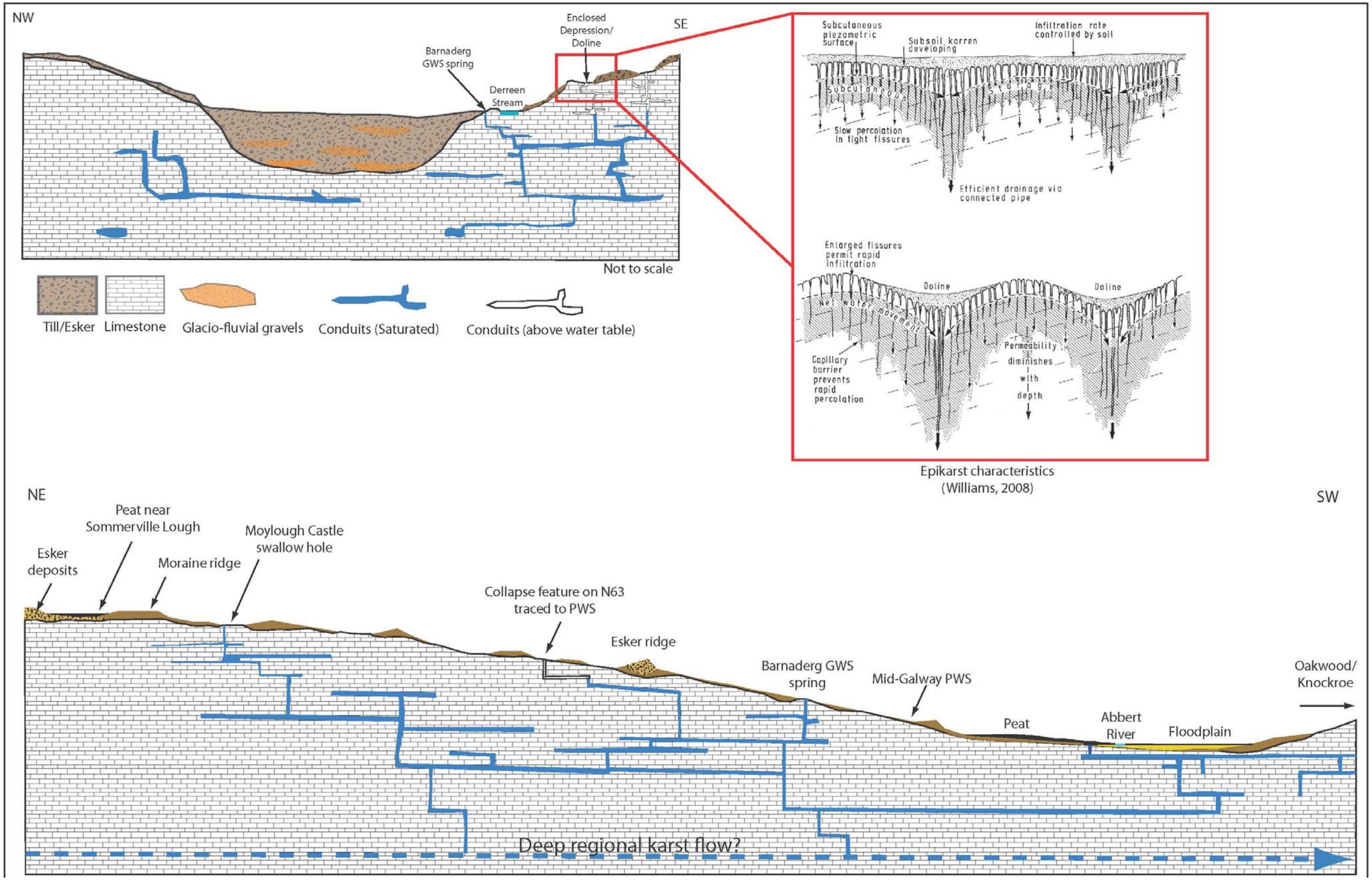


Figure 17: Conceptual model – cross-section

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.

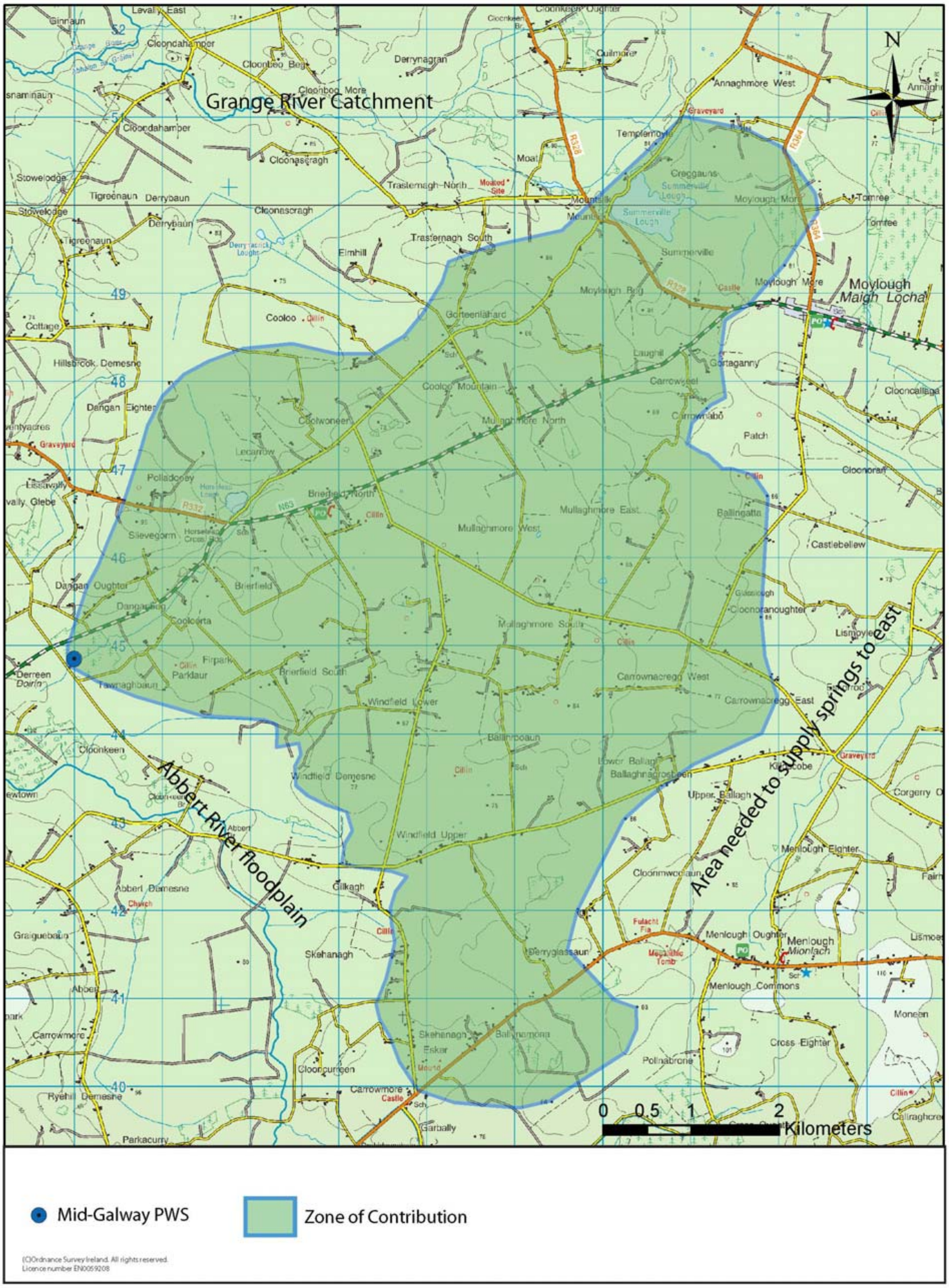


Figure 18: Estimated Zone of Contribution

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 m^3/d). It has a total area of approximately 49.8 km^2 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 km$^{2.}$ 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.

