# Establishment of Groundwater Source Protection Zones

## Kilkerrin Public Water Supply Scheme

December 2011 –

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 Kilkerrin 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 Kilkerrin-Moylough Public Water Scheme (PWS) is supplied from a single spring, herein referred to as the Marganure spring, in the townland of Marganure, Co. Galway. In 2010, the PWS distributed an estimated 1,150 $m^3$/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 Kilkerrin PWS is located approximately 3 km SE of Kilkerrin village, in the townland of Marganure. Accordingly, the spring is known locally as the Marganure spring. Three other unnamed springs are located in the same general vicinity, and are referenced herein as springs A, B and C. During very wet climatic conditions, other smaller seeps also appear in some of the surrounding fields.

The Marganure spring is contained within a fenced-in and covered concrete chamber. Water from the chamber is gravity-fed via a 4-inch diameter PVC pipe to a small pump house, where the water is chlorinated and pumped to a reservoir approximately 1.8 km to the N of the spring. Overflow from the spring chamber is directed to an adjacent drainage channel which flows to the south and ultimately to the Shiven River. Photographs of the springs and general points of interest are included in **Appendix A**.

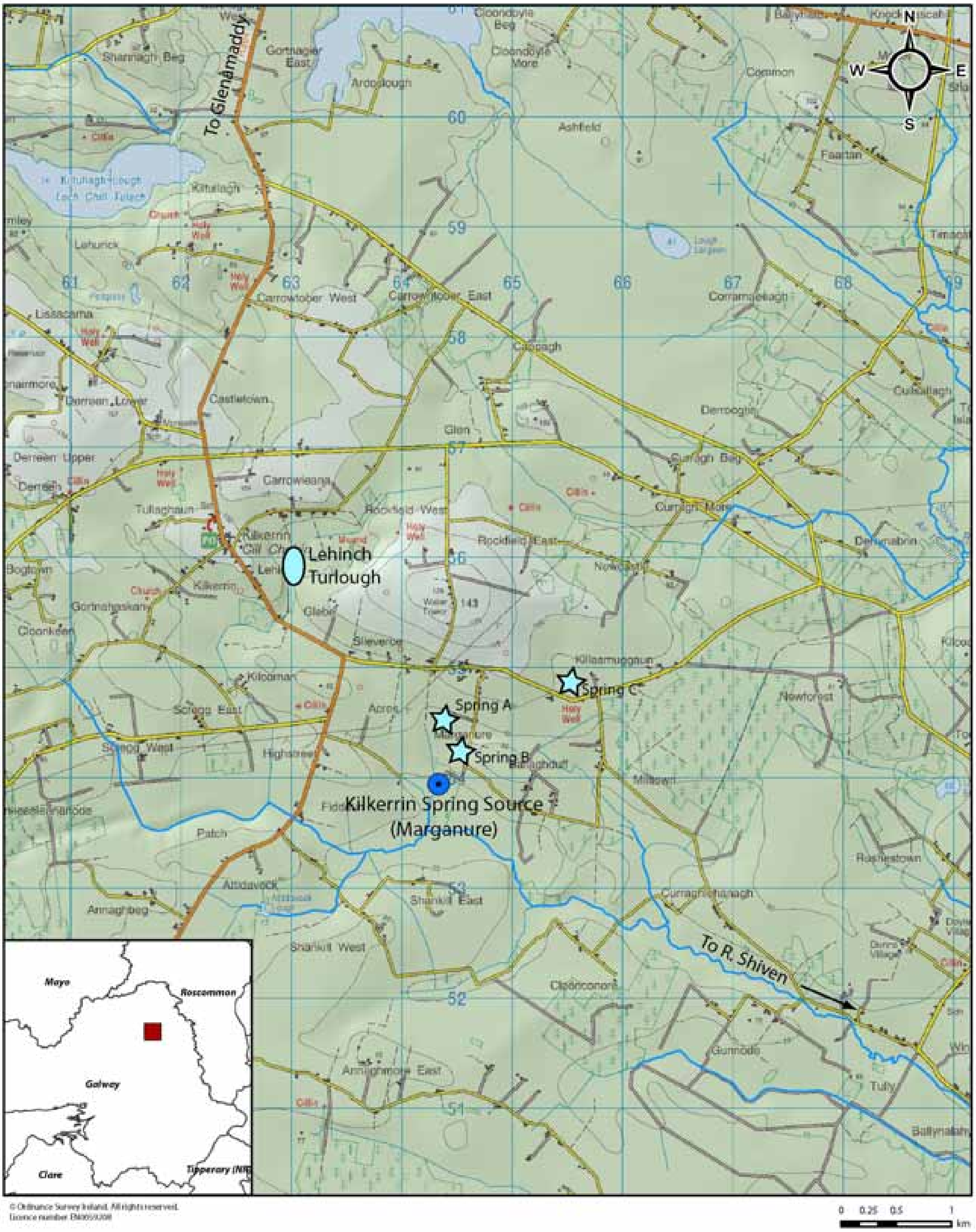





**Figure 1: Location Map**

# 4 Summary of Sources

**Table 1** provides a summary of the springs that are located in immediate vicinity of the PWS.

**Table 1: Spring Details**

| | Marganure Spring | Spring A | Spring B | Spring C* |
|---|---|---|---|---|
| Reporting Code | IE_SH_G_225_07_012 | n/a | | |
| Groundwater Body | Suck South (IE_WE_G_0225) | | | |
| Grid reference | 164349, 253939 | 164425, 254465 | 164633, 254365 | 165516, 255537 |
| Townland | Marganure | Marganure | Marganure | KIllasmuggaun |
| Source type | Spring | Spring | Spring | Seep* |
| Owner | Kilkerrin PWS | Private | Private | Private |
| Elevation (Ground Level - GPS) | 68 mOD | 78 mOD | 76 mOD | 85 mOD |
| Depth of chamber | >2 m | n/a | n/a | n/a |
| Dimension of chamber | 4 x 4 m | n/a | n/a | n/a |
| Depth to rock | Rock-close | >3 m | >3 m | Rock-close |
| Average Reported Abstraction ($m^3$/d) | 1,150 (range 1,000-1,250) | - | - | - |
