Establishment of Groundwater Source Protection Zones

Mountbellew Public Water Supply Scheme

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Revision B

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Project description

Since the 1980's, 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 Mountbellew 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 MountbellewPublic Water Scheme (PWS) is supplied from a single spring in the townland of Meelick, Co. Galway. In 2010, the PWS distributed an estimated 2,000 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 boreholes.
- To delineate source protection zones for the production wells in 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.

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 April 2011.

3 Location, Site Description and Spring Protection

As shown in **Figure 1**, the single spring that supplies water to the Mountbellew PWS is located approximately 2.1 km south of Mountbellew village in the townland of Meelick. Accordingly, the spring is known locally as the Meelick spring, and will be referenced as such in this report. It is contained within a fenced-in area as well as a covered concrete chamber. The water is chlorinated at source and pumped on to a reservoir at Fairhill, approximately 2.6 km to the southwest. Overflow from the spring chamber is directed to an adjacent channel which flows northwest before joining the Castlegar River. Photographs of the spring and general points of interest are included in **Appendix A**.

4 Summary of Sources

Table 1 provides a summary of the Meelick spring. The average quantity of water abstracted from the Meelick spring was 2,000 m^3/d in 2010/2011. Abstraction records indicate that the spring is pumped for between 19 and 24 hours on most days and that the abstraction ranges from 1,600 to 2,400 m^3/d on any given day.

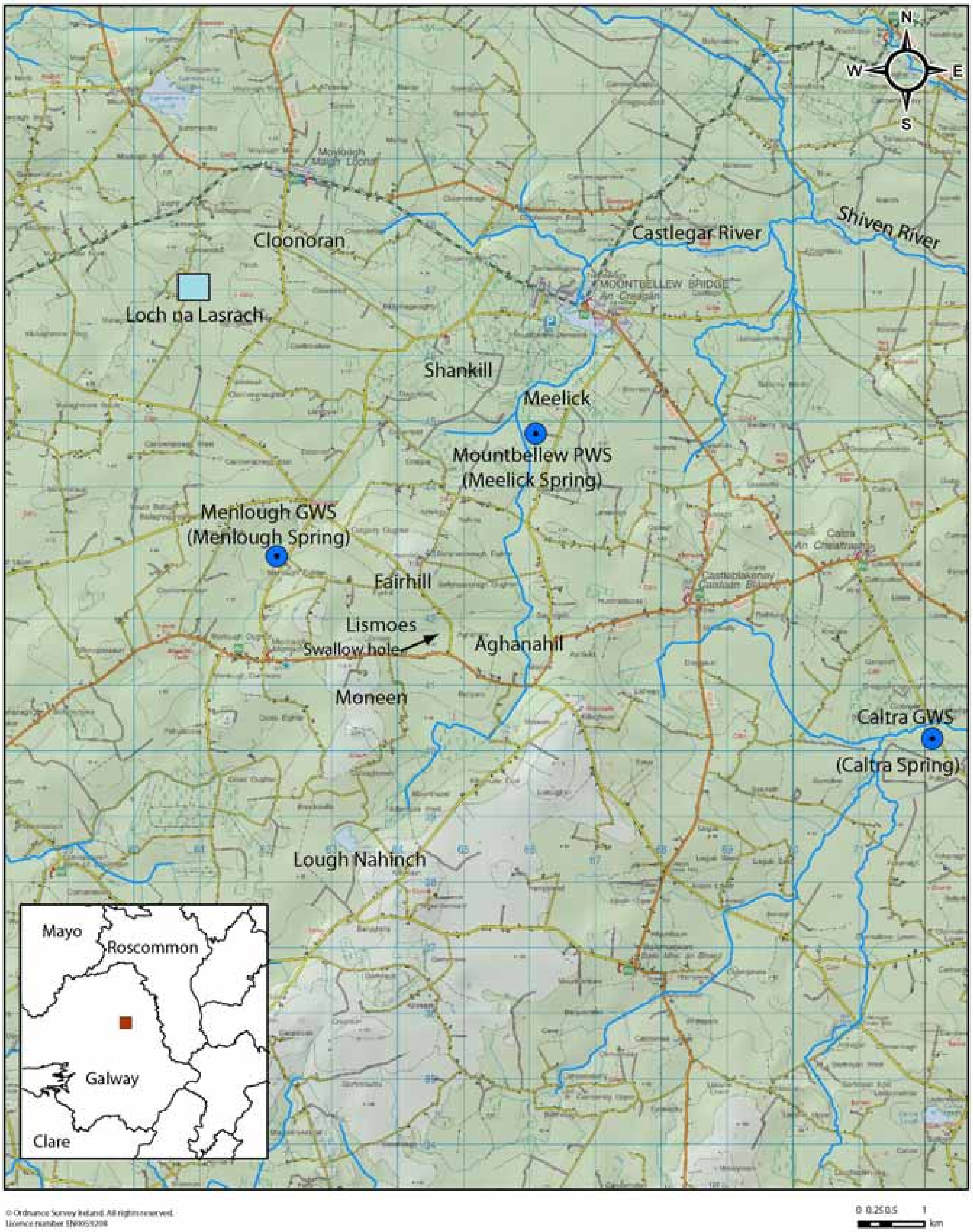


Figure 1: Location Map

Table 1: Spring Details

	Meelick Spring
Reporting Code	IE_SH_G_225_07_017
Groundwater Body	Suck South (IE_WE_G_0225)
Grid reference	166044, 244804
Townland	Mountbellew
Source type	Spring
Owner	Galway County Council
Elevation (Ground Level - GPS)	67 mOD
Depth of chamber	>2 m
Dimension of chamber	8 x 6 m
Depth to rock	Rock-close
Average daily abstraction (m^3/d):	2,000 (range 1,600-2,400)
Estimated discharge (m^3/d)*	7,530 (average)

Note:
** - May 2010 through July 2011, includes daily abstraction*

The overflow from the spring chamber is directed to a weir structure that is fitted with an automatic stage (level) recorder that has been monitored by the EPA since May 2010. By way of manual readings and a rating curve, the overflows have been estimated for the period between May 2010 and July 2011, as shown in **Figure 2.** During the monitoring period, the overflow ranged from virtually zero (no overflow) to approximately 462 l/s (39,917 m^3/d), with a mean discharge of 87 l/s (7,530 m^3/d). Except during prolonged dry weather conditions (such as those experienced in the summer of 2010), the abstracted quantity is relatively small compared to the total estimated discharge. The dry period experienced in the summer of 2010 is, according to the caretaker, unusual in that supply has rarely, if ever, experienced similar low-flow conditions since the PWS became operational. The fact that small overflows were recorded throughout the dry summer of 2010 indicates that the associated groundwater system has significant storage. On the other end of the scale, the upper limit or "capacity" of the Meelick spring to discharge water is not yet demonstrated (unfortunately, the existing weir was constructed after the extreme flooding events in November 2009).

The spring discharges are strongly influenced by rainfall events. **Figure 3** shows rainfall data from the nearest available rainfall station at Glenamaddy, approximately 15 km to the north of Mountbellew. **Figure 4** depicts cumulative rainfall and cumulative discharges from the Meelick spring between June 2010 and July 2011. The cumulative discharge graph shows a significant break in slope on September 6th, in response to the significant (51 mm) rainfall event that occurred on the same day. Following this event, the overflows increased rapidly from 4 l/s (345 m^3/d) to more than 150 l/s (12,960 m^3/d) in a 36-hour period.

Figure 5 shows details of the changes that occurred in water levels, estimated overflows, temperature and electrical conductivity (EC) as a function of the September 6th rainfall event. During a continuous monitoring period between 12:00 hrs on August 25th and 12:00 hrs on September 29th, a significant change in general spring behaviour occurred (started) on Day 12, corresponding to 09:00 hrs on September 6th. Prior to this time, water levels and overflows were low and steady. After this time, water levels and overflows rose quickly and in unison over the next 36 hours before starting to recede. This was followed by a sequence of similar rises and falls in water levels and overflows, each caused by individual rainfall events.

Following the September 6th rainfall event, the electrical conductivity (EC) response shows an approximate 36-hour time lag compared to the estimated overflows. In this lag time, an estimated 11,700 m^3 of water passed through the weir structure, and this volume represents (roughly) the water that was flushed out of storage. The instant decrease in EC from 727 μS/cm to 645 μS/cm marks the arrival of the flood pulse