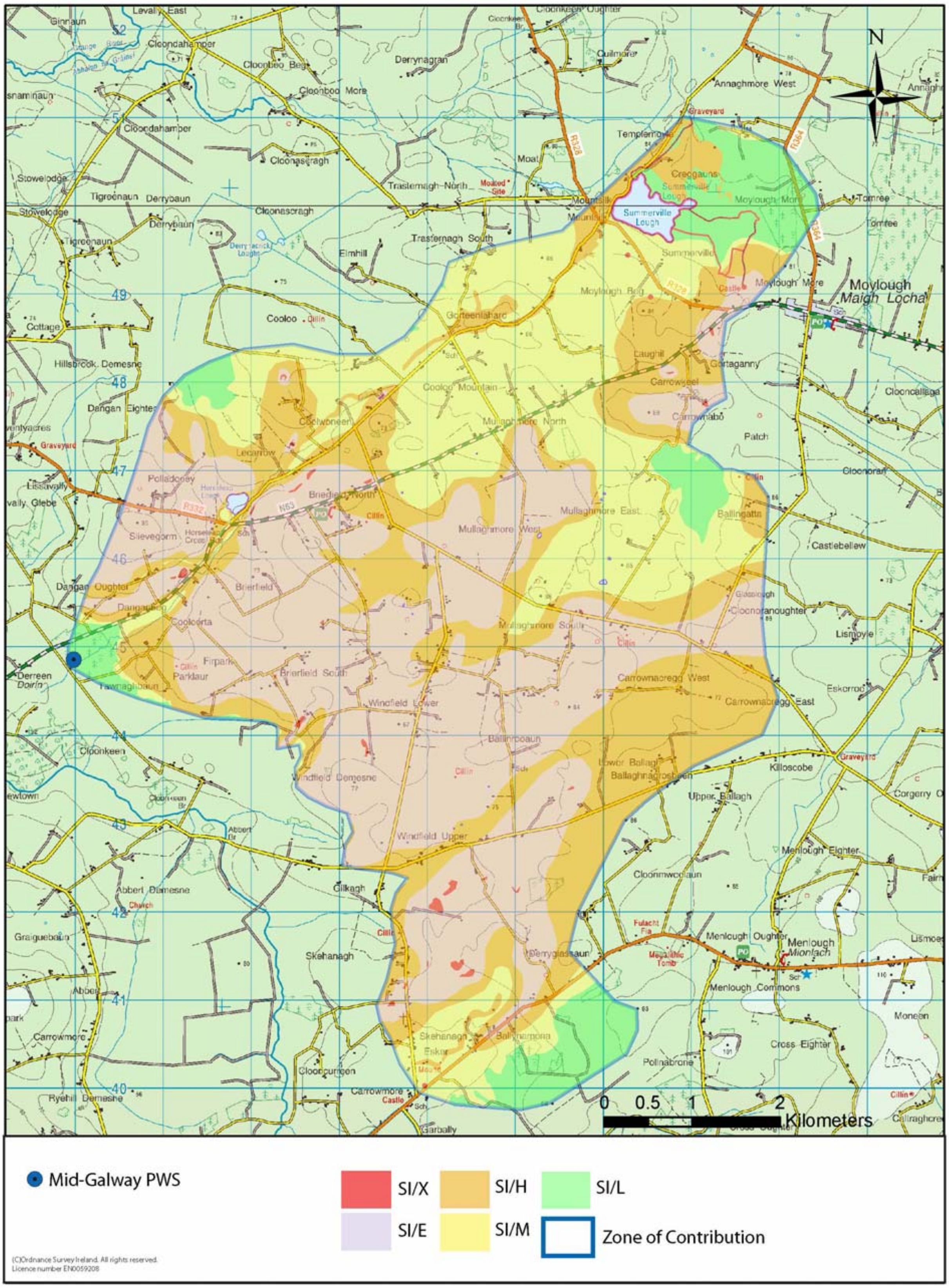


Figure 19: Source Protection Zones

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 though additional observations and monitoring of inflows/outflows at these locations.

14 References

Bartley, P. 2011. Personal communication with Dr. Pamela Bartley.

CDM Ireland Ltd., 2011. Establishment of Groundwater Source Protection Zones. Mountbellew Public Water Supply Scheme. Prepared for the Environmental Protection Agency and Galway County Council. December 2011.

CDM Ireland Ltd., 2012a. Establishment of Groundwater Source Protection Zones. Caltra Group Water Scheme. Prepared for the Environmental Protection Agency and Galway County Council. April 2012 (in preparation).

DELG/EPA/GSI, 1999. Groundwater Protection Schemes. Dept. of the Environment & Local Government; Environmental Protection Agency; Geological Survey of Ireland.

Drew, D.P. 1973. Ballyglunin Cave Co. Galway and the hydrology of the surrounding area. Irish Geography 6 (5), pp 610-17.EPA website. www.epa.ie

European Communities (Drinking Water) Regulations (2000). S.I. No. 439 of 2000.

Fitzgerald, D. and F. Forrestal, 1996. Monthly and annual averages of rainfall for Ireland 1961 to 1990. Meteorological Service Climatological Note No. 10. Glasnevin Hill, Dublin 9.

GSI website: www.gsi.ie

GSI, 2003. Clare-Corrib Groundwater Body – Water Framework Directive Initial Characterisation Summary – 1st Draft. Geological Survey of Ireland.

GWWG 2005. Guidance on the Assessment of the Impact of Groundwater Abstractions. Guidance Document No.GW5. Intergovernmental Working Group on Groundwater.

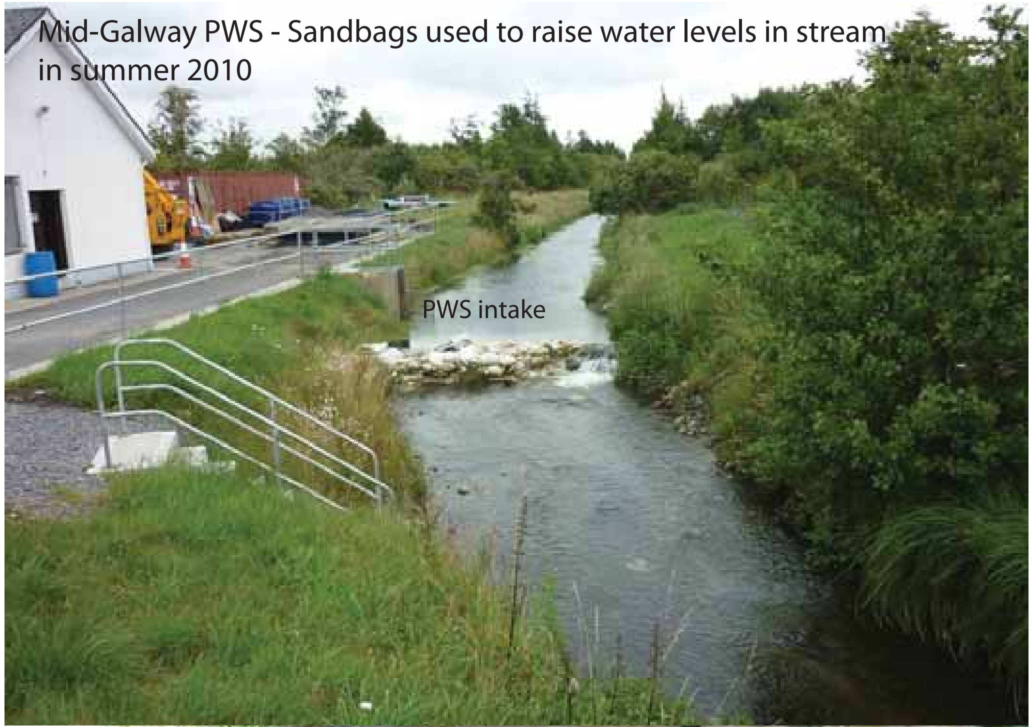
McConnell, B., MacDermot, C.V. and Long, C.B. (2002). Geology of South Mayo: A geological description of South Mayo, and adjacent parts of Galway and Roscommon to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 11, South Mayo.