| Estimated discharge ($m^3$/d)** | 1,000 to 5,875*** (2,678 average) | Dry to 4,000**** | Dry to 2,500**** | Dry to <1,000**** |

*Note:*
** - seeps appear along the bed of a small stream.*
*** - February 2010 through July 2011.*
**** - includes abstraction.*
*****- from spot measurements. The high end values shown are considered to be overestimates due to potential measurement errors (see Section 9.3).*

The average quantity of water abstracted from the Marganure spring was 1,150 $m^3$/d in 2010, with a recorded range from 1,000 to 1,250 $m^3$/d. Pumping generally takes place over a 19-23 hour period each day. The Marganure spring chamber has been gauged by the EPA since late-2009. The spring chamber is fitted with an automatic stage (level) recorder and a 90-degree V-notch weir. By way of manual readings and a rating curve, overflows from the spring chamber have been estimated for the period between February 2010 and July 2011. As shown in **Figure 2**, the overflow in this period ranged from zero (no overflow) to approximately 68 l/s (5,875 $m^3$/d), with a mean discharge of 31 l/s (2,678 $m^3$/d). The water level in the spring chamber drops and recovers with each pumping cycle which in turn affects the overflows across the weir. Hence, superimposed on the ‘true’ hydrograph of spring discharge are semi-regular oscillations which correspond to periods of pumping followed by periods without pumping. The maxima values shown in the hydrograph of **Figure 2** represent total discharges when the pump is off, the minima represent total overflows when the pump is on. 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.

One interesting feature of **Figure 2** is that the estimated overflow between November 2010 and April 2011 (the “wet season”) is relatively constant at approximately 0.05 $m^3$/s (4,320 $m^3$/d), peaking occasionally above 0.06 $m^3$/s (5,184 $m^3$/d). This relatively constant wet weather overflow implies that it is an underflow spring with a natural upper limit (capacity) to discharge groundwater. Weather summaries from Met Eireann for the same winter period indicate that rainfall statistics for western parts of Ireland were significantly above long-term averages during November and December 2010, and just below (90-95%) long-term averages during the subsequent winter months of 2011 (Met Eireann, 2010 and 2011). Although the historical maximum