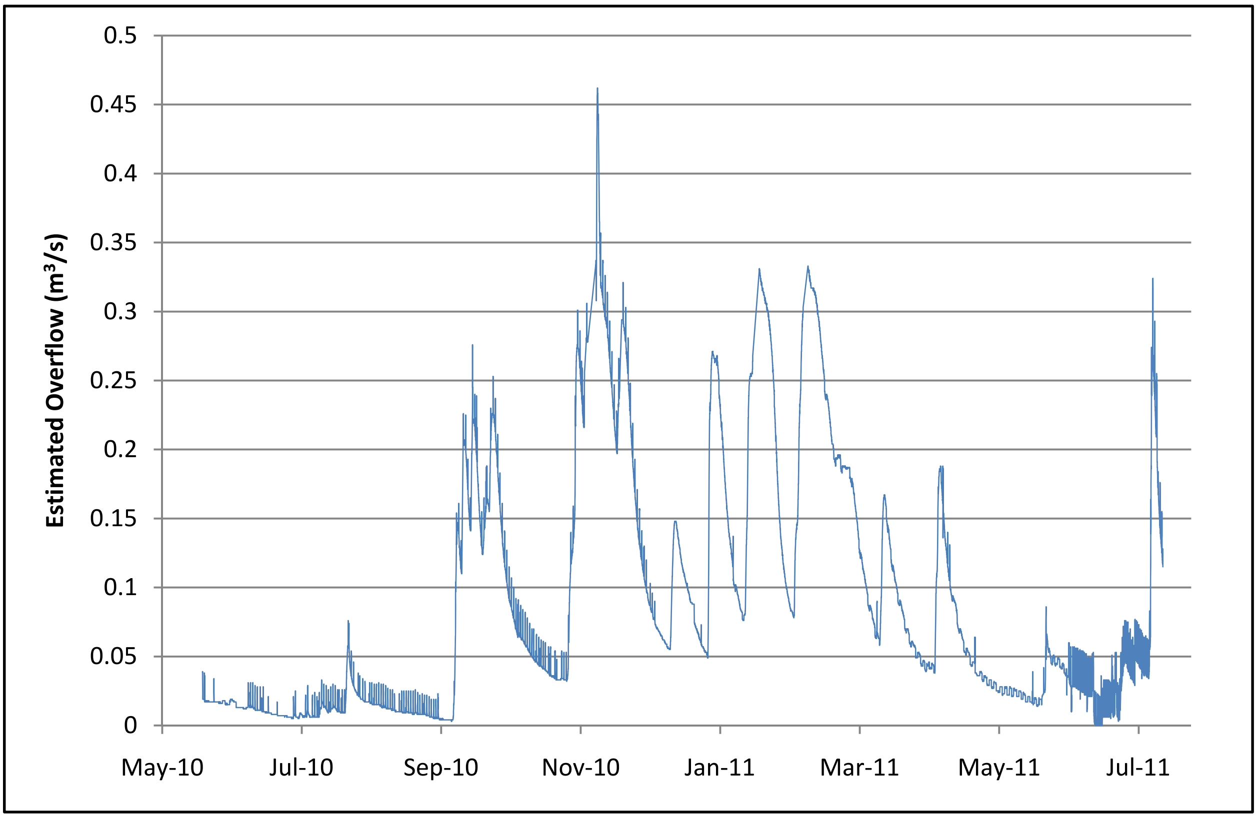


Figure 2: Estimated Overflow at the Meelick Spring

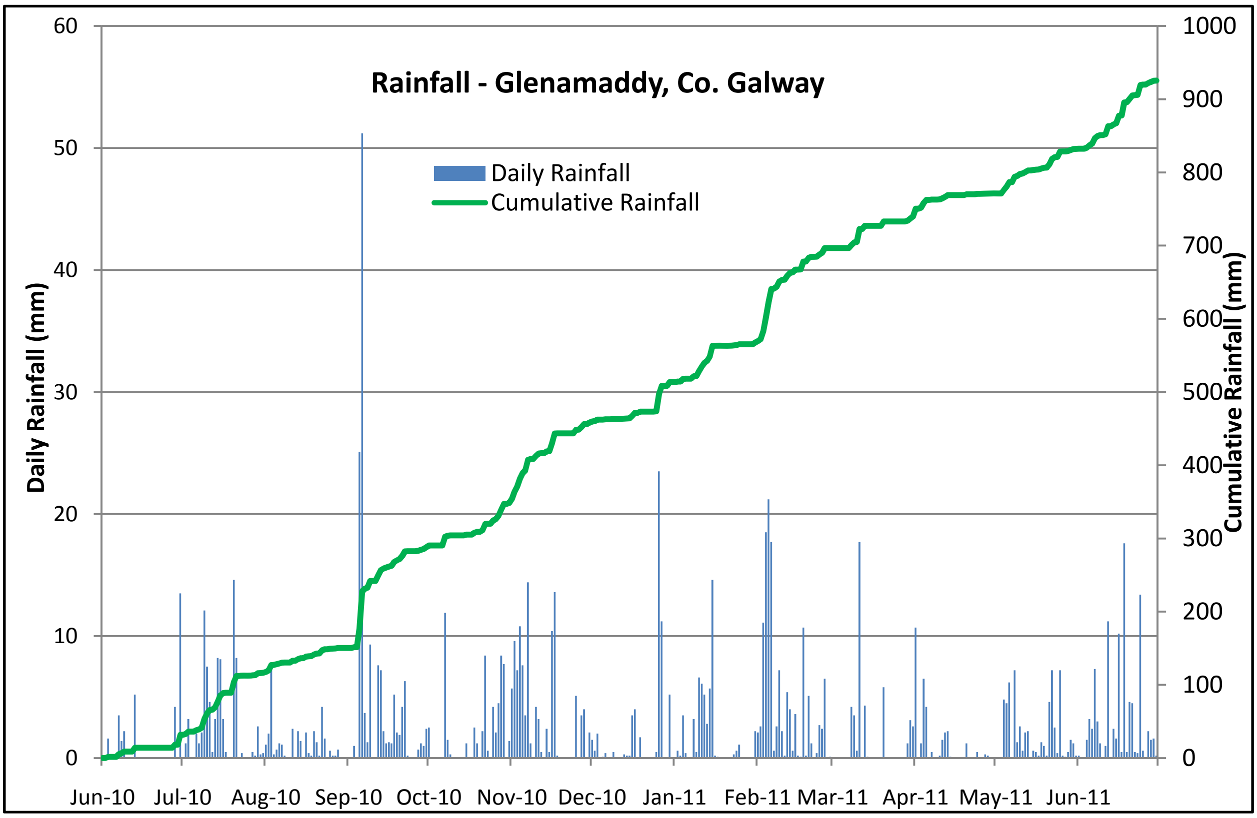


Figure 3: Daily and Cumulative Rainfall, June 2010 to July 2010

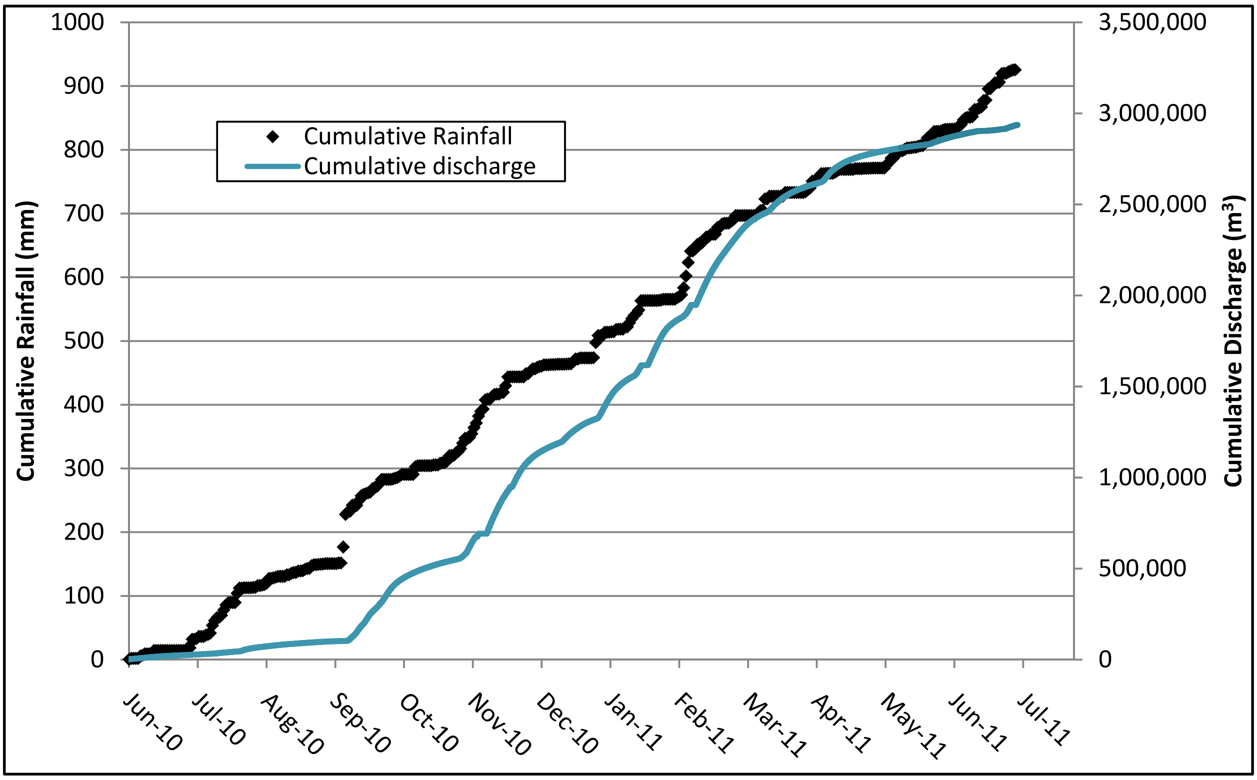


Figure 4: Cumulative Rainfall (Glenamaddy) and Cumulative Discharge (Meelick Spring)

through the karst system (*i.e.* the actual water that fell as rain in the September 6th storm event). The EC then fluctuates with a time-lag with subsequent flood pulses. Interestingly, over the remainder of the continuous monitoring period, the EC did not recover back to the same value that was measured pre-September 6th. The same is true for temperature, which increased with the arrival of the flood pulse. A similar behaviour was measured at the Marganure spring near Kilkerrin village (CDM, 2011).

4.1 Topography, Surface Hydrology, Landuse

The Meelick spring is located in the Shannon Basin River District, close to the border with the Western River Basin District. Regional drainage is to the east, towards the Suck River. Local drainage is to the north and east. The overflow from the Meelick spring is directed north toward the Castlegar River, which in turn joins the Shiven River (northeast of Mountbellew), and ultimately the Suck River. As such, the overflow from the Meelick spring is part of the headwaters of the Suck catchment.

The Meelick spring is located in a low-lying area surrounded by forest and peat to the west, north and east, and by agricultural (pasture) land to the south. Topography rises gently to the northwest towards Moylough and more steeply to the south towards Fairhill and Lough Nahinch (see **Figure 1**). The greatest topographic relief is in a southerly direction. Hills reach maximum elevations of approximately 110 mOD at Fairhill and Moneen, and 125 mOD near Lough Nahinch.

There are three unnamed streams that flow past Meelick Spring: one that originates as a spring at Cloonoran (near Moylough); one that originates in the raised peat area surrounding Lough Nahinch; and one that originates as small springs near the village of Menlough. Each of the streams also receives water from artificial drainage of surrounding land.

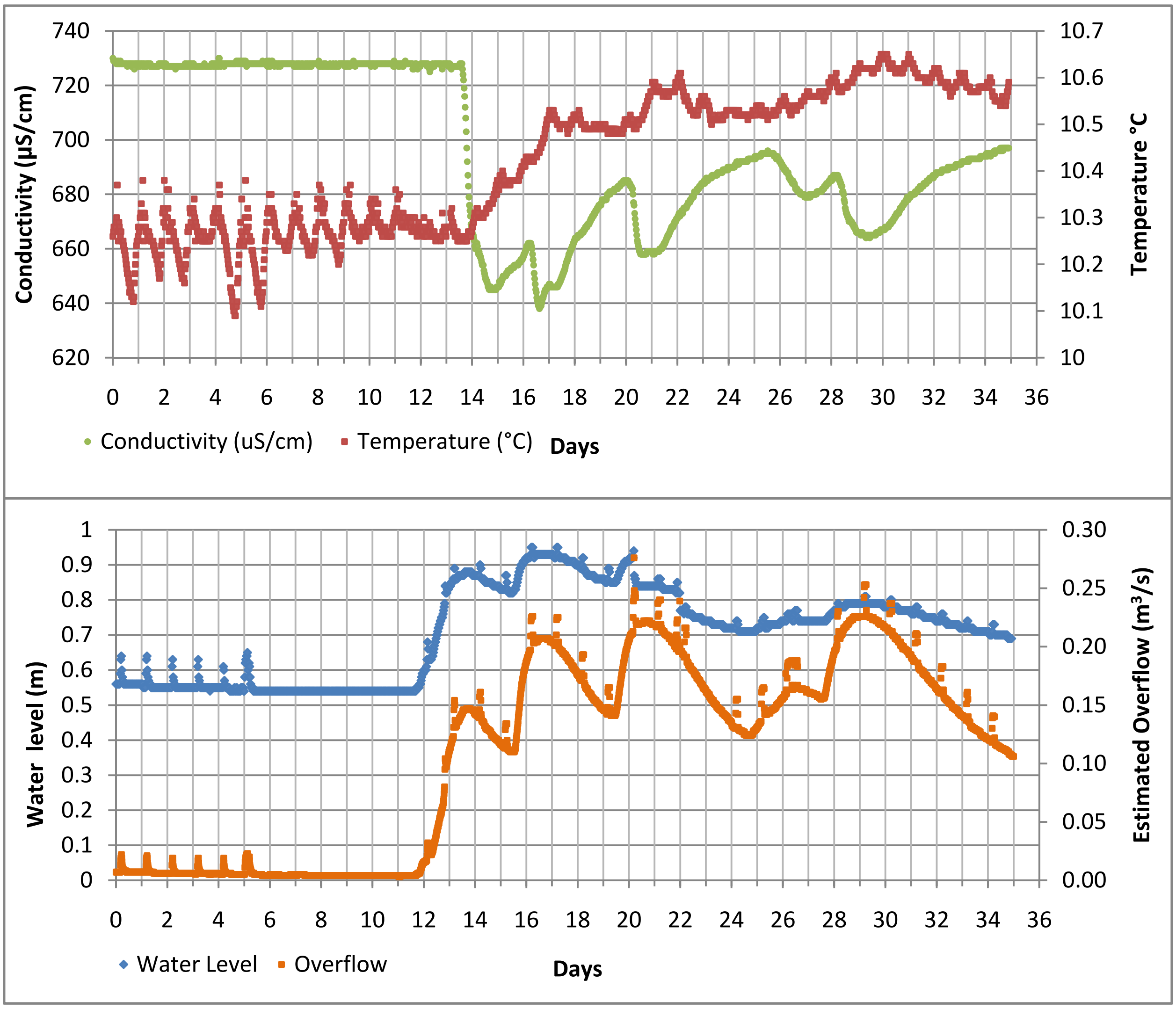


Figure 5: Detailed Measured Response to Rainfall Event on September 6th, 2010

A roughly E-W trending topographic depression occupies the area between Fairhill and Moneen (north-south) and Lismoes and Agahanhil (east-west). During and following significant rainfall events, the depression forms a "lake" which is drained by a swallow hole at Lismoes (see **Figure 1** and **Appendix A**). The "lake" collects surface runoff from surrounding hills and flow from both artificial drains and smaller seeps that appear on the southern slope of Fairhill during rainfall events. The filling of the topographic depression is usually quick (hours-days), whereas the draining (via the swallow hole) is slow (days-weeks). In some years, the lake remains a "constant" feature during the wet winter season. Some local residents refer to the lake as a turlough. Whether or not the swallow hole is behaving as an estavelle has not been conclusively determined.

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 (1057 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 briefly describes the relevant characteristics of the geological materials that underlie the area surrounding the PWS. 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 and karst features;
- Discussions with Markus Pracht of the bedrock section of the Geological Survey of Ireland.

6.1 Bedrock

As indicated in **Figure 6**, the bedrock in the immediate vicinity of the Meelick spring has been mapped by the GSI as Dinantian Pure Bedded Limestone. The closest outcrops at Fairhill consist of both thinly and massively bedded pale-grey and dark-grey limestones that dip gently (<10 degrees) to the north and northwest. Further east, near the village of Castleblakeny, dark-grey limestones dip gently (<5 degrees) to the east and southeast.

Summary logs of two boreholes located immediately adjacent to one another at Lismoes (see **Appendix B** and **Figure 6**) describe a uniform dark grey limestone to drilled depths of approximately 100 m. The limestone is inferred to represent the "Calp" (Hydro-G, 2007). Although Dinantian Upper Impure Limestone of the Lucan Formation ("Calp") has been mapped by the GSI immediately south of Lismoes and to the east of Caltra, the reported absence of shales and muddy limestone from the two boreholes (see **Appendix B**) could imply that the dark-grey limestone observed at Lismoes/Aghanahil may be part of a different formation than the Lucan (e.g. representative of a facies change in the Burren Formation).

In the same referenced boreholes, significant water strikes were reported at depths of 94 mbgl in one borehole and 105 mbgl in the other. The geological descriptions for these these depths (see **Appendix B**) are consistent with the boreholes having intersected a fault or, alternatively, sediment-filled karst conduit(s) –

> "very weathered limestone, orange clays of weathered rocks, angular cobbles and gravels, weathered limestone gravels with sandstone appearances".

A NE-SW trending fault has been mapped by the GSI (see **Figure 6**) in the same immediate vicinity (*i.e.* near Aghanahil, passing less than 1 km east of the swallow hole at Lismoes).

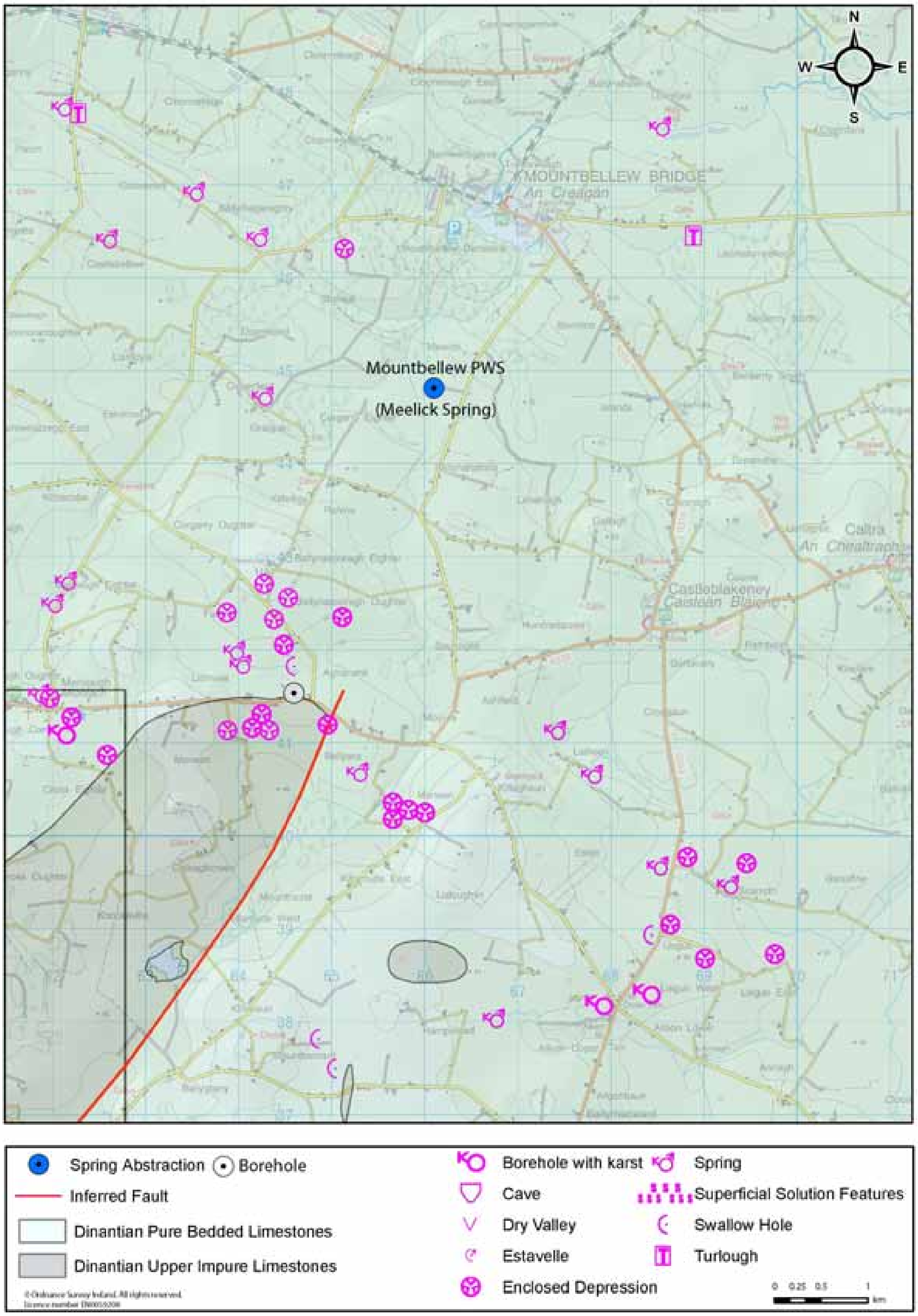


Figure 6: Bedrock/Rock Unit and Karst Features Map

6.2 Karst Features

As indicated in **Figure 6**, numerous karst features have been mapped as part of this study (see also **Appendix C**). The mapping was conducted during walkover surveys to identify potential recharge areas and injection points for dye tracing purposes (see Section 8.2). Only areas at a higher elevation than Meelick spring were surveyed. Karst features that have been identified include enclosed depressions/dolines and swallow holes. Much of the area surrounding Meelick spring is covered by thick subsoils and so karst features are not apparent in immediate vicinity of the spring.