Morris, J.H., Somerville, I.D. and MacDermot, C.V. (2003). Geology of Longford-Roscommon: A geological description of Longford-Roscommon, and adjoining parts of Cavan, Leitrim and Galway to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 12, Longford-Roscommon.

Williams, P. W. (2008). The role of the epikarst in karst and cave hydrogeology: a review. International Journal of Speleology, 37 (1), 1-10. Bologna (Italy). ISSN 0392-6672.

APPENDIX A

Photographs


Mid-Galway PWS - Sandbags used to raise water levels in stream in summer 2010


Stream flow measurements u/s of the PWS intake


Automatic gauge (flow recorder) d/s of the PWS intake

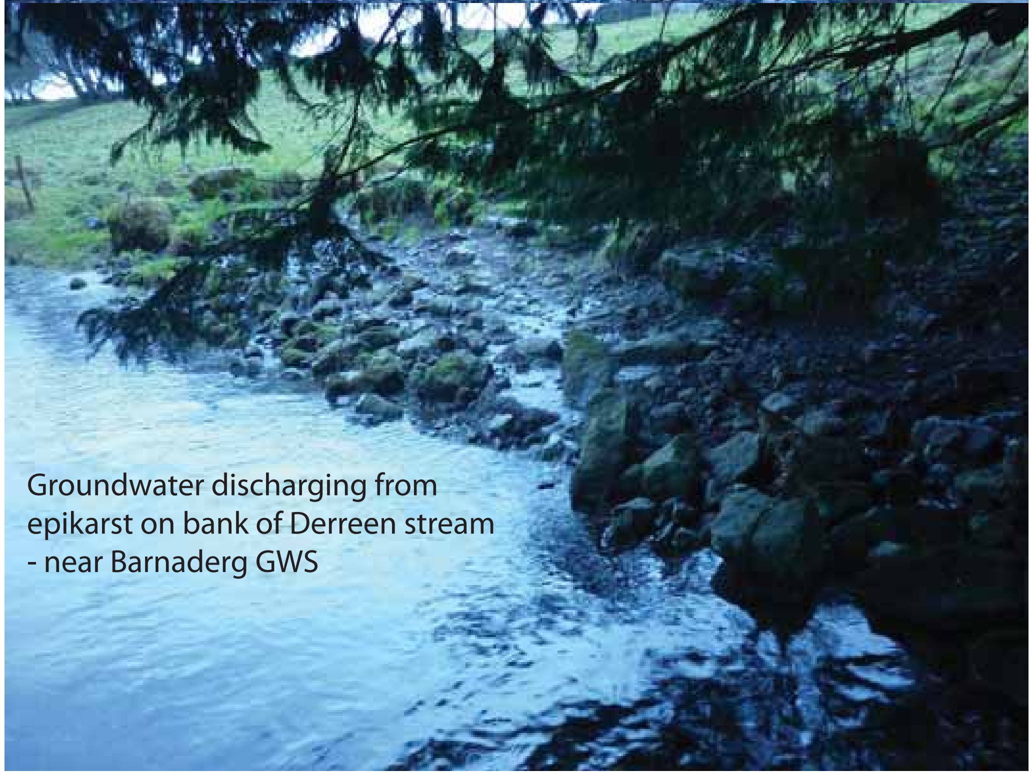

Looking downstream at pump intake structure

Photos: H. Moe

Barnderg GWS - spring chamber

Barnaderg GWS - new supply well being drilled (air-lifting in progress)

Small spring in field next to Barnaderg GWS



Groundwater discharging from
epikarst on bank of Derreen stream
- near Barnaderg GWS