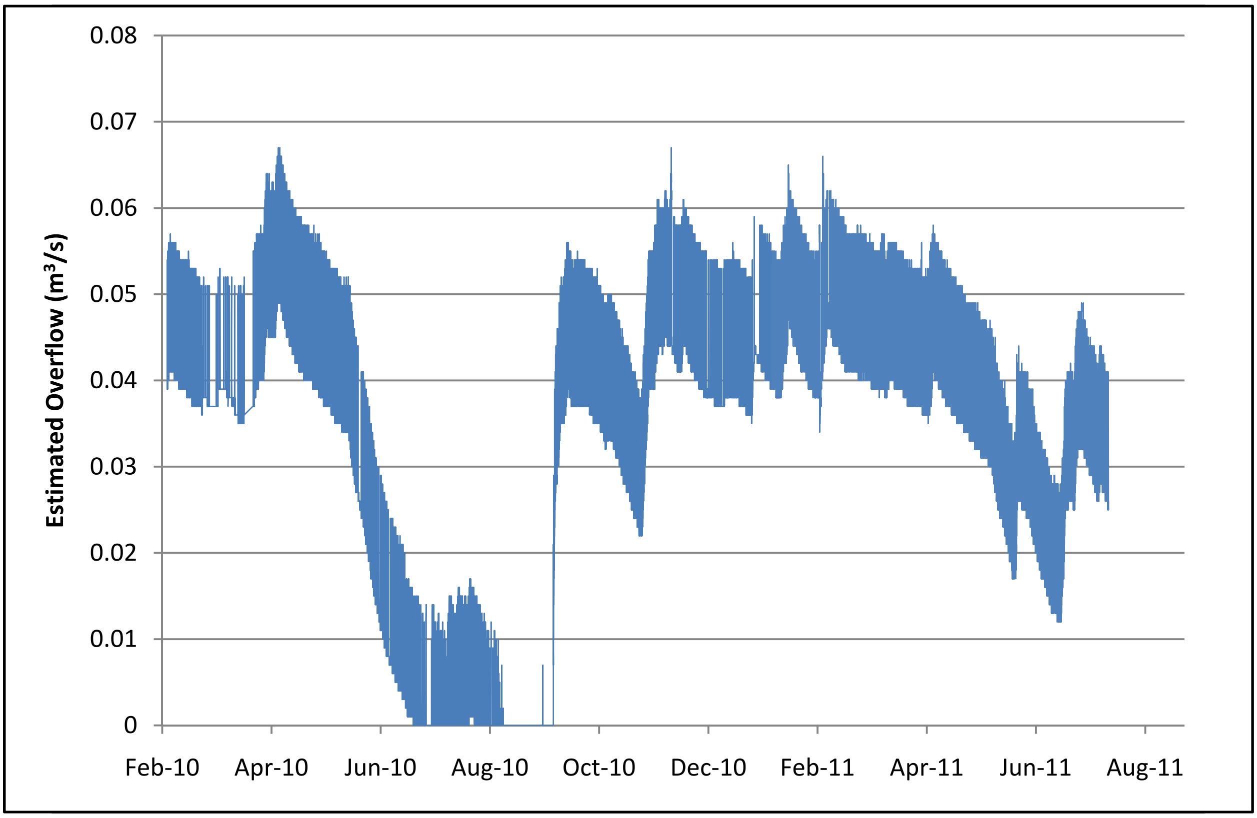



**Figure 2: Estimated Overflow at the Marganure Spring**

discharge from the spring is not known (measurements began in February 2010), the hydrograph in **Figure 2** is considered a reasonably valid indicator of the general hydraulic behaviour of the Marganure spring.

Springs A and B are smaller than Marganure but even so discharges of up to 27 and 15 l/s, respectively have been recorded (see Section 9.3). Situated at higher elevations than the Marganure spring, they appear to represent overflow springs. Following the dry summer of 2010, springs A and B started to discharge several days after Marganure, indicating that the discharges followed a period when the karst system feeding the Marganure spring "filled up".

The spring discharges are strongly influenced by rainfall events. **Figure 3** shows rainfall data from the nearest available rainfall station at Glenamaddy, approximately 5 km to the north of Kilkerrin village. Following a generally dry summer period, a significant rainfall event occurred on September 6th, when more than 50 mm fell in one day. **Figure 4** depicts the cumulative rainfall and resulting cumulative discharges from the Marganure spring between June 2010 and July 2011. A significant break in slope appears in the cumulative discharge graph on September 6th. Prior to this date, there was little or no overflow from the spring (springs A and B were also dry), but following the rainfall event, the overflows increased to greater than 4,000 $m^3$/d over a 3-day period. Springs A and B started discharging several days thereafter. Following the September 6 event, the cumulative discharge graph is remarkably straight and does not appear to respond much to rainfall, giving credence to the concept that it is an underflow spring with a finite discharge capacity (of between 0.05 and 0.06 $m^3$/s).