6.3 Depth to Bedrock

Depth to bedrock varies significantly across the general study area. Bedrock is exposed on the hills to the south (e.g. Fairhill) and in the direction of Castleblakeny. Closer to Meelick, bedrock is covered by several metres of glacial till. The position of Meelick spring in a peaty area is of geological curiosity given the absence of outcrops at the spring location. Subsoil sampling and 2-D resistivity surveys were conducted to try and identify depth to bedrock and general subsoil characteristics near the spring. Unfortunately, 2-D resistivity profiles could not be generated at the spring location itself due to the presence of nearby sources of electrical interference. Nonetheless, survey lines were run within 100 m of the spring at the margins of the forest that surrounds the spring (see also **Appendix D** and Section 9). Results indicate that depth to bedrock increases from 5 m at the edge of the forest to more than 12 m in the peat areas of Shankill. The trend is for greater subsoil thickness away from the spring. he 2-D resistivity surveys indicate that the top of few metres of bedrock are extensively weathered, with one profile indicating the potential presence of deep karstic weathering of the limestone to 20 m depth.

6.4 Soil and Subsoil Geology

Mapped soils within the study area, see **Figure 7**, include deep, well drained mineral soils (BminDW) at higher elevations and shallow peaty soils on lower ground. Mapped subsoils, see **Figure 8**, consist primarily of cutover peat (cut) and glacial till (TLs) derived from underlying limestones. The cutover peat occupies low-lying areas near Meelick spring. Other subsoil types mapped in the study area are pockets of esker deposits to the west and Holocene lacustrine marls to the south (in the direction of Lismoes).

Window sampling to 4 m depth in vicinity of the Meelick spring indicated clayey subsoil with a mixed content of silt, sand and gravel, consistent with interpretations of 2-D resistivity profiles (see **Appendix D**) which define the till as either gravelly CLAY or clayey GRAVEL. Subsoil permeability, as mapped by Teagasc, is low and moderate across the area.

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 Mountbellew 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 Co. Galway has been developed by the GSI. As shown in **Figure 9**, vulnerability is Extreme across the hills to the south where bedrock is exposed or estimated to be within 1 m of the ground surface. An exception is the raised bog area surrounding and just north of Lough Nahinch, where vulnerability is Low on account of low permeability subsoil and peat. The vulnerability in lower-lying areas generally range from High to Low, reflecting the variable nature of subsoil types and depths to bedrock. In the immediate vicinity of the main spring, vulnerability is mapped as Moderate and Low.

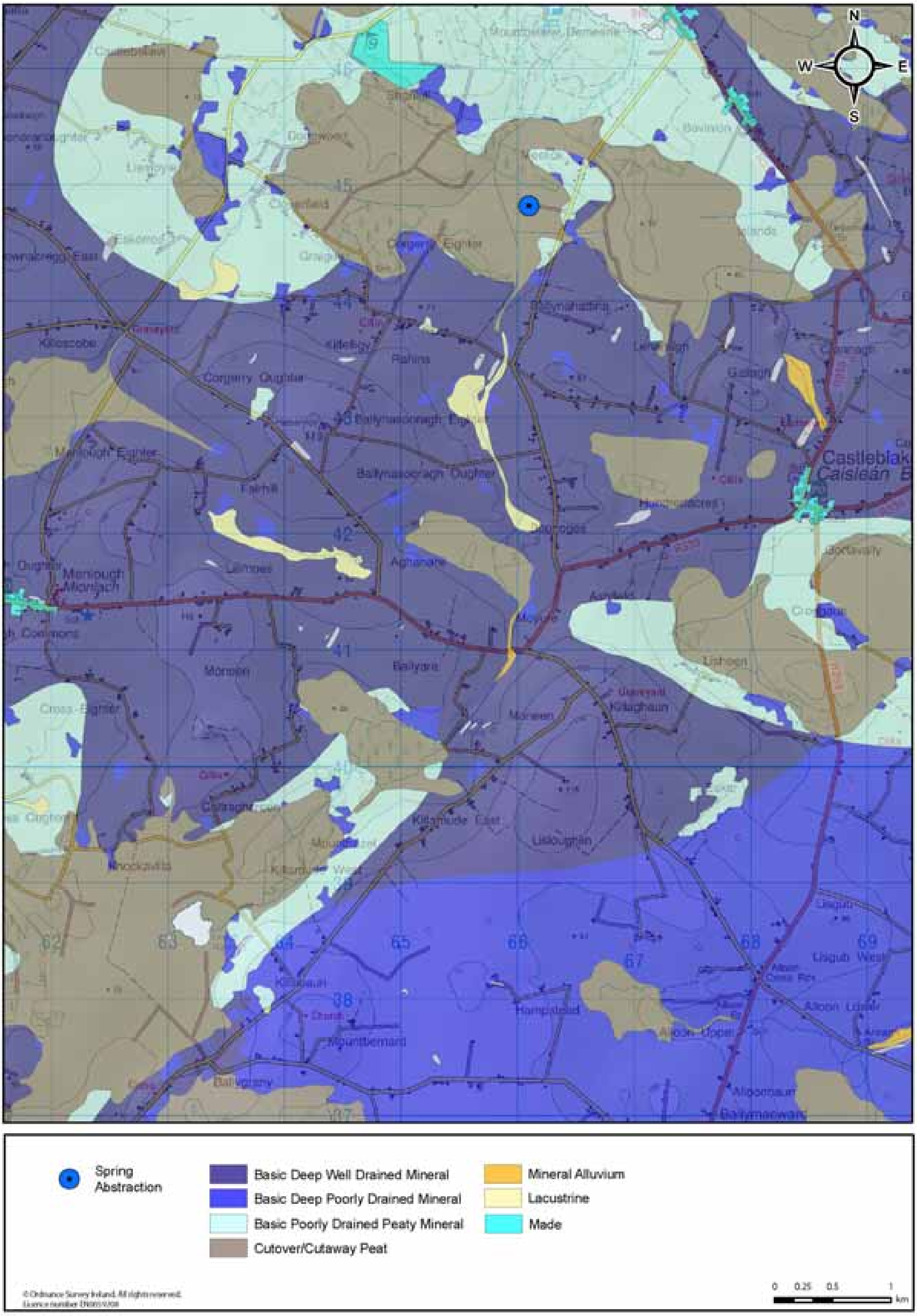


Figure 7: Soils Map

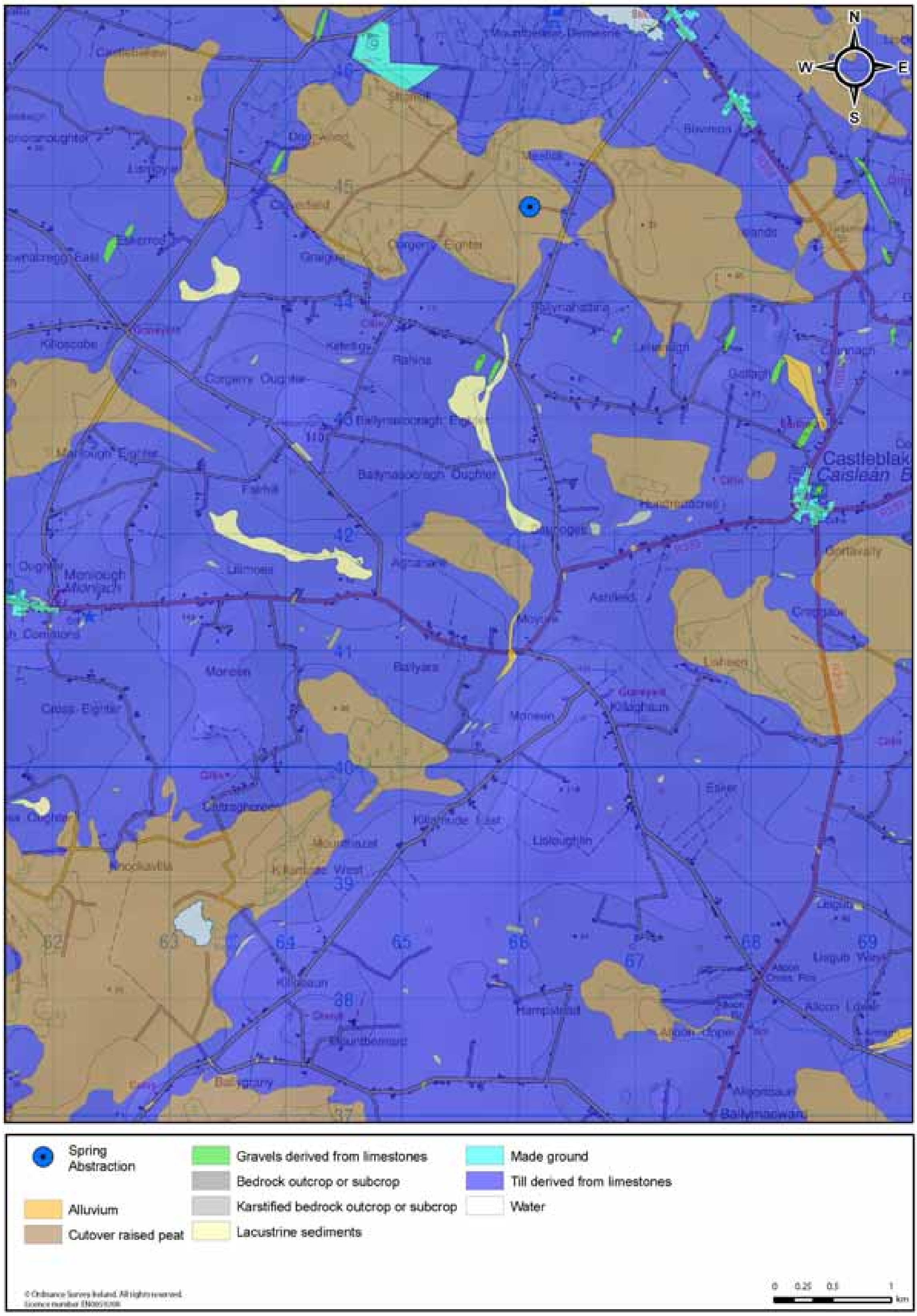


Figure 8: Subsoils Map

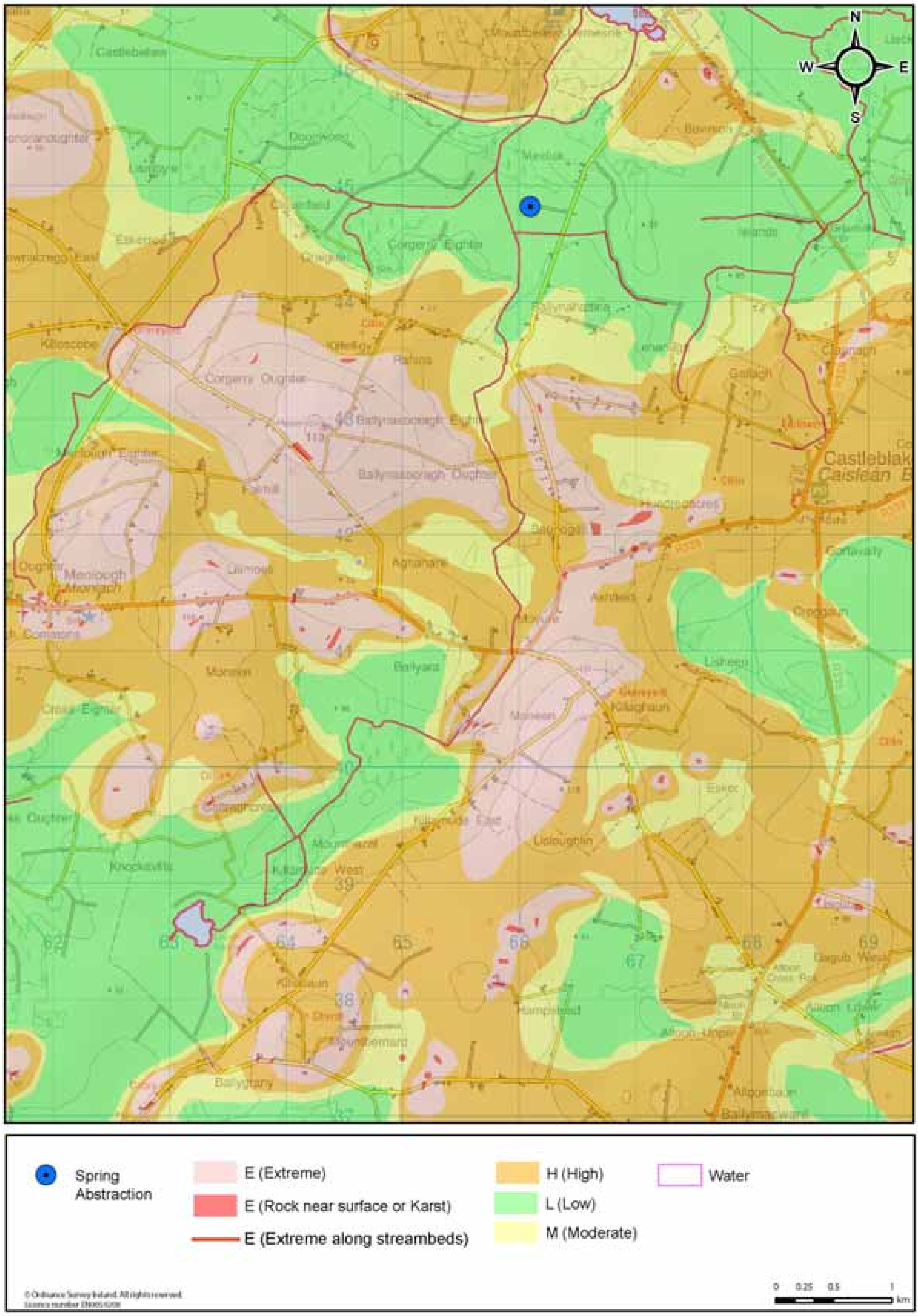


Figure 9: Groundwater Vulnerability Map

8 Hydrogeology

This section describes the current understanding of the hydrogeology in the vicinity 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 Suck South groundwater body (GWB) which has been classified by the EPA as being of "Good" status. 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 are expected to dictate flow patterns, directions and rates. These vary in space and may also vary in time in line with different hydrometeorological conditions. General topographic and drainage considerations suggest that groundwater flow will generally be from south to north, with a possible influence also from the west.

To establish flow directions, travel times, and zones of contribution(s), 6 dye tracer tests were conducted from 6 dye injection locations between June 2010 and April 2011, specifically targeting the Meelick spring. As summarised in **Appendix E**, only one test, from the swallow hole at Lismoes, was positively traced to the Meelick spring. The other tests are summarised as follows:

- One test from a swallow hole at Moylough Castle, 6.2 km to the NW of Meelick spring did not result in tracer detection at Meelick, but resulted in confirmed traces to springs near Danganbeg, 9 km SW of Moylough.
- One test from a swallow hole at Loch na Lasrach (see **Figure 1**), 5.7 km to the WNW of Meelick spring also did not result in tracer detection at Meelick, but resulted in confirmed traces to the springs near Danganbeg and Brierfield South, 8 km SW of Moylough.
- One test from a swallow hole in Annaghmore, 2.5 km to the N of Moylough village did not result in any positive detections at any of the locations sampled, including Meelick.
- One test from a swallow hole near Caltra village, 5.8 km to the ESE of the Meelick spring did not result in any positive detections at any of the locations sampled, including Meelick.
- One test from a swallow hole at Lisgub, 6.2 km to the SE of the Meelick spring did not result in any positive detections at any of the locations sampled, including Meelick.

From these results, it is inferred that the main groundwater catchment of the Meelick spring is due SSW of the spring, associated with the swallow hole at Lismoes. This southern area is, therefore, included in the inferred zone of contribution (ZOC) to the spring (see Section 9). The NNE flow direction established is in sharp contrast with the demonstrated SW flow directions established for the water supply schemes of Mid-Galway, Barnaderg, and Brierfield (CDM 2011a), and the inferred easterly flow direction associated with Caltra (CDM 2011b).