Photos:
H. Moe

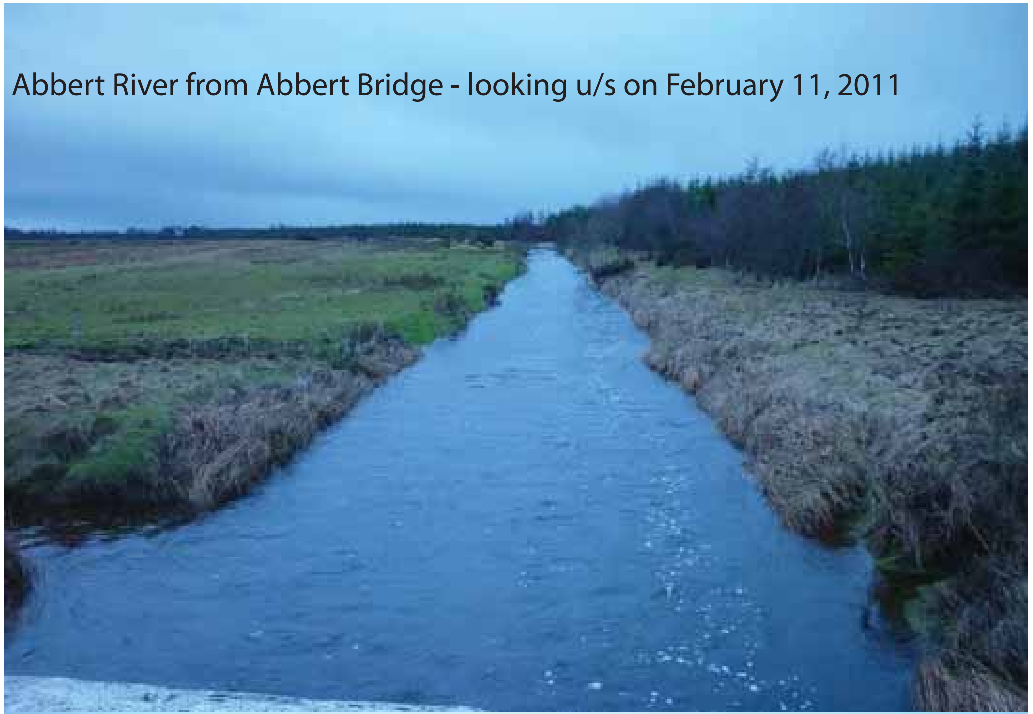
Pollifrin Spring - August 2010

Brierfield GWS - sourced from Pollifrin

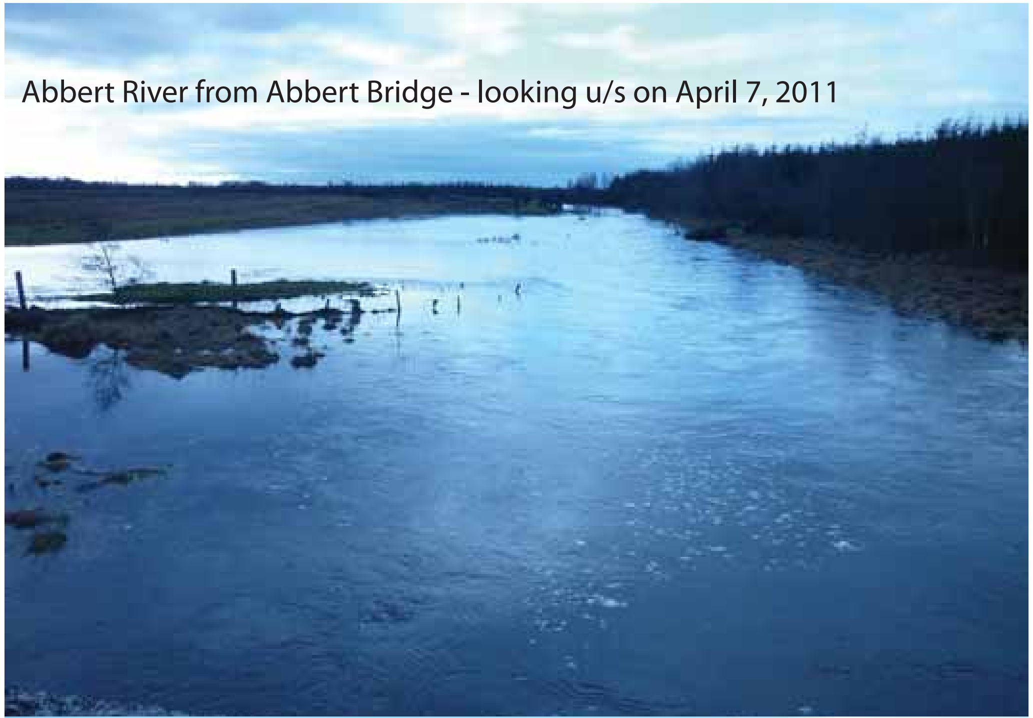
Brierfield GWS intake - August 2010

Brierfield GWS intake - January 2011

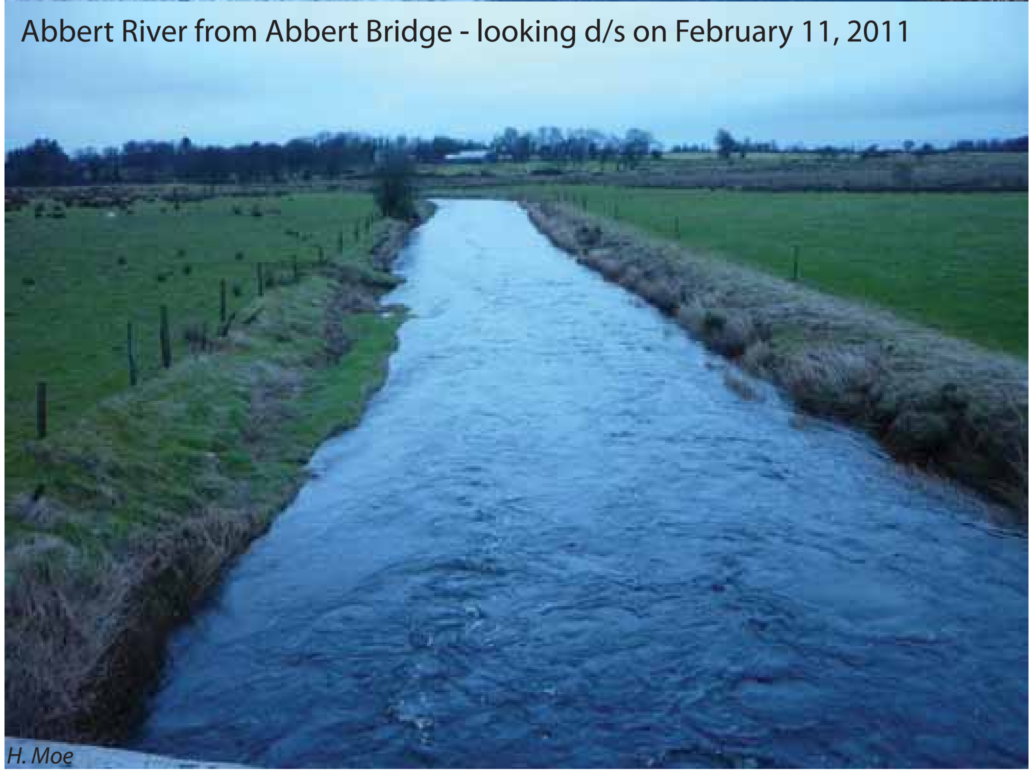
Photos:
H. Moe



Abbert River from Abbert Bridge - looking u/s on February 11, 2011

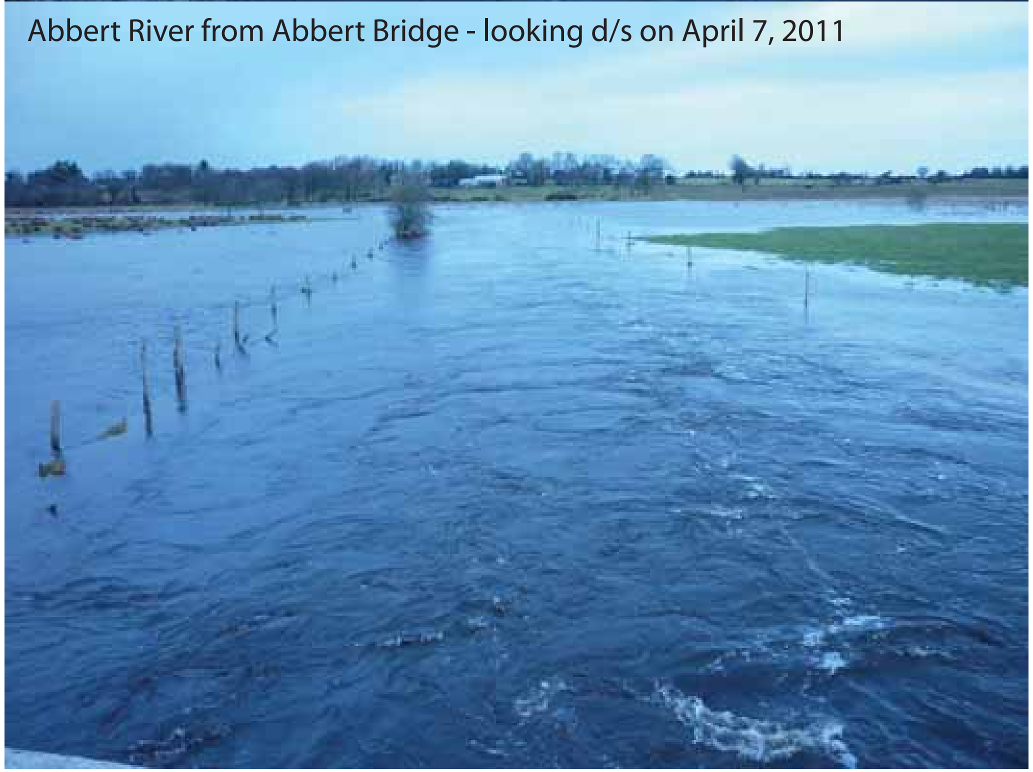


Abbert River from Abbert Bridge - looking u/s on April 7, 2011



Abbert River from Abbert Bridge - looking d/s on February 11, 2011

H. Moe



Abbert River from Abbert Bridge - looking d/s on April 7, 2011

Photos:
H. Moe

Spring - near Pollifrin - dry - August 2010

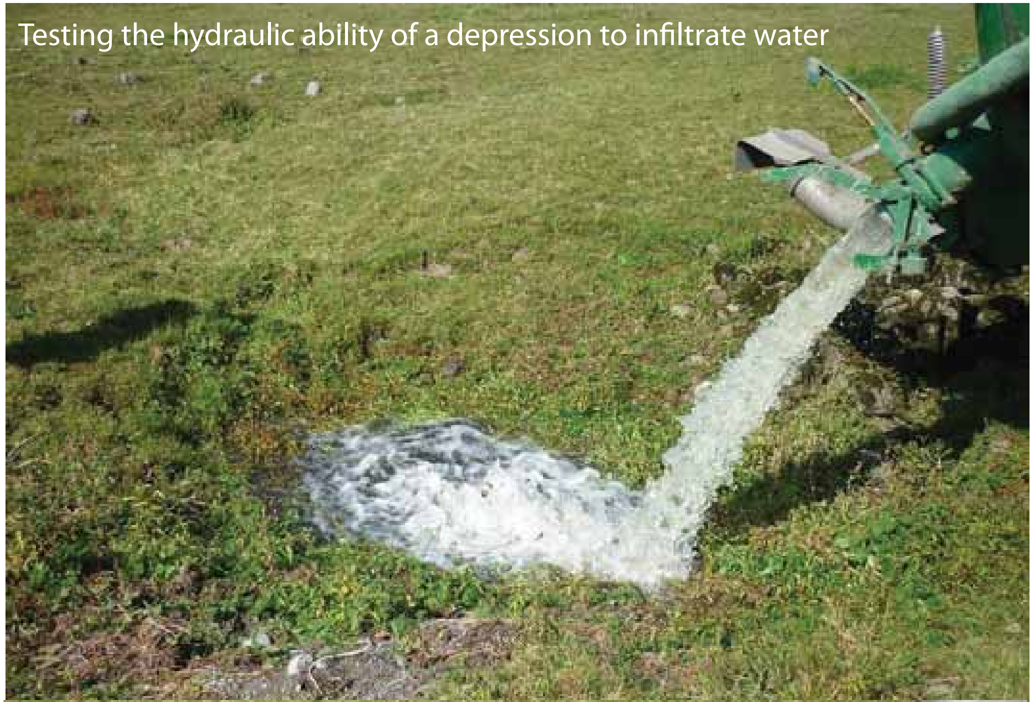
Spring - near Pollifrin - February 2011

Joints in limestone - near Pollifrin

Joints in limestone - near Pollifrin

Photos:
H. Moe

Subtle enclosed depressions in 'extreme' vulnerability areas



Testing the hydraulic ability of a depression to infiltrate water

Shallow enclosed depression in well drained 'extreme' vulnerability setting

Testing the hydraulic ability of a depression to infiltrate water - 2 minutes later

Photos: H.Moe


Small enclosed depressions - Skehanagh - summer 2010


Small enclosed depressions - Skehanagh - autumn 2010


Doline - Brierfield North - summer 2010


Doline - Brierfield North - December 2010

Photos: H. Moe


Doline


Enclosed depression


Enclosed depression


Enclosed depressions

Photos:
H. Moe

Swallow hole behind Moylough Castle - July 2010

Swallow hole behind Moylough Castle - December 2010

Ponded water draining to swallow hole behind Moylough Castle

Ponded water draining to swallow hole behind Moylough Castle

Photos: H. Moe

Photos:
H. Moe

Ballynamona swallow hole

Tributary of Abbert River at Drehidunabale Bridge - looking upstream

Tributary of Abbert River at Drehidunabale Bridge - looking downstream
(note loss of flow - possible sinking stream)

Photos:
H. Moe


Loch Na Lasrach - August 2010


Loch Na Lasrach - August 2010


Loch Na Lasrach - August 2010 (esker in background)

Photos: H. Moe

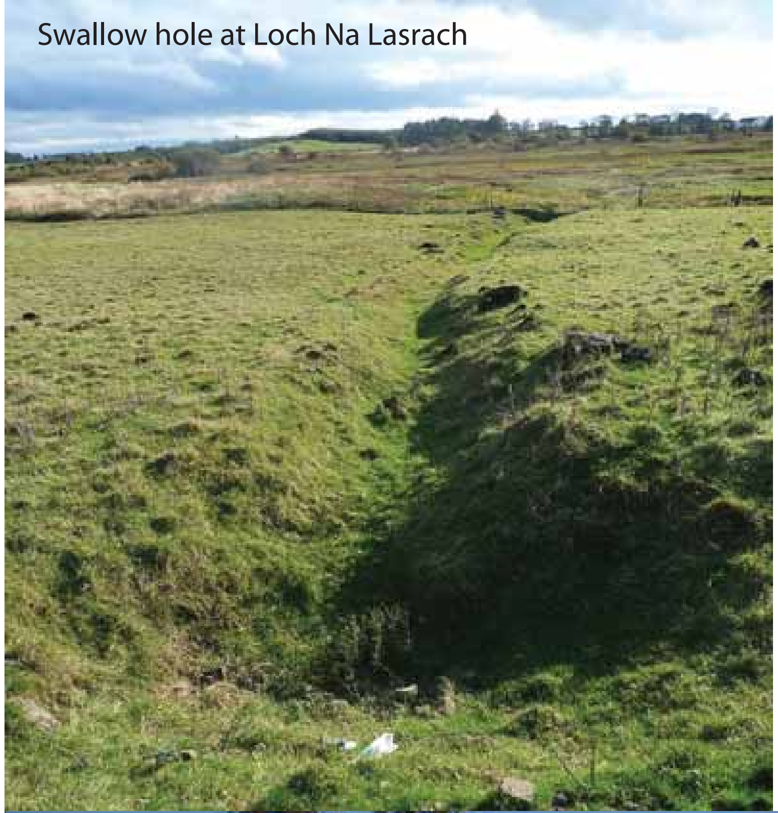

Loch Na Lasrach


Loch Na Lasrach


Loch Na Lasrach


Loch Na Lasrach

Photos:
H. Moe


Swallow hole at Loch Na Lasrach


Swallow hole at Loch Na Lasrach


Indications of smaller swallow holes at Loch Na Lasrach

Photos:
H. Moe


Excavated channel leading to natural outwash channel at northern end of Loch Na Lasrach


Main outwash channel - looking northeast from northern shore of Loch Na Lasrach


Secondary parallel outwash channel


Outwash channel - looking southwest from Cloonoran Turlough

Photos: H. Moe

Cloonoran spring

Flora on Cloonoran Turlough - Moylough

Turlough Plants

Cloonoran Turlough

Cloonoran Turlough - Moylough Turlach Cluain Óráin - Maigh Locha

Turloughs

Features associated with Turloughs

Photos:
H. Moe


Horseleap Lough (dry, summer 2010)


Sommerville Lough (December 2010)