8.3 Hydrochemistry and Water Quality

The Mountbellew PWS has been monitored semi-annually by the EPA between 1995 and 2006, and 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 near the main spring, prior to chlorination. 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 10 to 13**, representing up to 36 samples in total (through 2009), and results are highlighted as follows:

- The water is hard (average 367 mg/l $CaCO_3$). The average field conductivity is 703 μS/cm with a range between 507 and 787 μS/cm. The average field pH is 6.9 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 14 mg/l with a mean of 8 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 24 mg/l with a mean of 18 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.

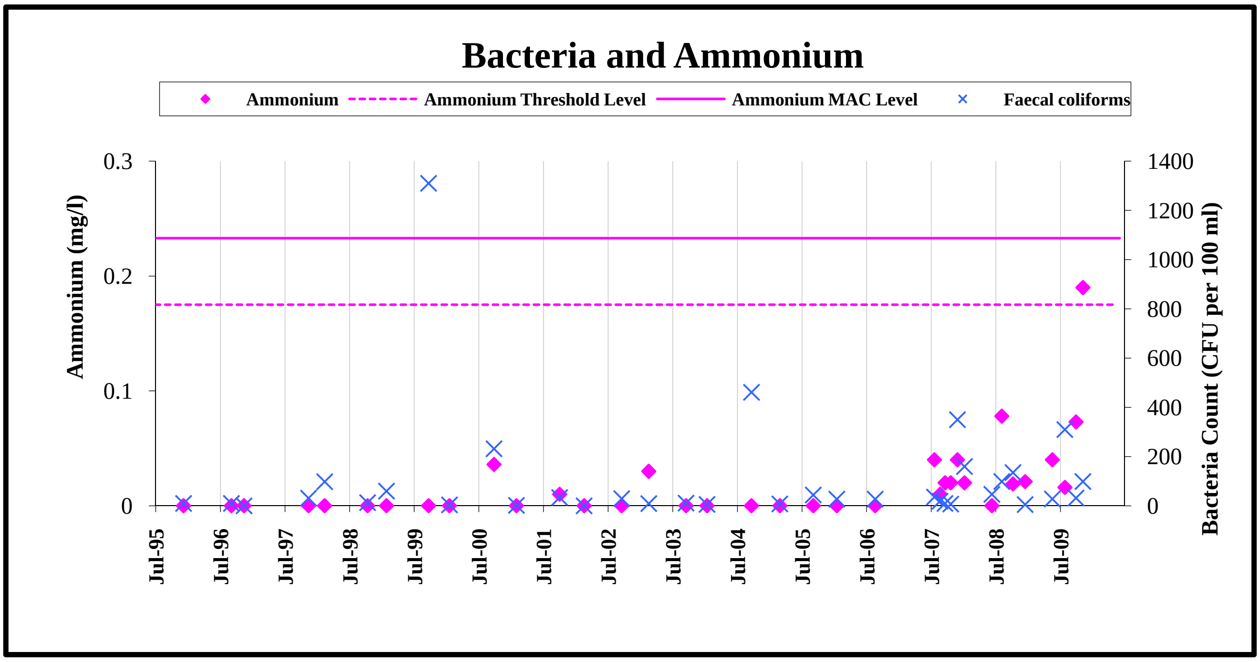
- The mean concentration of Molybdate Reactive Phosphate (MRP), or orthophosphate, is 0.025 mg/l (as P), which is below the EPA status Threshold Value for "Good" groundwater status of 0.035 mg/l P. However, between 2000 and 2006, concentrations generally exceeded the threshold. Since 2006, there has been a marked improvement in related concentrations (see **Figure 13**).

- There have been several exceedances of relevant threshold values for both iron and manganese, particularly in the period 2000 through 2006.

- The sulphate, magnesium and calcium levels 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.

- The concentrations of all other trace metals are low and/ or below laboratory detection limits.

- There has been one detection 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 also below respective laboratory limits of detection.



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

Figure 10: Bacteria Counts and Ammonium Concentrations

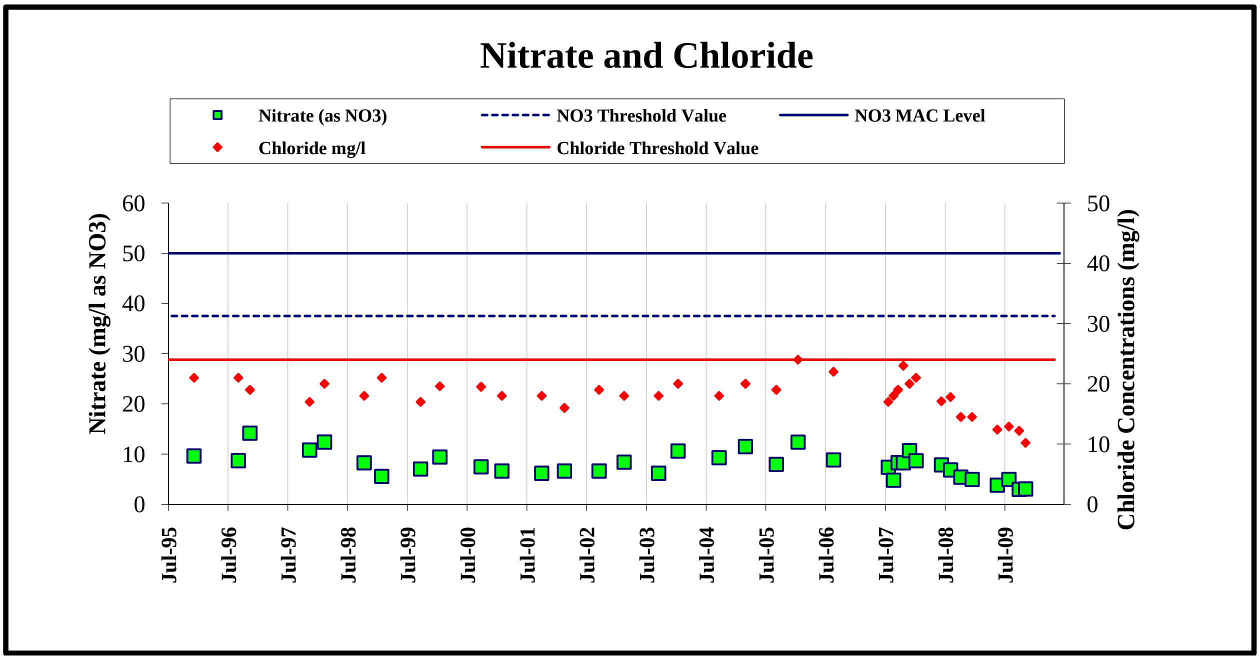
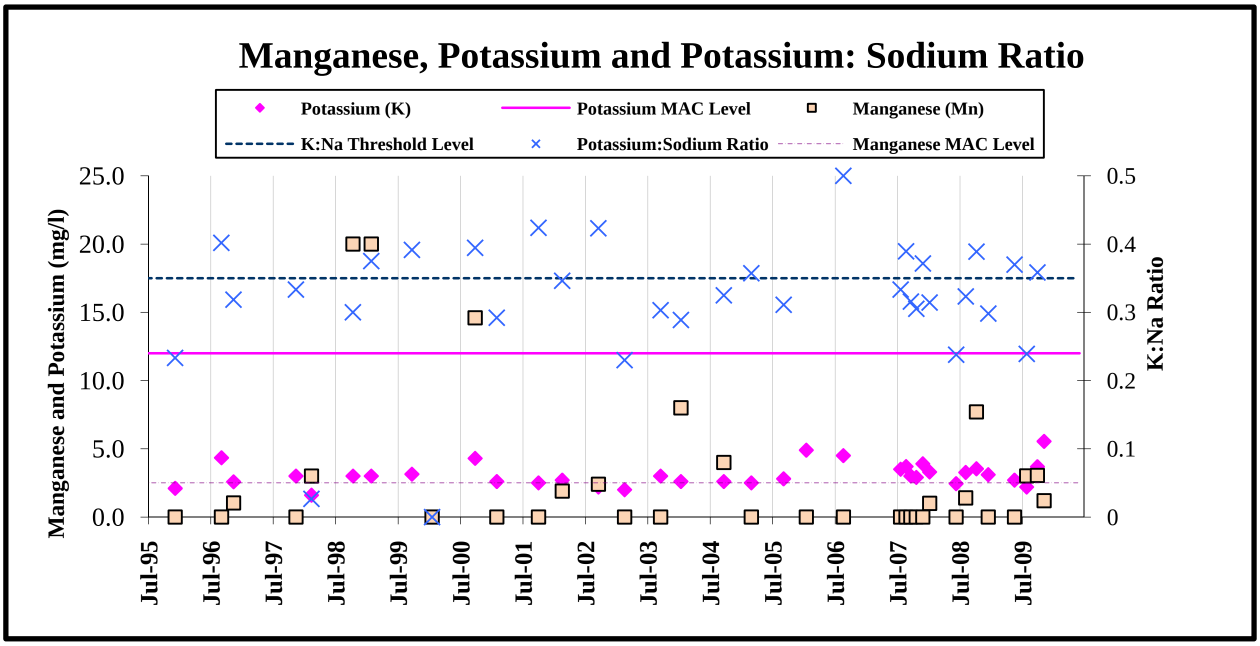
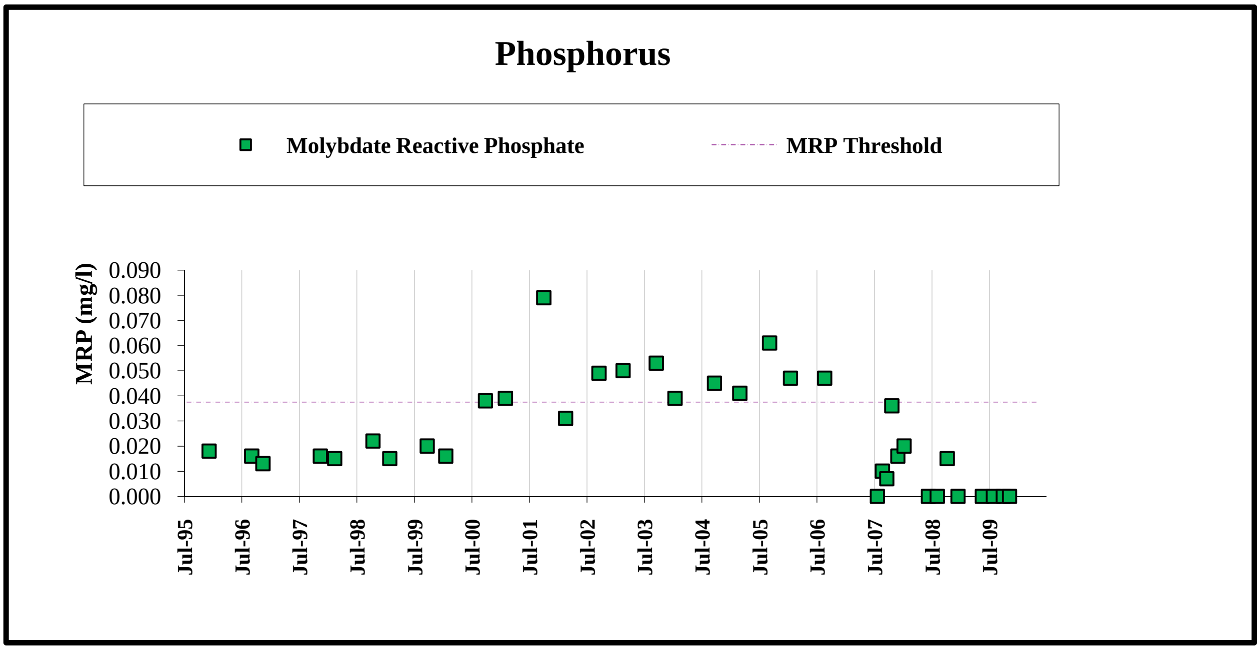


Figure 11: Nitrate and Chloride Concentrations



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

Figure 12: Manganese and Potassium Concentrations and K/Na Ratios



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

Figure 13: MRP Concentrations

In summary, groundwater quality at the PWS is generally good, although there are periodic impacts from bacteriological contamination. A slight 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 Mountbellew PWS. The established link between the swallow hole at Lismoes and Meelick spring is 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.* A flow rate of 1,700 m/d through the karst system has been established from the tracer test at Lismoes. The associated flow gradient between the Lismoes swallow hole and Meelick spring is 0.004. Recharge to the karstic aquifer within the study area takes place primarily in the exposed bedrock areas of Fairhill, Lismoes and Moneen. Where exposed, the epikarst (the upper, more fractured and weathered zone in karstified rocks) appears to be well developed.

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, whereas the *shape* of the ZOC is controlled by groundwater flow directions and gradients, as well as subsoil and rock 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 Meelick spring are provided in **Figures 14 and 15.** Meelick spring discharges from a karstified limestone aquifer in which groundwater flows via fissures, fractures and conduits. The primary flow gradient is from the south to the north, with an established SSW-NNE connection between a swallow hole at Lismoes and the spring at Meelick. This swallow hole drains shallow groundwater and surface water which collects in a topographic depression between Lismoes and Moneen. As well, two small overflow springs appear near Fairhill during wet weather events, and their combined discharges (max. estimated 20 l/s) drain overland to the swallow hole at Lismoes.

Besides the swallow hole, recharge to the groundwater system also occurs diffusely and at other specific points that are represented by dolines and, potentially, sections of streams that lose water to the underlying aquifer. The relative quantities that recharge diffusely and at point locations are not known. However, the proportion of diffuse recharge is undoubtedly significant. Recharge rates are highest where subsoils are thin or absent and lowest where subsoils are thick and/or comprise low permeability sediments. Higher recharge rates are therefore associated with the elevated areas surrounding Fairhill and Moneen, and the lowest recharge rates would be associated with the peat areas of Meelick, Shankill, and Lough Nahinch. In exposed bedrock outcrop areas, the epikarst appears to be well developed which facilitates and concentrates vertical percolation of water. Shallow groundwater flow in the epikarst will generally follow topographic gradients. The epikarst may be less developed or absent beneath some areas that are covered by thick till, as calcareous tills can buffer the pH of infiltrating water.