Esker deposits near Sommerville Lough


Esker ridge near Horseleap Lough

Photos: H. Moe

APPENDIX B

Mapped Karst Features

Feature Type	Easting	Northing	General Area	Comments
Swallow Hole	161070	249100	Moylough	Polladirk
Swallow Hole	161443	249197	Moylough	Castle
Spring	154553	245111	Danganbeg	Barnaderg GWS
Spring	155120	245506	Danganbeg	
Spring	154625	245191	Danganbeg	
Spring	154553	245212	Danganbeg	Seepages from bedding
Spring	156165	237579		Tober Geal
Spring	156014	237476		
Spring	155849	237448		
Spring	154354	244887	Danganbeg	
Spring	154383	244958	Danganbeg	
Spring	154487	245172	Danganbeg	Piped to stream
Spring	154460	245306	Danganbeg	
Spring	154896	245357	Danganbeg	
Spring	155085	245067	Danganbeg	
Spring	154663	245138	Danganbeg	
Spring	156019	244177	Brierfield South	Pollifrin
Spring	154331	243254	Newtown	
Spring	153205	243390	Newtown	tiny spring
Spring	156539	244074	Brierfield South	tiny spring
Spring	154993	241546	Abbert Demesne	
Spring	156568	240830	Skehanagh	
Swallow Hole	157164	239287	Gorteendrisha	suspected losing stream by bridge
Swallow Hole	158532	240299	Ballynamona	
Doline	157975	240138	Garbally	
Swallow Hole	158249	240259	Esker	never saw it active
Swallow Hole	151850	246686	Carrowmanagh	
Swallow Hole	151674	246356	Carrowmanagh	
Spring	151953	245869	Carrowmanagh	tiny spring
Swallow Hole	160902	247272	Carrownabo	
Swallow Hole	160713	247301	Carrownabo	
Swallow Hole	157515	246858	Brierfield North	collapse feature - 2009
Enclosed Depression	150712	242092	Oakwood	
Enclosed Depression	151147	242052	Oakwood	
Spring	156537	237643		
Spring	156410	239244		
Spring	156880	239353		
Spring	156793	239708		
Doline	157961	240133		
Swallow hole	158262	240255		
Enclosed Depression	162174	251480		
Enclosed Depression	153160	248233		
Enclosed Depression	153138	248128		
Enclosed Depression	152771	247940		
Enclosed Depression	152901	247895		
Enclosed Depression	153835	248409	Hillsbrook demesnse	
Enclosed Depression	150813	246955		
Enclosed Depression	150804	246904		
Enclosed Depression	150767	246883		
Enclosed Depression	150819	246865		
Enclosed Depression	150962	247056		
Enclosed Depression	150977	247104		
Enclosed Depression	151080	247144		
Enclosed Depression	151081	247135		
Swallow Hole	150632	247384		
Enclosed Depression	151308	246253		
Enclosed Depression	151441	246194		
Enclosed Depression	151470	246279		
Enclosed Depression	151511	246182		
Enclosed Depression	151582	246299		
Enclosed Depression	151649	256355		
Enclosed Depression	151675	246354		

Enclosed Depression	151602	246436		
Enclosed Depression	151602	246236		
Swallow Hole	151792	246437		
Swallow Hole	151812	246366		
Enclosed Depression	151840	246322		
Enclosed Depression	151808	246310		
Enclosed Depression	151803	246159		
Enclosed Depression	151813	246204		
Enclosed Depression	151450	246443		
Enclosed Depression	151584	246444		
Enclosed Depression	151381	246536		
Enclosed Depression	151511	246593		
Enclosed Depression	151537	246671		
Enclosed Depression	151475	246646		
Enclosed Depression	151412	246665		
Enclosed Depression	151728	246624		
Enclosed Depression	151871	246616		
Swallow hole	151890	246666		
Swallow hole	158264	240262		
Swallow hole	158528	240305		
Swallow hole	157970	240030		
Enclosed Depression	162174	251480	Annaghmore	Annaghmore

APPENDIX C

Subsoil Logs – window sampling (2010)

WINDOW SAMPLE RECORD

REPORT NUMBER 15028

CONTRACT Galway Sites

PROBE NO. **WS501**
SHEET Sheet 1 of 1

CO-ORDINATES

GROUND LEVEL (mOD)

DATE DRILLED 24/11/2010
DATE LOGGED 24/11/2010

CLIENT Galway County Council
ENGINEER CDM Ireland Ltd

SAMPLED BY CK
LOGGED BY JL

Depth (m)	Geotechnical Description	Legend	Depth (m)	Elevation	Water Strike	Depth of Sample Run (m)	Recovery (%)	Blowcount	Vane Test (KPa)	Hand Penetrometer (KPa)
0.0	TOPSOIL: Soft to firm brown sandy slightly gravelly CLAY with occasional rootlets. Sand is fine to coarse. Gravel is subangular to subrounded fine to medium of various lithologies.		0.45							
	Firm grey brown sandy slightly gravelly CLAY with a low cobble content. Sand is fine to coarse. Gravel is subangular to subrounded fine to medium of various lithologies. Cobbles are subrounded of limestone.		0.60							
1.0	Soft grey to light grey brown slightly sandy SILT. Sand is fine to medium.		1.70			0.00-1.00	90	35 blows		
	Firm light brown very sandy gravelly CLAY. Sand is fine to coarse. Gravel is subangular to subrounded fine to medium of various lithologies.		2.00			1.00-2.00	30	59 blows		
2.0	Light brown clayey slightly gravelly SAND. Sand is fine to coarse. Gravel is subangular to subrounded fine to coarse of various lithologies.		2.30							
	Firm to stiff light brown sandy gravelly CLAY. Sand is fine to coarse. Gravel is subangular to rounded fine to coarse of sandstone and limestone.		2.80			2.00-2.80	100			
3.0 4.0 5.0	Final Depth 2.80m									

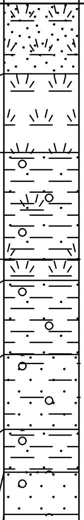
General Remarks

Installations

WINDOW SAMPLE RECORD

REPORT NUMBER 15028

CONTRACT	Galway Sites	**PROBE NO.**	**WSS02**
		SHEET	Sheet 1 of 1
CO-ORDINATES		**DATE DRILLED**	24/11/2010
GROUND LEVEL (mOD)		**DATE LOGGED**	24/11/2010
CLIENT	Galway County Council	**SAMPLED BY**	CK
ENGINEER	CDM Ireland Ltd	**LOGGED BY**	JL



Depth (m)	Geotechnical Description	Legend	Depth (m)	Elevation	Water Strike	Depth of Sample Run (m)	Recovery (%)	Blowcount	Vane Test (KPa)	Hand Penetrometer (KPa)
0.0	TOPSOIL: Soft brown sandy gravelly CLAY with frequent rootlets. Sand is fine to coarse. Gravel is subangular to subrounded fine to medium of limestone.		0.33							
	Spongy dark brown pseudofibrous PEAT		0.70							
1.0	Soft to firm grey sandy slightly gravelly organic CLAY. Sand is fine to medium. Gravel is subangular to subrounded fine to medium of limestone.		1.20			0.00-1.00	75	41 blows		
	Spongy dark brown to black pseudofibrous PEAT		1.30							
	Firm light grey brown very sandy gravelly CLAY. Sand is fine to coarse. Gravel is subangular to subrounded fine to coarse of limestone and sandstone.		1.65							
	Light grey brown clayey gravelly SAND. Sand is fine to coarse predominantly medium to coarse. Gravel is subangular to subrounded fine to coarse of sandstone.		2.00			1.00-2.00	80	119 blows		
2.0	Soft grey brown sandy slightly gravelly slightly organic CLAY with pockets of brown spongy peat. Sand is fine to coarse. Gravel is subangular to subrounded fine to medium of various lithologies.		2.20			2.00-2.40	100			
	Grey to grey brown slightly gravelly SAND with a low cobble content. Sand is medium to coarse. Gravel is subangular to subrounded fine to medium of limestone. Cobbles are subrounded of limestone.		2.40							
3.0	Final Depth 2.40m									
4.0										
5.0										

General Remarks

Installations

WINDOW SAMPLE RECORD

REPORT NUMBER 15028

CONTRACT Galway Sites

PROBE NO. **WSS03**
SHEET Sheet 1 of 1

CO-ORDINATES

GROUND LEVEL (mOD)

DATE DRILLED 24/11/2010
DATE LOGGED 24/11/2010

CLIENT Galway County Council
ENGINEER CDM Ireland Ltd

SAMPLED BY CK
LOGGED BY JL

Geotechnical Description	Depth (m)	Elevation	Water Strike	Depth of Sample Run (m)	Recovery (%)	Blowcount	Vane Test (KPa)	Hand Penetrometer (KPa)
Subangular to rounded COBBLES of limestone and mudstone with some grey brown gravelly sand. Sand is fine to coarse. Gravel is subangular to subrounded fine to coarse of limestone.				0.00-1.00	70	127 blows		
	1.20							
Grey brown sandy GRAVEL. Sand is medium to coarse. Gravel is angular to subrounded fine to coarse of limestone.	1.80							
Plastic brown to dark brown clayey amorphous PEAT with a low cobble content. Cobbles are subangular to subrounded of limestone.	2.00			1.00-2.00	80	52 blows		
Brown slightly silty sandy GRAVEL with a low cobble content. Sand is medium to coarse. Gravel is angular to subrounded fine to coarse of limestone. Cobbles are subrounded of limestone.	2.35							
Plastic dark brown to black amorphous PEAT	2.55							
Firm light grey brown slightly gravelly sandy CLAY. Sand is fine to coarse. Gravel is subangular to subrounded fine to medium of limestone.	2.80			2.00-2.80	100			
Final Depth 2.80m								

General Remarks

Installations

WINDOW SAMPLE RECORD

REPORT NUMBER 15028

CONTRACT Galway Sites

PROBE NO. WSS04
SHEET Sheet 1 of 1

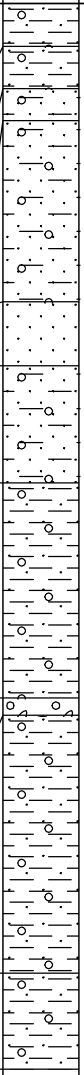
CO-ORDINATES 160,370.00 E
249,742.00 N

GROUND LEVEL (mOD)

DATE DRILLED 24/11/2010
DATE LOGGED 24/11/2010

CLIENT Galway County Council
ENGINEER CDM Ireland Ltd

SAMPLED BY CK
LOGGED BY JL



Depth (m)	Geotechnical Description	Legend	Depth (m)	Elevation	Water Strike	Depth of Sample Run (m)	Recovery (%)	Blowcount	Vane Test (KPa)	Hand Penetrometer (KPa)
0.0	Soft brown sandy slightly gravelly CLAY with occasional rootlets. Sand is fine to medium. Gravel is subangular to subrounded fine to medium of various lithologies.		0.20							
	Soft to firm brown very sandy gravelly CLAY. Sand is fine to coarse. Gravel is subangular to subrounded fine to medium of various lithologies.		0.40							
	Grey brown slightly clayey gravelly SAND. Sand is fine to coarse. Gravel is subrounded fine to medium of various lithologies.		0.55			0.00-1.00	70	63 blows		
1.0	Light brown slightly clayey slightly gravelly SAND. Sand is fine to medium. Gravel is subangular to subrounded fine to medium of limestone.		1.40							
	Light brown SAND. Sand is fine to medium.		1.70							
2.0	Light brown and dark brown slightly clayey gravelly SAND. Sand is fine to coarse. Gravel is subangular to subrounded fine to coarse of limestone.		2.25			1.00-2.00	60	75 blows		
3.0	Firm to stiff golden brown sandy gravelly CLAY. Sand is fine to coarse. Gravel is angular to subrounded fine to coarse of limestone.		3.26			2.00-3.00	100	65 blows		
	Band of grey gravel. Gravel is subrounded to rounded, fine to coarse of limestone.		3.34							
4.0	Firm to stiff golden brown sandy gravelly CLAY. Sand is fine to coarse. Gravel is angular to subrounded fine to coarse of limestone.		4.55			3.00-4.00	85	80 blows		
	Firm golden brown slightly sandy gravelly CLAY. Sand is fine to medium. Gravel is angular to subrounded fine to coarse of limestone.		5.00			4.00-5.00	45	124 blows		
5.0	Final Depth 4.55m									

General Remarks

Installations

WINDOW SAMPLE RECORD

REPORT NUMBER 15028

CONTRACT	Galway Sites	**PROBE NO.**	**WSS05**
		SHEET	Sheet 1 of 1
CO-ORDINATES	160,919.00 E 249,546.00 N	**DATE DRILLED**	25/11/2010
GROUND LEVEL (mOD)		**DATE LOGGED**	25/11/2010
CLIENT	Galway County Council	**SAMPLED BY**	CK
ENGINEER	CDM Ireland Ltd	**LOGGED BY**	JL

Geotechnical Description	Legend	Depth (m)	Elevation	Water Strike	Depth of Sample Run (m)	Recovery (%)	Blowcount	Vane Test (KPa)	Hand Penetrometer (KPa)
TOPSOIL: Soft brown sandy CLAY with abundant rootlets. Sand is fine to medium.		0.10							
Soft to firm sandy to very sandy slightly gravelly CLAY with rare rootlets. Sand is fine to medium. Gravel is subangular to subrounded fine to medium of limestone.					0.00-1.00	55	89 blows		
		1.35							
Brown clayey sandy GRAVEL. Sand is medium to coarse. Gravel is subangular fine to medium predominantly fine of various lithologies.		1.45							
Firm light grey brown very sandy gravelly CLAY with a low cobble content. Sand is fine to coarse. Gravel is subangular to subrounded fine to medium of limestone. Cobbles are subangular of limestone.		1.80			1.00-2.00	65	74 blows		
Firm light brown sandy gravelly CLAY. Sand is fine to coarse. Gravel is subangular to subrounded fine to coarse of limestone.		2.00							
Brown slightly clayey gravelly SAND. Sand is medium to coarse. Gravel is subangular to subrounded fine of various lithologies.		2.20							
Soft to firm light brown and brown sandy gravelly CLAY. Sand is fine to coarse. Gravel is subangular to subrounded fine to coarse of limestone.		2.40							
Firm to stiff light brown sandy gravelly CLAY. Sand is fine to coarse. Gravel is subangular to subrounded fine to medium of limestone.		2.80			2.00-2.80	100			
Final Depth 2.80m									

General Remarks

Installations

WINDOW SAMPLE RECORD

REPORT NUMBER 15028

CONTRACT Galway Sites

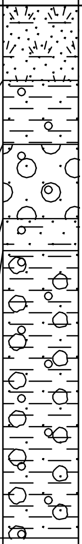
PROBE NO. WSS07
SHEET Sheet 1 of 1

CO-ORDINATES 161,040.00 E
249,589.00 N
GROUND LEVEL (mOD)

DATE DRILLED 24/11/2010
DATE LOGGED 24/11/2010

CLIENT Galway County Council
ENGINEER CDM Ireland Ltd

SAMPLED BY CK
LOGGED BY JL

Depth (m)	Geotechnical Description	Legend	Depth (m)	Elevation	Water Strike	Depth of Sample Run (m)	Recovery (%)	Blowcount	Vane Test (KPa)	Hand Penetrometer (KPa)
0.0	TOPSOIL: Soft brown sandy slightly gravelly CLAY with frequent rootlets. Sand is fine to medium. Gravel is subangular to subrounded fine to medium of various lithologies.		0.35							
	Firm grey brown very sandy gravelly CLAY. Sand is fine to coarse. Gravel is subangular to subrounded fine to coarse of limestone.		0.65							
1.0	Grey subangular to subrounded COBBLES of limestone with a little grey gravelly sand. Sand is medium to coarse. Gravel is subangular to subrounded fine to coarse of limestone.		1.00			0.00-1.00	70	65 blows		
	Grey slightly clayey gravelly SAND. Sand is medium to coarse. Gravel is subrounded fine to coarse of limestone.		1.15							
2.0	Firm to stiff light brown sandy gravelly CLAY with a low cobble content. Sand is fine to coarse. Gravel is subangular to subrounded fine to coarse of limestone. Cobbles are subangular to subrounded of limestone.		2.50			1.00-2.00	100	107 blows		
						2.00-2.50	50			
3.0 4.0 5.0	Final Depth 2.50m									

General Remarks

Installations

WINDOW SAMPLE RECORD

REPORT NUMBER 15028

CONTRACT	Galway Sites
PROBE NO.	**WSS08**
SHEET	Sheet 1 of 1
CO-ORDINATES	161,894.00 E 249,681.00 N
GROUND LEVEL (mOD)	
DATE DRILLED	25/11/2010
DATE LOGGED	25/11/2010
CLIENT	Galway County Council
ENGINEER	CDM Ireland Ltd
SAMPLED BY	CK
LOGGED BY	JL