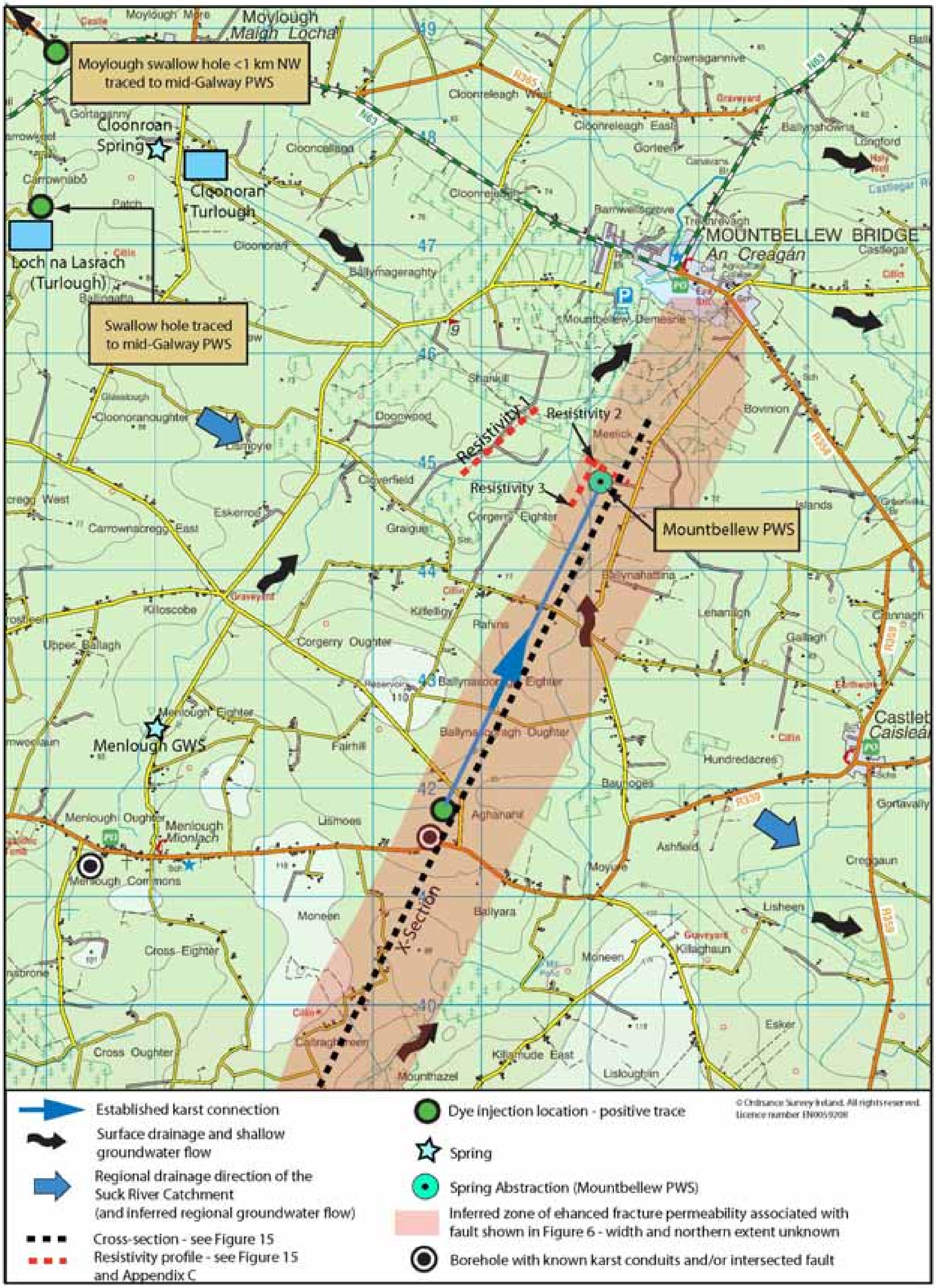


Figure 14: Conceptual model – plan map

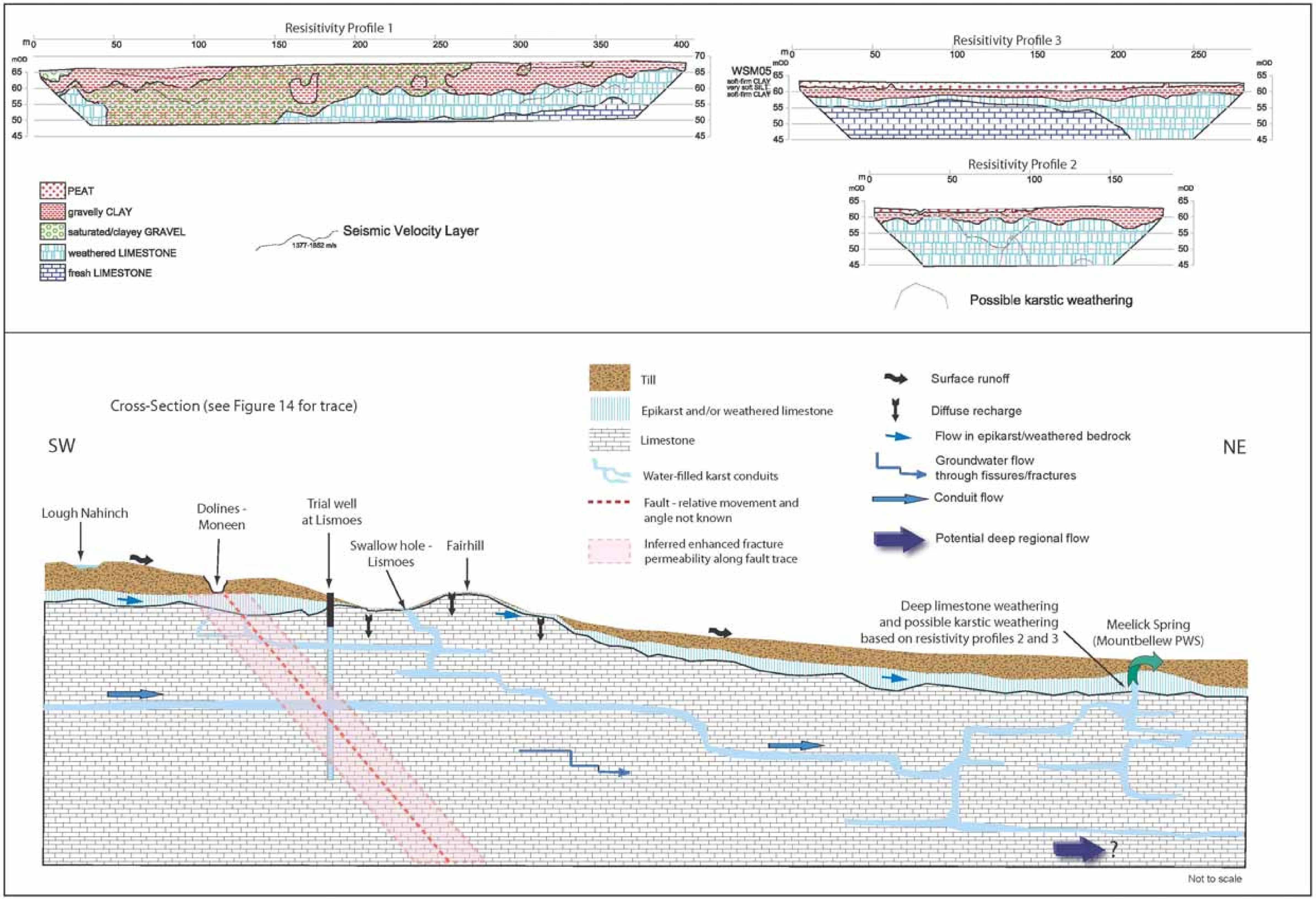


Figure 15: Conceptual model – cross-section

As evidenced by continuous flow monitoring at Meelick Spring, the aquifer system responds rapidly to rainfall. Flood pulses are evident as changes to measured discharges, water levels and chemistry (*i.e.* as indicated by electrical conductivity). Groundwater flow velocities in the karst conduits are high (1,700 m/d measured from the swallow hole at Lismoes) and because of the combination of high flow velocities and the Extreme groundwater vulnerability to the south, both the aquifer generally and the Mountbellew PWS specifically are susceptible to pollution, with little or no attenuation potential for contaminants in the subsurface (other than by dilution).

The established NNE flow direction is inferred to be influenced by enhanced fracture permeability. Existing mapping by the GSI suggests that a SW-NE trending fault may run through the study area, and combined with potential fault breccias observed in two boreholes at Lismoes, there are indications that groundwater flow may, in part, be structurally influenced or controlled.

To the NW of Meelick spring, glacial deposits more than 10 m thick overlie bedrock and drain shallow groundwater from Cloonoran and Moylough towards the peat areas of Shankill and Meelick. These deposits may provide storage and contribute a small proportion of water to the spring, particularly during extended dry weather periods (such as the summer of 2010). Resistivity surveys in the Meelick and Shankill areas indicate that the top few metres of bedrock are extensively weathered, adding to potential storage properties in the subsurface environment at these locations. The smaller seeps and springs that appear in the area between Cloonoran and Meelick are believed to be related to shallow groundwater flow in the glacial deposits (e.g. buried meltwater channels) and the epikarst.

9.2 Boundaries

Groundwater flows to the Meelick spring by gravity and all areas at a higher elevation than the spring are potentially within the ZOC. The delineated ZOC, shown in **Figure 16**, was developed from a combination of tracer test results, topographic interpretations, and water balance considerations (see Section 9.3). The ZOC has been divided into two parts: a ZOC with higher confidence (HC) and a ZOC with lower confidence (LC). The HC ZOC covers the catchment area of the swallow hole at Lismoes (which has been traced to the spring) and the areas of High and Extreme groundwater vulnerability near Fairhill and Moneen (where recharge rates are inferred to be highest, see Section 9.3). The LC ZOC includes a broader area that is needed to support the higher measured spring discharges described in Section 4. The LC ZOC is extended in a southerly direction rather than a westerly direction on the basis of three main observations:

- The general trend of geological structures, which is believed to influence flow patterns, is SSW-NNE;
- Springs are present to the west and require their own contributing areas to account for respective discharges – the largest of these are: a) the source of the Menlough GWS; and b) the spring feeding the “Cloonoran Turlough”, near Moylough village (see **Figure 1**).
- Dye tracer materials injected in swallow holes at Moylough Castle and Loch na Lasrach, both situated on higher ground to the west (see **Figure 1**), were traced to in a south-westerly direction towards Danganbeg.

In **Figure 16**, the **northern boundary** is defined by topography and the relatively thick, low permeability subsoils around Meelick Spring (whereby the Low vulnerability areas around the spring have been excluded from the ZOC). The **southern boundary** is similarly shaped by low permeability subsoil and peat, in this case excluding Low vulnerability areas along the SW-NE trending valley that stretches from Lough Nahinch to Ballyara just south of Aghanahil. The southern boundary incorporates Extreme and High groundwater vulnerability areas associated with two topographic ridges that broadly follow the general structural trend of geological features, and that extend as far south as Lough Nahinch. The **eastern boundary** is marked by topography, allowing eastward drainage towards smaller springs that are present south of Castleblakeney, notably at Lisheen and Hampstead/Aloon, and that give rise to streams that flow towards the Clonbrock River. The **western boundary** is similarly guided by topography and drainage patterns, including the recognition that both the Menlough and Cloonoran springs require contributing areas to account for respective discharges.

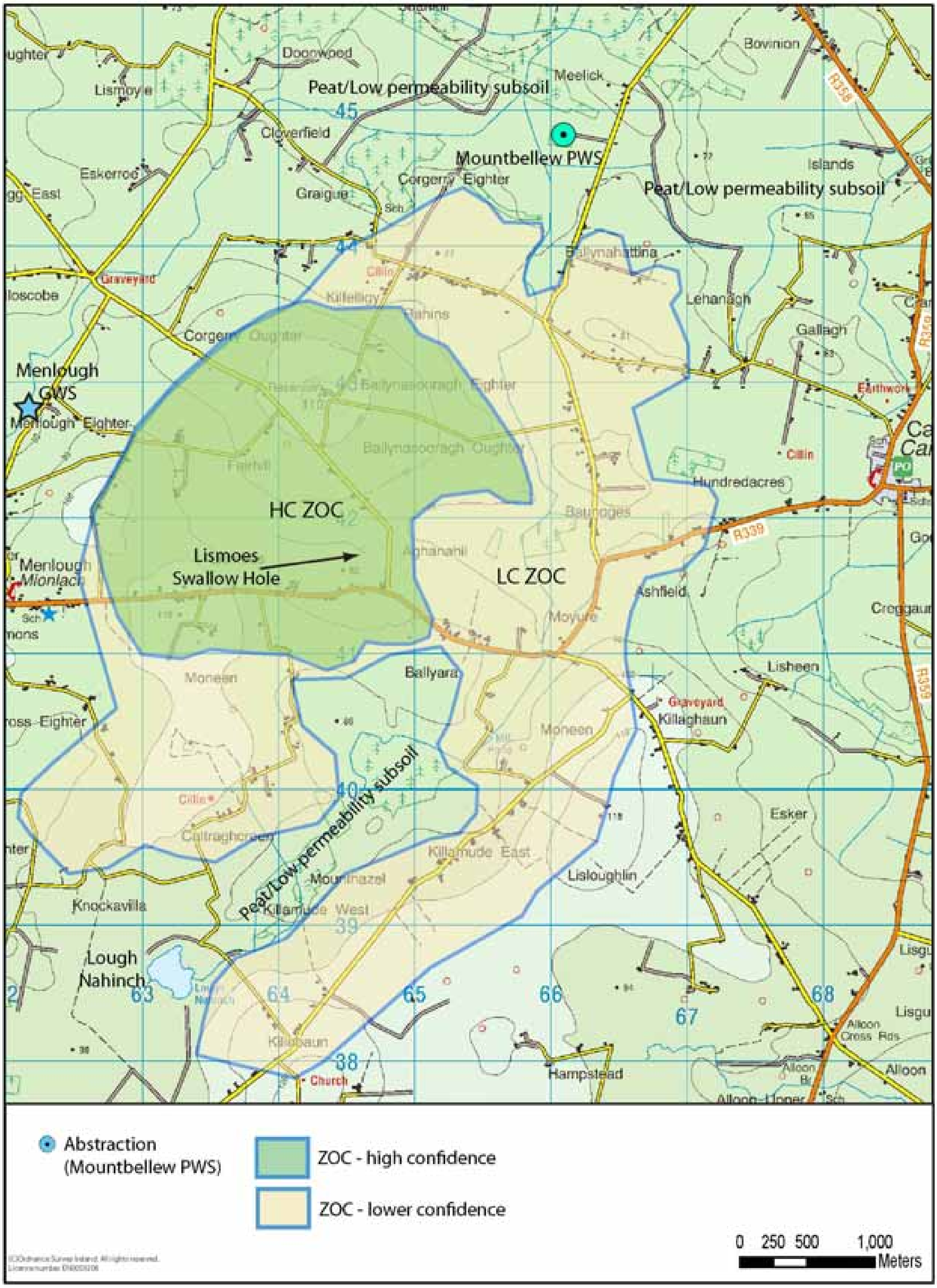


Figure 16: Estimated Zone of Contribution

9.3 Recharge and Water Balance

The term 'recharge' refers to the amount of water that replenishes the groundwater flow system. In the catchment area of the Meelick spring, recharge occurs both diffusely (distributed over wider areas) and at specific points (swallow holes and dolines). Although recharge cannot be measured directly, it can be 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 and recharge is important in source protection delineation, 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 Meelick spring 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 around Fairhill, an R_c of approximately 90% can be expected (i.e. 90% of effective rainfall infiltrates into the groundwater system). To support the average measured discharge of 7,530 m^3/d at Meelick spring, a 5 km^2 area of Extreme vulnerability would be needed. An estimated 3.9 km^2 area, centered on Fairhill, is actually available, but this is supplemented by additional areas of High and Moderate vulnerability that also contribute to recharge and that are part of the same catchment which marks the HC ZOC shown in **Figure 16.** Given the general catchment characteristics, an area-weighted recharge coefficient (R_c) of 78% is considered reasonable for the 5.9 km^2 area of the HC ZOC. Using the meteorological statistics in Section 5, the average annual recharge over the HC ZOC is estimated to be 473 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 (65% of HC ZOC)	90%
Rc for High vulnerability areas (32% of HC ZOC area)	60%
Rc for Moderate vulnerability areas (3% of HC ZOC)	40%
Bulk recharge coefficient for HC ZOC	78%
Annual recharge rate	473 mm

It follows that the remaining 22% of the water balance is represented by surface runoff. Such runoff is generated within the catchment as witnessed during storm events in November 2010 and February 2011. The runoff flows to the topographic depression near Lismoes and point locations such as dolines in the same general vicinity before draining underground.

A recharge rate of 473 mm/yr equates to 7,645 m^3/d over the HC ZOC, which is nearly equivalent to the 7,530 m^3/d average measured discharge at Meelick Spring over the measurement period. The measured average discharge can, therefore, be accounted for by the recharge conditions defined above.

For peak discharges, averages can rarely if ever be used. This is especially true for karstic aquifers where recharge mechanisms and rates are part of a hydrological continuum that changes continuously between extreme end members. To account for higher discharges, additional contributing area is needed. That area is defined by the LC ZOC in **Figure 16**, and is inferred to extend south rather than west for reasons described in Section 9.2. The potential extent of contributions from the south (and west) have not yet been fully tested and would require additional study, including tracer testing from point locations on the topographic ridges on either side of Lough Nahinch. As well, expanded and detailed event-based measurements would be needed to quantify existing known or suspected water entry points as well as the hydraulic understanding of local streams and surrounding springs.

10 Source Protection Zones

The Source Protection Zones are a landuse planning tool which enables an objective, geoscientific assessment of the risk to groundwater 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). As demonstrated by the tracer tests, a flow velocity of 1,700 km/d have been recorded from the karst at Meelick, which means that, once in the conduit system, pollutants can reach the PWS within 24-36 hours from the main recharge areas at Lismoes, Moneen, and Fairhill. For this reason, the entire ZOC is defined as an SI. This is especially critical in the High and Extreme vulnerability areas, and within the catchment of the swallow hole at Lismoes.

The resulting groundwater Source Protection Zones are shown in **Figure 17**. Within the HC ZOC, nearly all of the SI is designated as SI/Extreme (total 65%) or SI/High (32%), the remainder 3% being SI/M. Within the total combined HC and LC ZOC areas, SI designations are as follows:

- SI/X: 1.0% of total ZOC area
- SI/E: 40.2% of total ZOC area
- SI/H: 43.4% of total ZOC area
- SI/M: 15.4% of total ZOC area

11 Potential Pollution Sources

Potential sources of groundwater pollution within the ZOC are associated with farmyards, landspreading of slurry, livestock grazing close to dolines and swallow holes (generally), as well as onsite wastewater treatment systems (OSWTS). The nearest farmyard to the swallow hole at Lismoes is about 200 m away, and there are several OSWTS within a 500 m of the same feature.

12 Conclusions

The Meelick Spring discharges water from a karstified limestone aquifer in which groundwater flows through fissures, fractures and open conduits that facilitate rapid transport of water. The primary contributing area to the Meelick Spring is the catchment area of the swallow hole at Lismoes and the topographic depression that extends roughly E-W in the area between Fairhill and Aghanahil. Water entering the swallow hole at Lismoes

has been traced directly to the Meelick spring. Spring discharges at Mountbellew are reasonably well quantified over the referenced measurement period, and range significantly from an estimated minimum 2,000 m^3/d to an estimated maximum 40,000 m^3/d, and an average of about 7,500 m^3/d. The ZOC is primarily to the south of the spring. Results from tracer testing have demonstrated a karst conduit system from the SSW to the NNE, possibly influenced by enhanced fracture permeability associated with geological faulting.

Apart from the immediate area surrounding Fairhill, Moneen and Aghanahil which includes the catchment of a swallow hole at Lismoes, there is uncertainty about contributing areas to the spring. For this reason, the ZOC of the Meelick Spring has been divided into areas of high confidence and lower confidence. The high confidence areas have been delineated on the basis of geological observations, topographic interpretations, and dye tracer testing. The lower confidence areas represent additional, potential contributing areas that are needed to support water balance calculations. The total ZOC area considered is 18.1 Km^2.

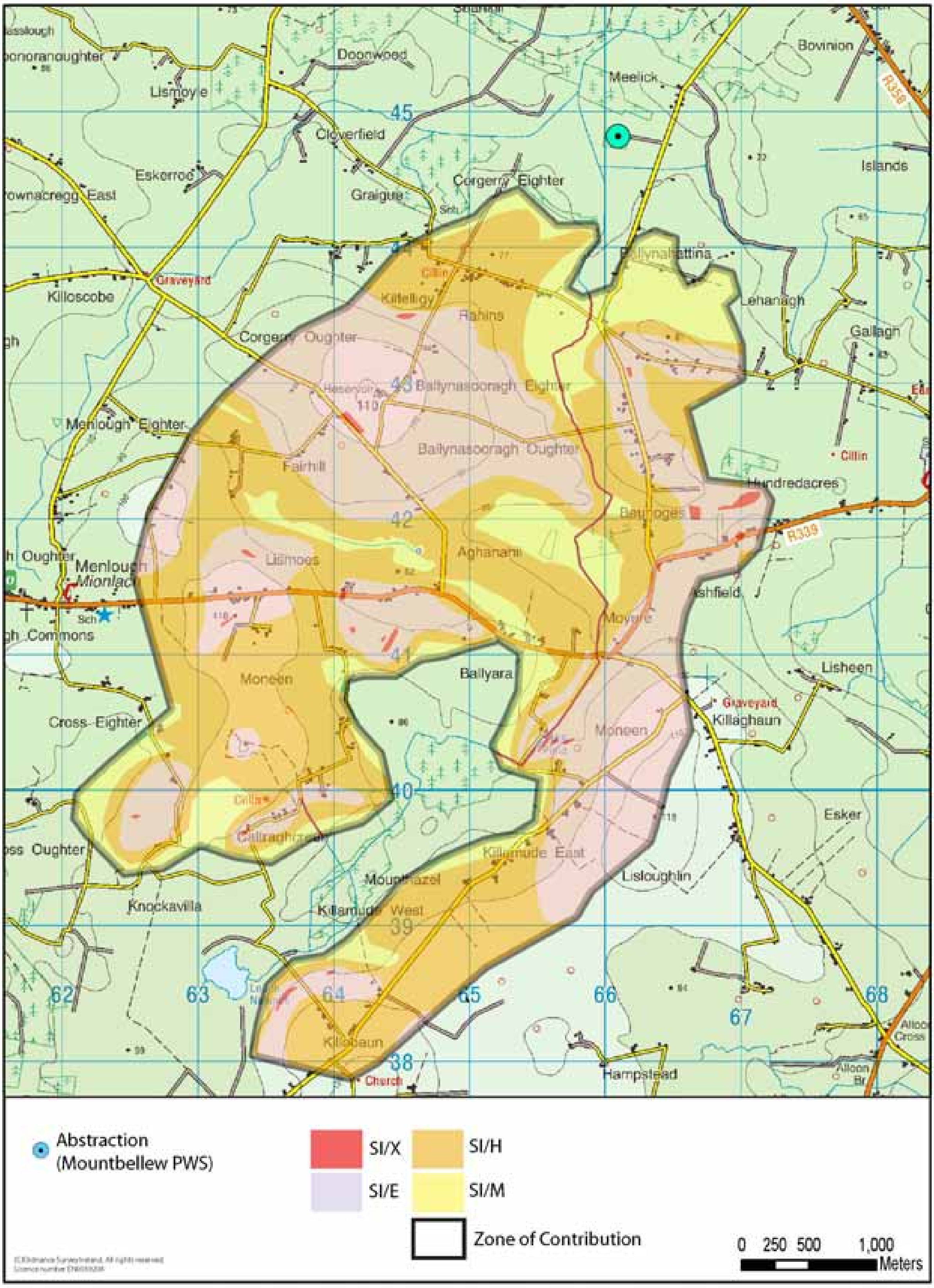


Figure 17: Source Protection Zones

Groundwater flow and ZOCs in karst aquifers are difficult to predict and will change in line with hydrometeorological conditions. Consequently, the ZOC delineation presented herein is mainly guided by average conditions (rainfall, recharge and discharge). Some degree of uncertainty with boundaries will always exist, and at the present time, the greatest uncertainties associated with the ZOC to the Mountbellew PWS are related to the extents of the southern and western boundaries, as well as the exclusion of areas of Low groundwater vulnerability. The majority of water is considered to be recharged from Extreme and High vulnerability areas, but it cannot be entirely ruled out that Low vulnerability areas will also contribute some water to the spring.

Water quality data from the Meelick spring shows historical and periodic evidence of contamination by organic waste sources. Groundwater quality is especially vulnerable to pollution in the surface catchment of the swallow hole at Lismoes. The greatest risk of pollution appears to be associated with farmyards, landspreading of slurry, livestock grazing near point locations of groundwater recharge, and possibly also private onsite wastewater treatment systems.

13 Recommendations

Given the vulnerability of the Mountbellew 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 spring water quality.

To verify and/or improve the present understanding of the ZOC boundaries, particularly the LC ZOC, detailed event-based measurements of key hydrological features should be carried out in an expanded study area to include streams and drainages around Menlough, Lisheen, Aloon, as well as the area between Menlough and Moylough (e.g. at Cloonoran Turlough). Karst mapping should equally be expanded into areas to the south of Lough Nahinch (which marked the southern extent of the study area that is considered in this report). Where relevant karst features are identified, these should be tracer tested to include monitoring at Meelick spring as well as several other spring sources in the area, including the group water schemes of Menlough and Caltra as well as the small springs at Lisheen and Hampstead/Aloon.

14 References

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

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

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. South Suck 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.

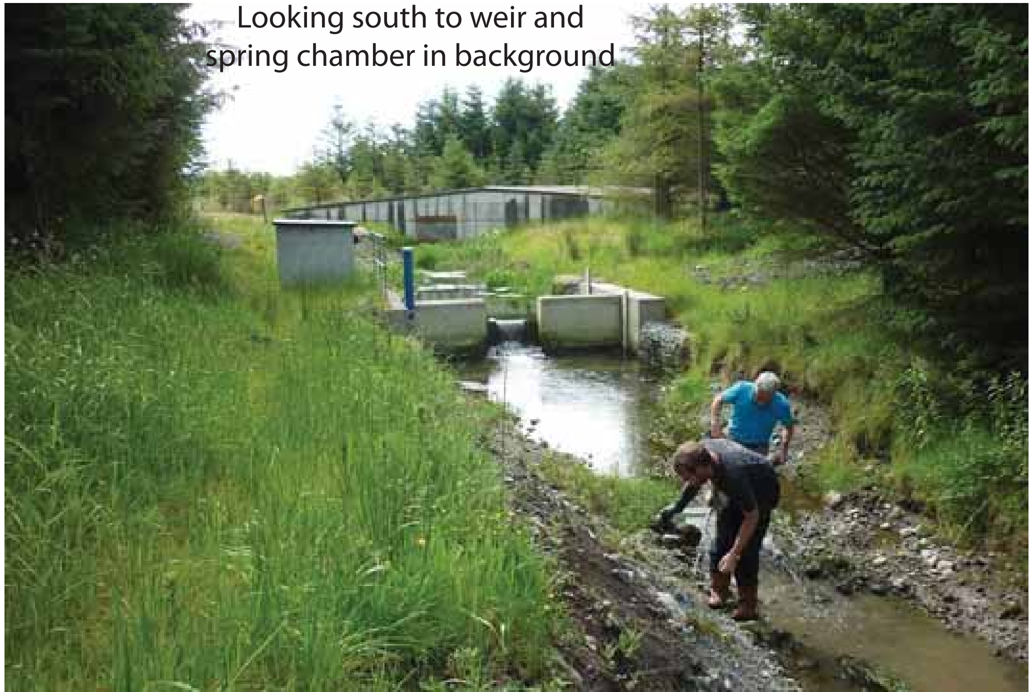
Hydro-G, 2007. Hydrogeological Report and Pumping Test Results for the Proposed Group Water Scheme, Menlough, Co. Galway. Final Report. Prepared for Ryan Hanley Engineers, Galway.

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.

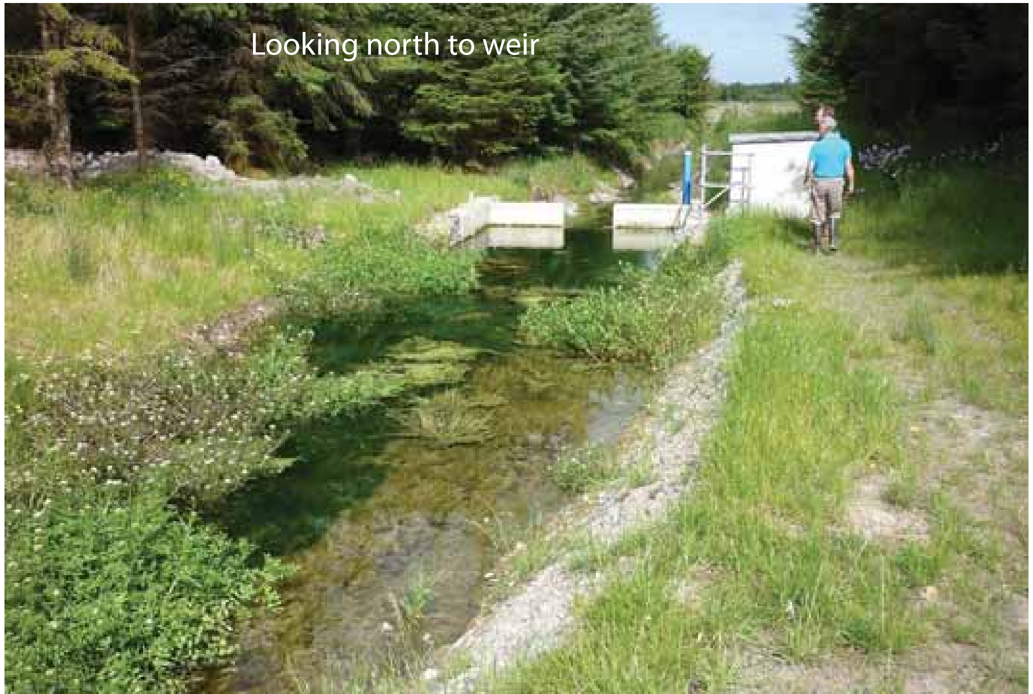
Morris, J.H., Somerville, I.D. and MacDermot, C.V. (2003) Geology of Longford-Roscommon: A geological description of Longford-Roscommon, and adjoining parts of Cavan, Leitrim and Galway to accompany the Bedrock Geology 1:100,000 Scale Map Series, Sheet 12, Longford-Roscommon.