Depth (m)	Geotechnical Description	Legend	Depth (m)	Elevation	Water Strike	Depth of Sample Run (m)	Recovery (%)	Blowcount	Vane Test (KPa)	Hand Penetrometer (KPa)
0.0	Spongy dark brown pseudofibrous to amorphous PEAT									
1.0						0.00-1.00	63	8 blows		
			1.50							
	Plastic dark brown to black pseudofibrous to amorphous PEAT									
2.0						1.00-2.00	50	4 blows		
			2.65							
	Plastic dark brown amorphous PEAT with rare rootlet									
			2.95			2.00-3.00	35	48 blows		
3.0	Grey brown silty slightly gravelly SAND. Sand is fine. Gravel is subangular to subrounded fine to medium of limestone.									
			3.15							
	Firm to stiff grey sandy gravelly CLAY. Sand is fine to coarse. Gravel is subangular to subrounded fine to coarse of limestone.					3.00-3.70	79			
			3.70							
	Final Depth 3.70m									
4.0										
5.0										

General Remarks

Installations

WINDOW SAMPLE RECORD

REPORT NUMBER 15028

CONTRACT Galway Sites

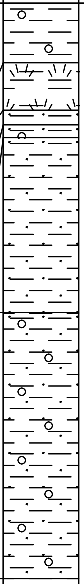
PROBE NO. WSS09
SHEET Sheet 1 of 1

CO-ORDINATES 161,582.00 E
250,379.00 N
GROUND LEVEL (mOD)

DATE DRILLED 25/11/2010
DATE LOGGED 25/11/2010

CLIENT Galway County Council
ENGINEER CDM Ireland Ltd

SAMPLED BY CK
LOGGED BY JL



Depth (m)	Geotechnical Description	Legend	Depth (m)	Elevation	Water Strike	Depth of Sample Run (m)	Recovery (%)	Blowcount	Vane Test (KPa)	Hand Penetrometer (KPa)
0.0	Soft brown to light brown slightly gravelly peaty CLAY with occasional fragments of decaying timber. Gravel is subangular to subrounded fine to medium of various lithologies.		0.28							
	Plastic brown slightly clayey amorphous PEAT		0.50							
	Soft light grey brown slightly sandy organic CLAY. Sand is fine to medium.		0.57							
1.0	Firm light grey mottled brown sandy slightly gravelly CLAY. Sand is fine to coarse. Gravel is subangular to subrounded fine to medium of limestone.		0.63			0.00-1.00	100	41 blows		
	Firm golden brown sandy to very sandy CLAY. Sand is fine to coarse.		1.45			1.00-2.00	55	84 blows		
2.0	Firm to stiff light grey brown to light grey sandy gravelly CLAY. Sand is fine to coarse. Gravel is angular to subrounded fine to medium of limestone.		2.70			2.00-2.70	100			
	Final Depth 2.70m									
3.0										
4.0										
5.0										

General Remarks

Installations

APPENDIX D

Tracer Test Results

Mid-Galway PWS – Summary of Dye Tracer Testing

Date	Injection site	Description	Input NGR	Tracer Used	Comments	Output site	Output NGR	Flow rate
Aug. 5, 2010	Moylough Castle Sink	3 permanent swallow holes	161440E/ 249228N	Fluorescein 4 kgs / 4 litres	Powder injected into sinking water ~ 3 l/s	Mid-Galway and Barnaderg GWS	153927E/ 244748N & 154470E/ 245135N	30.8 m/hr or 739 m/d
Oct. 12, 2010	Windfield Demesne	Large filled-in collapse	157152E/ 244132N	Optical Brightener 15 litres	Injected with 2 x 2600 gallon tankers. Water ponded, but flowed down within 1 hour	Mid-Galway PWS and Pollifrin	153927E/ 244748N & 156014E/ 244121N	<1 week – cotton was examined after 1 week. Actual travel time not known, but trace confirms connection. Clear peak from Briarfield and Mid Galway, not in Blank
Dec. 9, 2010	Carrowmanagh swallow hole	Natural swallow hole	151850E/ 246686N	Fluorescein 4 kg / 5 litres	Fluorescein poured into swallow holes	No dye recovered at any of the locations sampled, including Mid-Galway PWS	n/a	Presumed to have migrated SW towards springs near Abbeyknockmoy[1]
Dec. 9, 2010	Loch Na Lasrach turlough	Swallow hole, possibly an estavelle, at northern edge of turlough - natural drainage	160917E/ 247454N	Rhodamine 2 kgs / 10 litres	Dye poured into active swallow hole, under ice, and moved away quickly	Mid-Galway PWS and Pollifrin	153927E 244748N & 156014E/ 244121N	Positive trace to Mid-Galway PWS and Brierfield GWS. 64m/h or 1544m/d (for both springs)
Feb. 4, 2011	Annaghmore swallow hole	Swallow hole in depression	162170E 251460N	Rhodamine 3 kg	Dye flushed with 2000 gallon tanker x 2. Dye poured directly into opening in the rock and drained quickly	No dye recovered at any of the locations sampled including Mid-Galway PWS	n/a	No result

Date	Injection site	Description	Input NGR	Tracer Used	Comments	Output site	Output NGR	Flow rate
Feb. 4, 2011	Ballynamona swallow hole	Active swallow hole draining stream (20 l/s	158532E/ 240299N	Fluorescein 3 kg/4 litres	Poured directly into active swallow hole	No dye recovered at any of the locations sampled including Mid-Galway PWS[2]	n/a	No result – dye quantity may have been insufficient/too dilute to be detected at Mid-Galway PWS
Feb. 4, 2011	Brierfield North doline	Collapse feature next to the N63	157515E/246858N	Optical Brightener 10 litres	Natural trickle of water into hole from melting snow. Dye flushed in with 2000 gallon tanker x 2.	Mid-Galway, Barnaderg GWS, Pollifrin, Barnaderg GWS bridge	153927E/ 244748N & 154470E/ 245135N & 156014E/ 244121N & 154553E/ 245212N	Detected within 24 hours of injection.
Apr.5, 2011	Ballynamona swallow hole	Active swallow hole draining stream (20 l/s)	158532E/ 240299N	Optical Brightener 15 litres	Poured directly into active swallow hole	No detections at of the locations sampled[3], including Mid-Galway PWS	n/a	No result
Oct. 3, 2011	Ballynamona swallow hole	Active swallow hole draining stream (20 l/s)	158532E/ 240299N	Optical Brightener 30 litres	Poured directly into active swallow hole	Barnaderg GWS (not detected at Mid-Galway PWS[[4, 5] or Pollifrin)	154470E/ 245135N	>2 and <5 weeks – no detection after 2 weeks, but detected after 5 weeks. Actual travel time not known, but trace confirms connection.

Note:

1 - unfortunately, not sampled.

2 - two springs to the SW of Ballynamona (possible output sites near the Killaclogher River) were not be sampled. However, subsequent tests on April 5 and October 3, 2011 using optical brightener and cotton detectors did not establish a connection between Ballynamona and these springs.

3 - cotton detectors had been placed at the two springs near the Killaclogher River, but could not be retrieved (not found).

4 - surprising, given how Mid-Galway PWS is downstream of the discharge from the Barnaderg GWS, where the OB was detected. The cotton sampler at the Mid-Galway PWS was retrieved from the stream bank, and may not have been lying in the main flow path of the stream as the OB moved past.

5 - the OB was not detected in the cotton detectors in the two springs by the Killaclogher River.