APPENDIX A

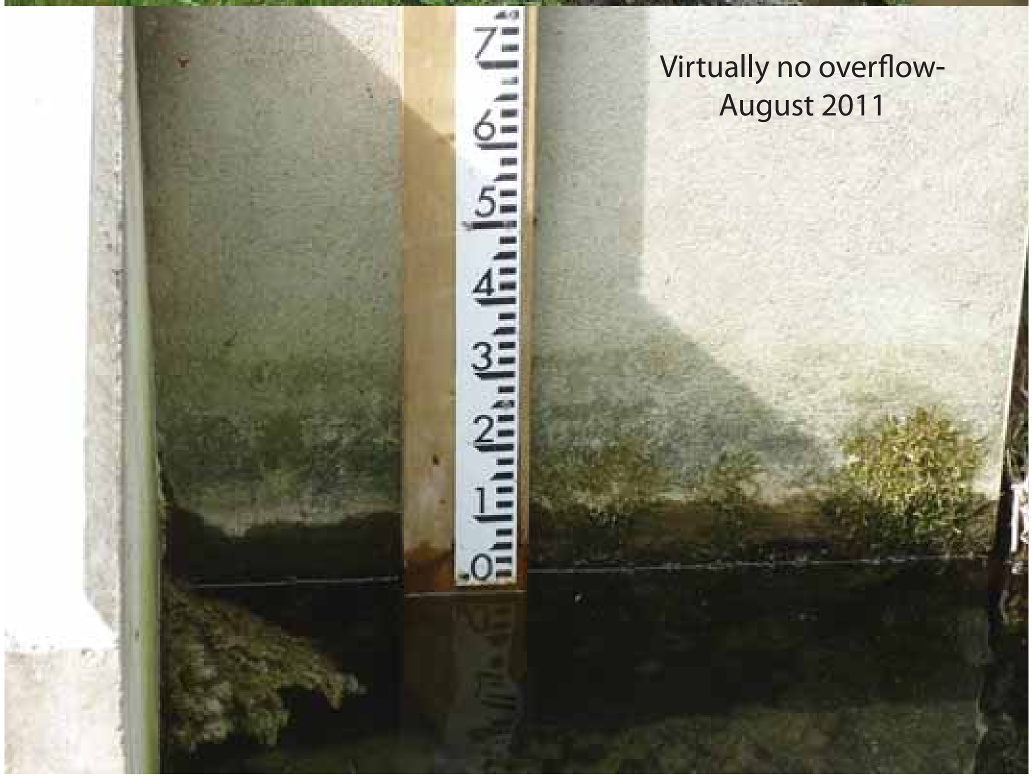
Photographs



Looking south to weir and spring chamber in background

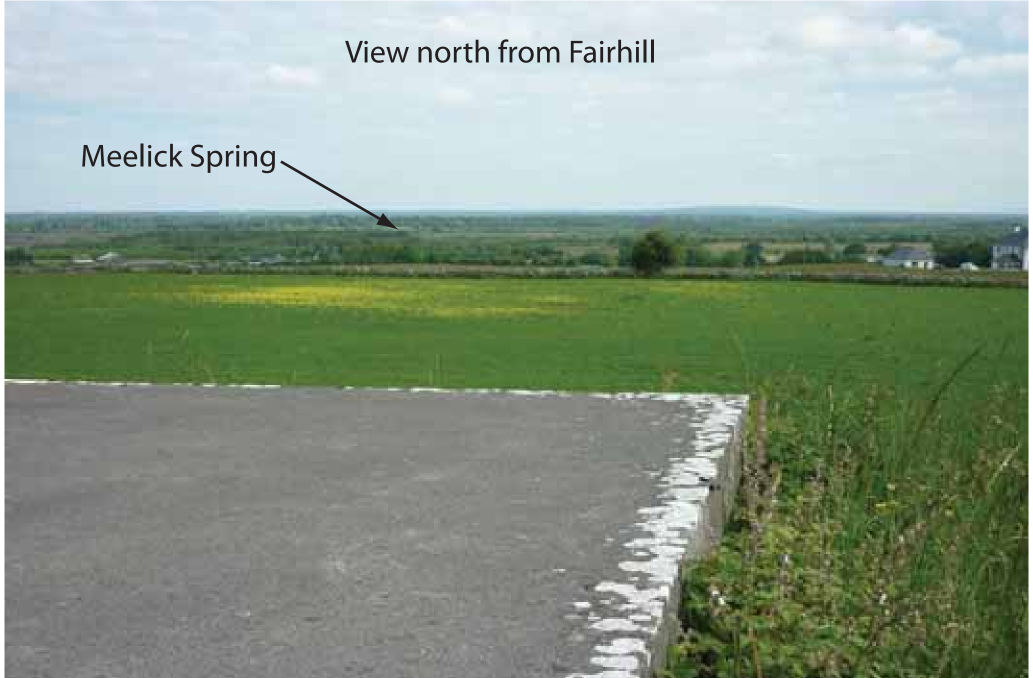


Looking north to weir



Virtually no overflow- August 2011

Looking west to second spring chamber



View north from Fairhill


Small spring at Fairhill
(drains to swallow hole at Lismoes)


Swallow hole - Lismoes (dry conditons)


Swallow hole - Lismoes (flooded)

Doline at Moneen

Trial Wells-Lismoes

Clayey Sand at Shankill/Meelick

Peat surrounding Lough Nahinch

Coarser sediment at Shankill/Meelick

APPENDIX B

Borehole Logs (from Hydro-G, 2007)

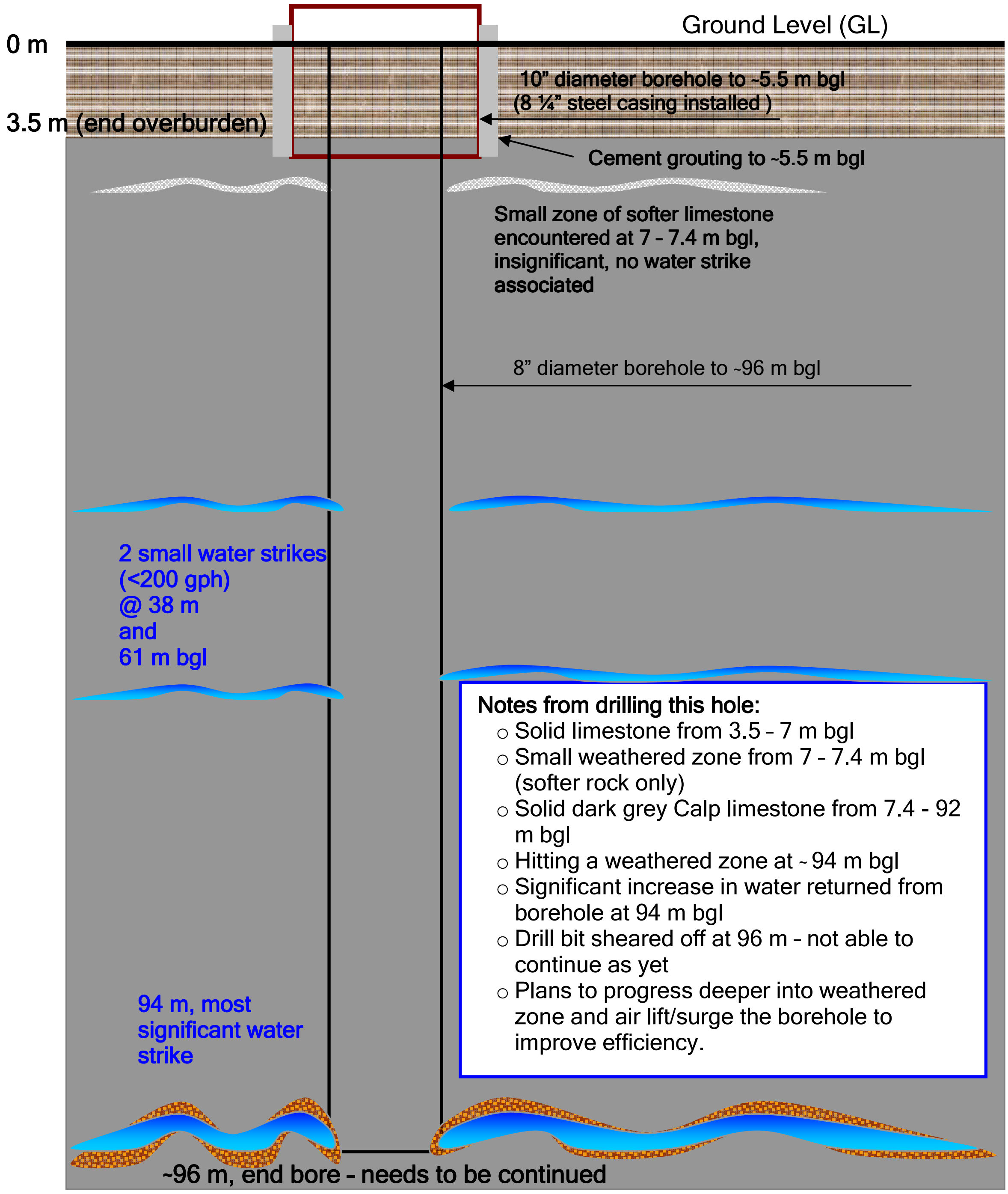


Figure 3 Schematic (not to scale) of Menlough 8” borehole at Menlough, Co Galway.

Menlough GWS Production Water Supply Borehole - Drilled 24th & 25th October 2007

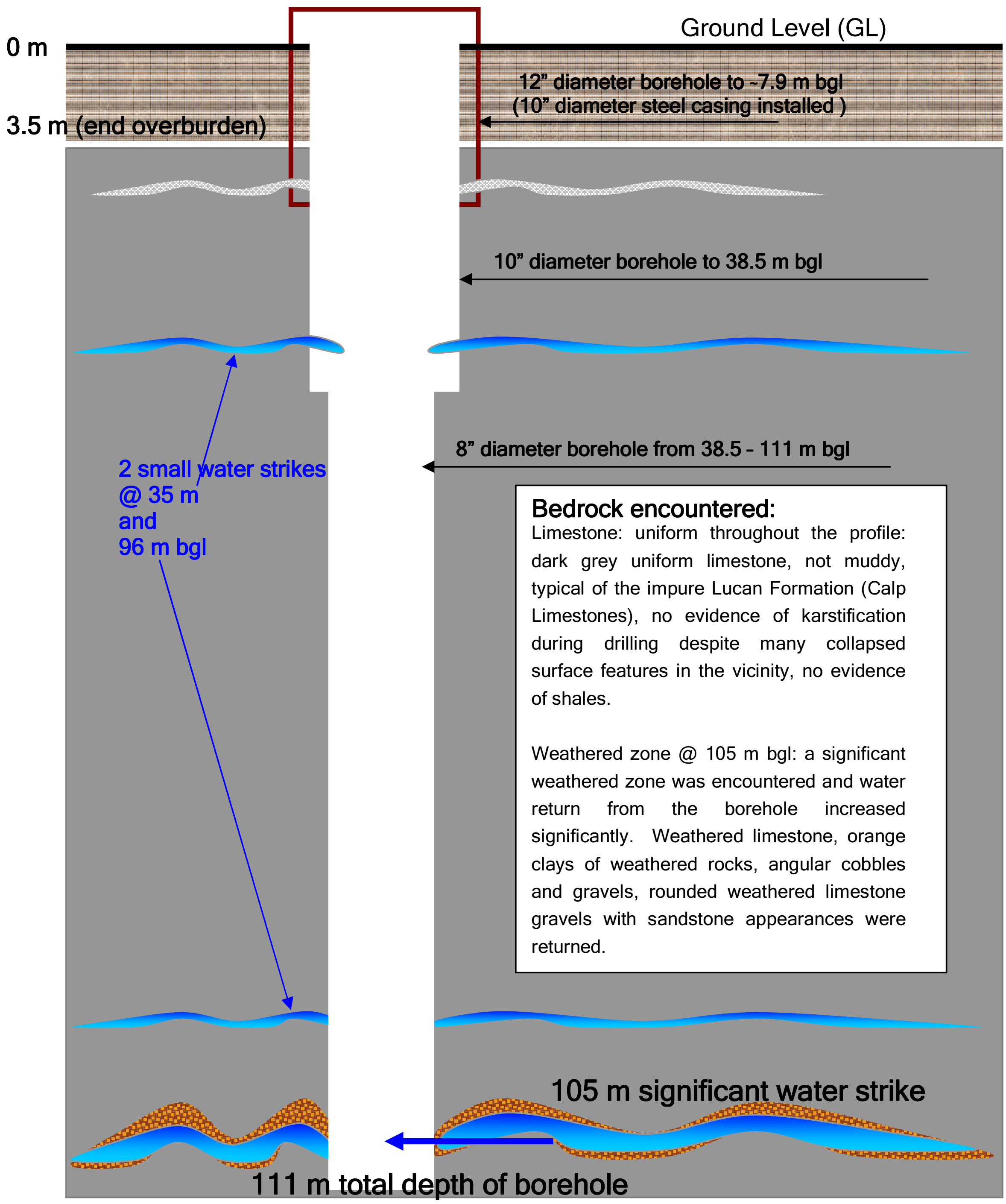
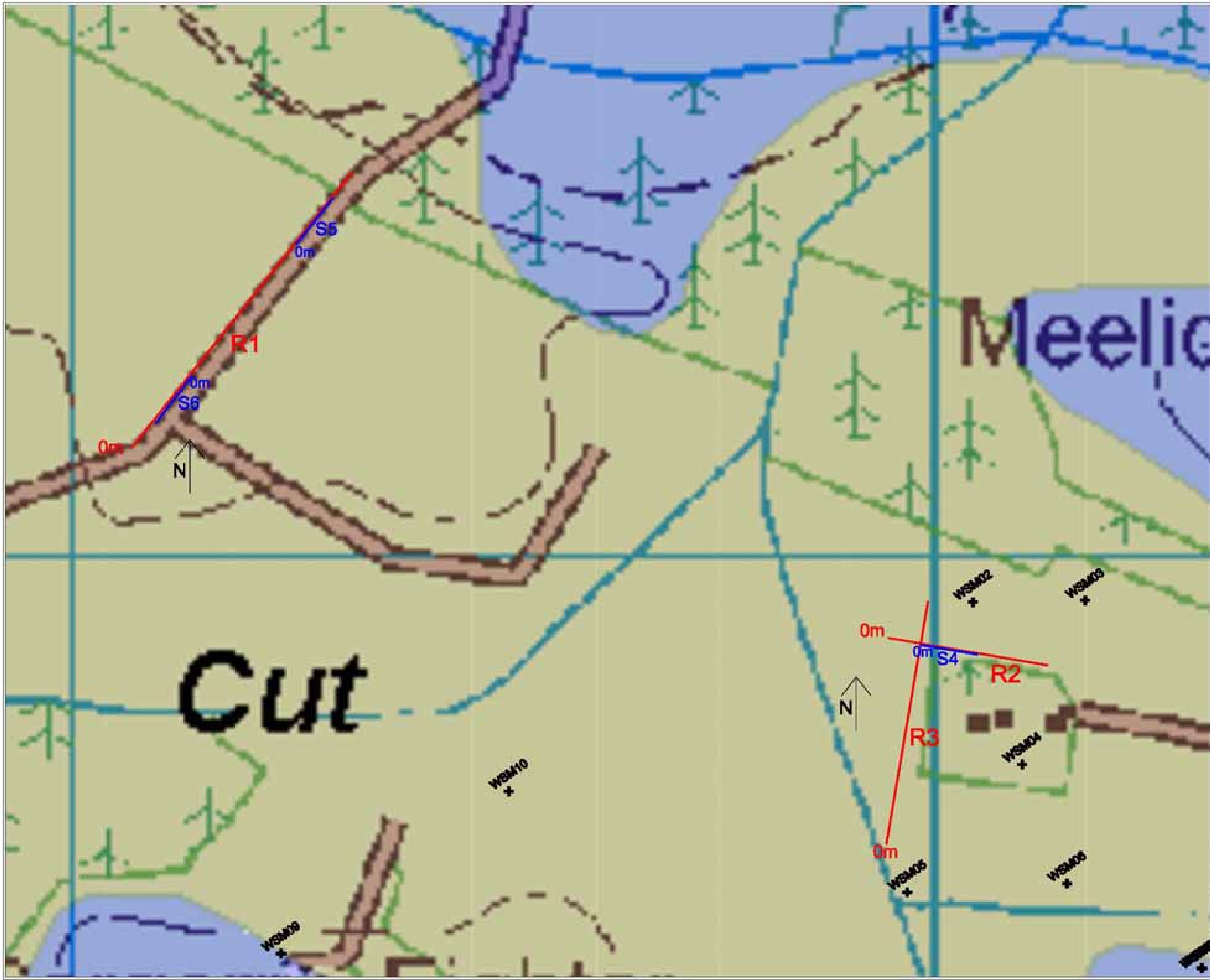


Figure 4 Schematic (not to scale) of Menlough production well Menlough, Co Galway.

APPENDIX C

Mapped Karst Features



INDEX MAP:

LEGEND:

Resistivity Profile

Seismic Profile

WSM03 Window Sample

Till derived chiefly from Limestone (Teagasc subsoils)

Peat (Teagasc subsoils)

apex geoservices

	Source Protection Zones - Mountbellew
	10361_01
	09-02-11
	COM
	1:4000 @ A3

		SOR	POC

FIGURE 1: Geophysical Survey Locations
Scale 1:2000

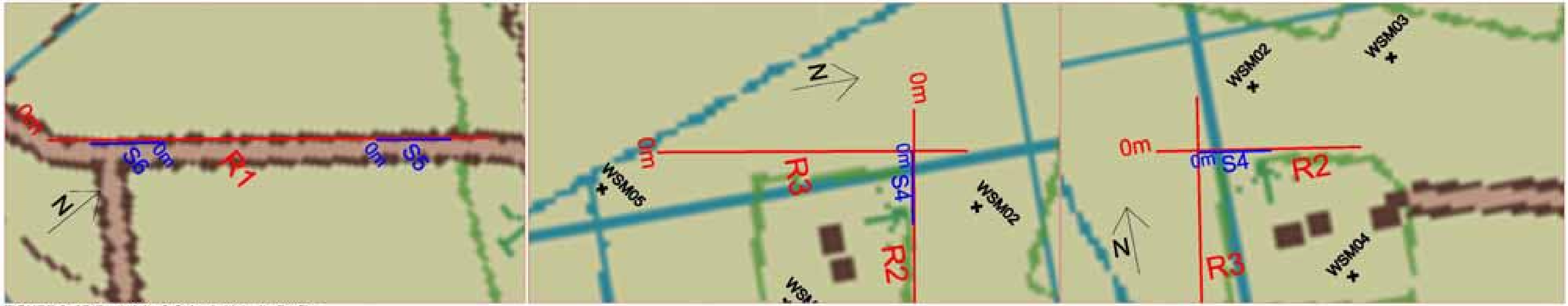


FIGURE 2: 2D Resistivity & Seismic Velocity Profiles
Scale 1:2000

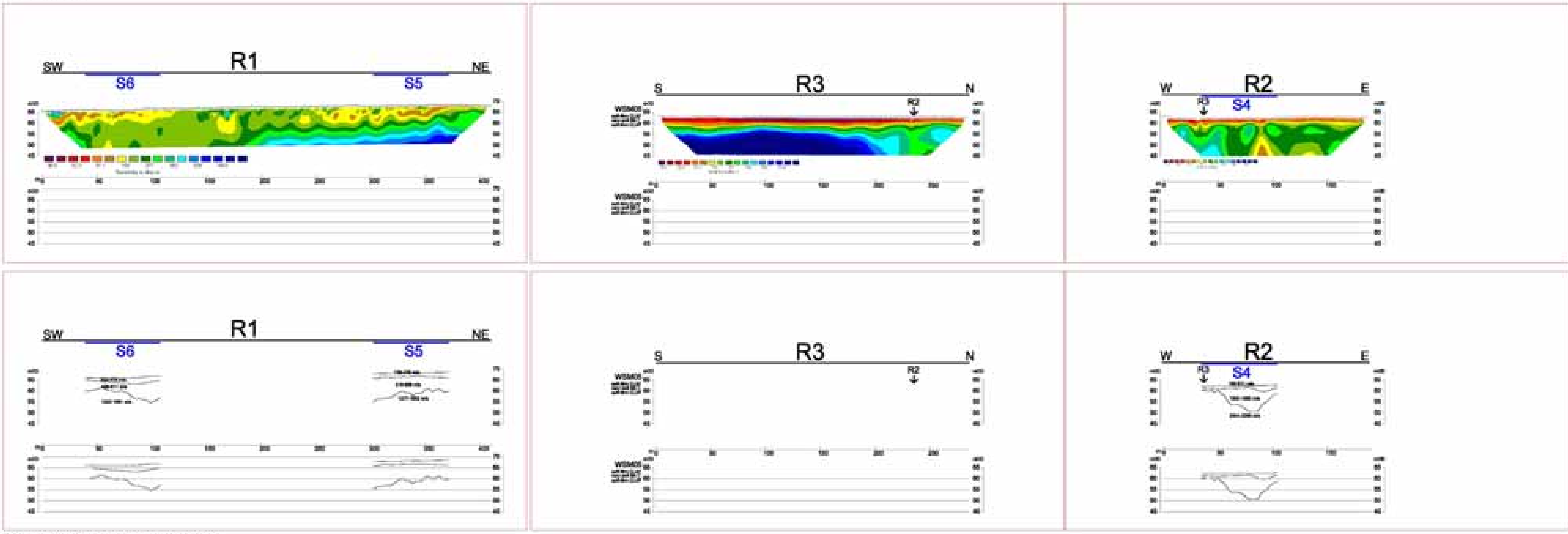
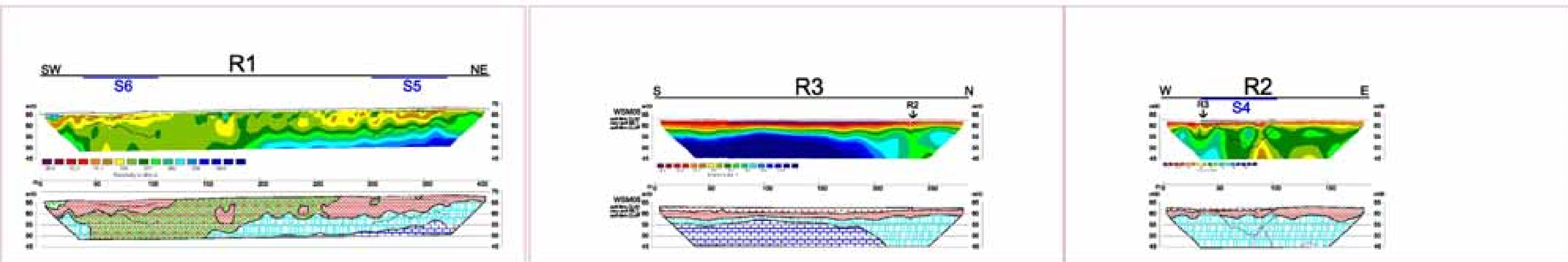


FIGURE 3: Geological Interpretation
Scale 1:2000 (Hz), (Vertical x 2)



INDEX MAP:

LEGEND:

- PEAT
- gravelly CLAY
- saturated/clayey GRAVEL
- weathered LIMESTONE
- fresh LIMESTONE
- Seismic Velocity Layer
- Possible karstic weathering

NOTES:

TITLE:	GEOPHYSICAL SURVEY
PROJECT:	Source Protection Zones Project
CLIENT:	CDM
DRAWING:	Interpreted Geophysical Results, Mountbellew
DRAWING NUMBER:	10051_03
SCALE:	Horz 1:2000 (Vert x 2)
DATE:	February 2011
DRAWN: SOR	CHECKED: POC

REVISION:	DATE:	DRAWN:	CHECKED:

apex geoservices

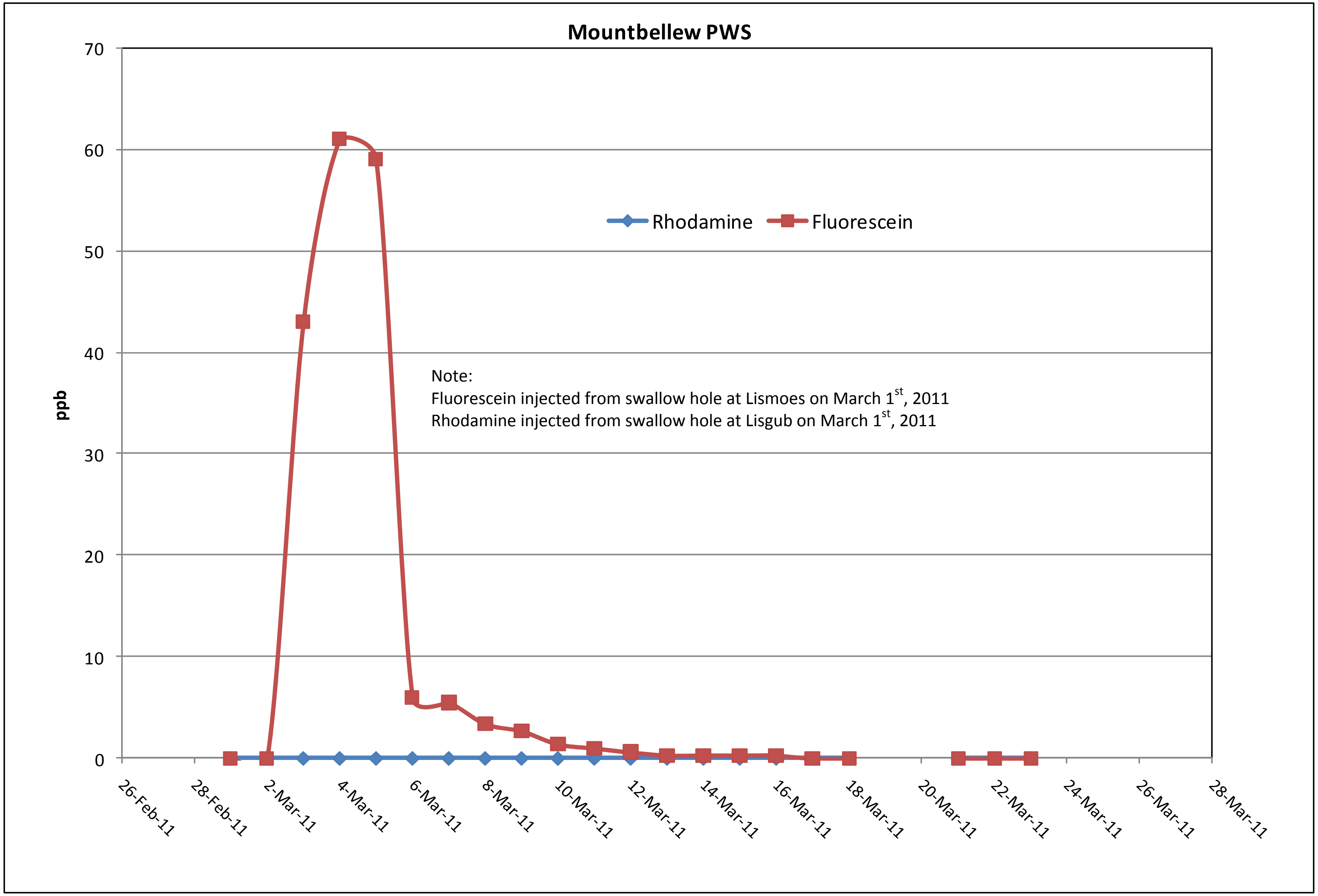
Feature Type	Easting	Northing	General Area	Comments
Swallow Hole	164556	241830	Lismoes	Traced to Mountbellew PWS spring
Spring	163945	241998	Lismoes	Seep
Spring	164014	241851	Lismoes	
Enclosed Depression	164271	242708	Ballynasooragh	
Enclosed Depression	164531	242559	Ballynasooragh	
Enclosed Depression	164377	242326	Ballynasooragh	
Enclosed Depression	163869	242399	Fairhill	
Doline	164274	241347	Moneen	Deep
Doline	164141	241185	Moneen	
Enclosed Depression	163877	241140	Moneen	
Doline	162217	241227	Menlough	
Doline	162606	240934	Menlough	
Spring	161848	241534	Menlough	Seep
Enclosed Depression	161967	241487	Menlough	
Doline	162007	241405	Menlough	
Spring	162135	242741	Menlough	Menlough GWS
Spring	164251	244729	Cloverfield	
Spring	164197	246440	Ballymageraghty	Reported by locals, not witnessed
Enclosed Depression	165136	246315	Shankill	
Spring	162097	247842	Cloonoran	Feeds Cloonoran Turlough across the way
Turlough	162269	247771	Cloonoran	
Spring	163516	246931	Cloonoran	Reported by local farmer, covered, not witnessed
Doline	164948	241225	Aghanahil	
Spring	165273	240691	Ballyara	Seep, reported, not witnessed
Enclosed Depression	164328	241137	Moneen	
Spring	161994	242503	Menlough	Reportedly a covered small spring, near a ditch
Spring	168613	241825	Castleblakeny	
Spring	167775	240673	Killaghaun	
Spring	167252	241120	Lisheen	
Spring	168482	239643	Esker	
Spring	167233	241119	Lisheen	
Doline	165630	240366	Killamude	
Doline	165633	240264	Killamude	
Doline	165692	240343	Killamude	
Doline	165914	240318	Moneen	
Doline	168644	239744	Esker	

APPENDIX D

Site Investigations

Mountbellew PWS - Summary of Dye Tracing

Date	Injection site	Description	Input NGR	Tracer Used	Comments	Output site	Output NGR	Result/Flow Velocity
5/08/10	Moylough Castle sink	Three adjacent swallow holes	161440E 249228N	Fluorescein 4 kgs / 4 litres	Powder injected into sinking water ~ 3 l/s	Mid-Galway PWS and Barnaderg GWS (not Mountbellew PWS)	153927E 244748N & 154470E 245135N	Positive trace to Mid-Galway PWS and Barnaderg GWS. 30.8 m/hr or 739 m/d
2/411	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 Mountbellew PWS	n/a	Inconclusive
9/12/10	Loch na Lasrach Turlough sink	Swallow hole at northern edge of turlough with natural drainage	160917E 247454N	Rhodamine 2 kgs / 10 litres	Dye poured into sinking under ice and moved away quickly	Mid-Galway PWS and Brierfield GWS (not Mountbellew PWS)	156014E 244121N & 153927E 244748N	Positive trace to Mid-Galway PWS and Brierfield GWS. 64m/h or 1544m/d (for both springs)
9/12/10	Caltra swallow hole	Small swallow hole with natural drainage	171815E 243589N	Fluorescein 4 kg /5 litres	Dye flushed with 1 x 2600 gallon tanker. 90% of dye straight into ground <10% on snow	No dye recovered at any of the locations sampled, including Mountbellew PWS	n/a	Inconclusive
3/1/2011	Lismoes sink	Small active swallow hole with natural drainage	164615E 241771N	Fluorescein 4 kg/5 litres	Naturally draining swallow hole	Mountbellew PWS	166094E 244818N	Positive trace to Mountbellew PWS. 71 m/hr or 1,700 m/d
3/1/2011	Lisgub sink	Small active swallow hole with natural drainage	168490E 238970N	Rhodamine 4 kg	Naturally draining swallow hole	No dye recovered at any of the locations sampled, including Mountbellew PWS	n/a	Inconclusive



Mountbellew PWS
ppb
70
60
50
40
30
20
10
0
Rhodamine
Fluorescein
Note:
Fluorescein injected from swallow hole at Lismoes on March 1st, 2011
Rhodamine injected from swallow hole at Lisgub on March 1st, 2011
26-Feb-11
28-Feb-11
2-Mar-11
4-Mar-11
6-Mar-11
8-Mar-11
10-Mar-11
12-Mar-11
14-Mar-11
16-Mar-11
18-Mar-11
20-Mar-11
22-Mar-11
24-Mar-11
26-Mar-11
28-Mar-11

APPENDIX E

Tracer Test Results