**Figure 5** depicts changes in water levels, estimated overflows, temperature and electrical conductivity in the spring chamber between 15:00 hrs on August 25th and 11:30 hrs on September 29th. An obvious change in behaviour occurs after approximately 12 days of continuous monitoring, corresponding to 13:30 hrs on September 6th. Prior to this time, the abstraction causes water level fluctuations up to 1 m within the spring chamber, and the corresponding overflow is zero. After this time, as a function of the rainfall on September 6th, the chamber filled up to a water level that is equivalent to the cut in the V-notch weir, when overflows resumed (approximately midnight on September 7th).

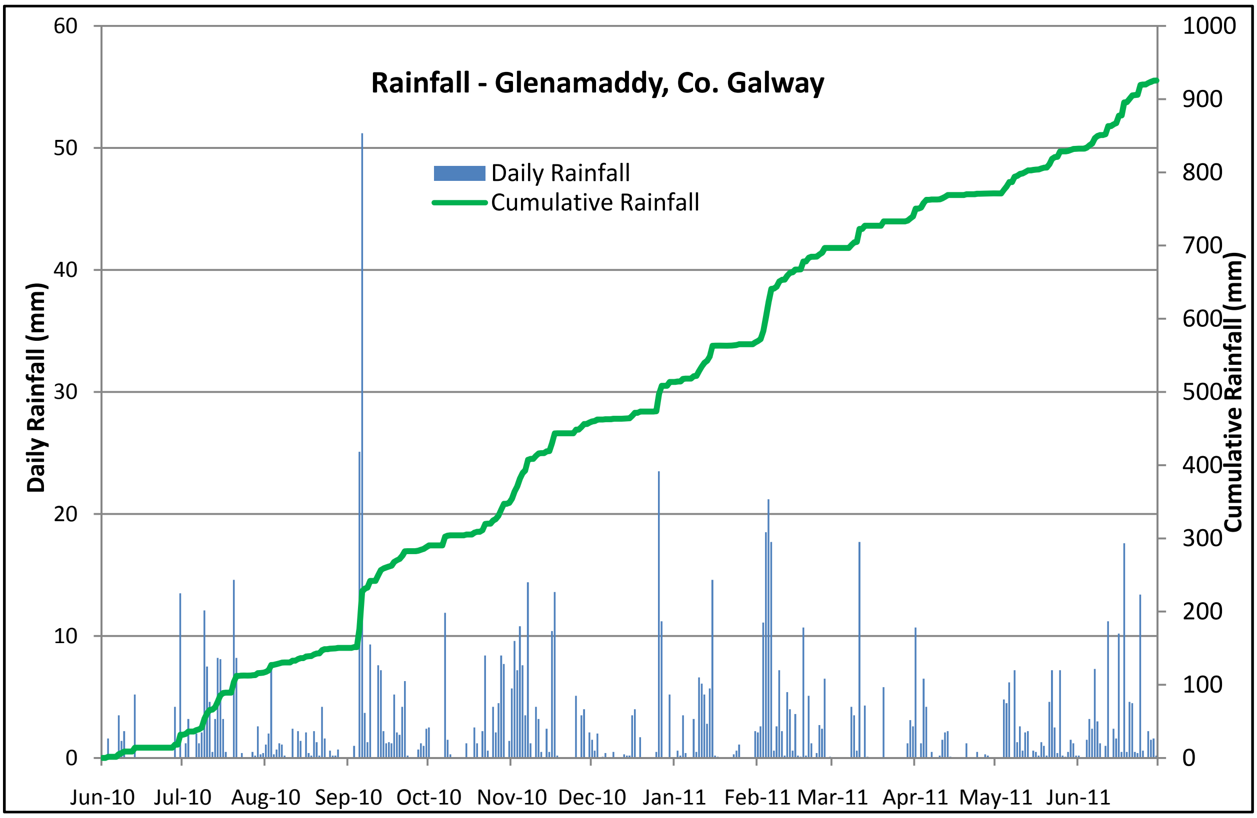



**Figure 3: Daily and Cumulative Rainfall, June 2010 to July 2011**

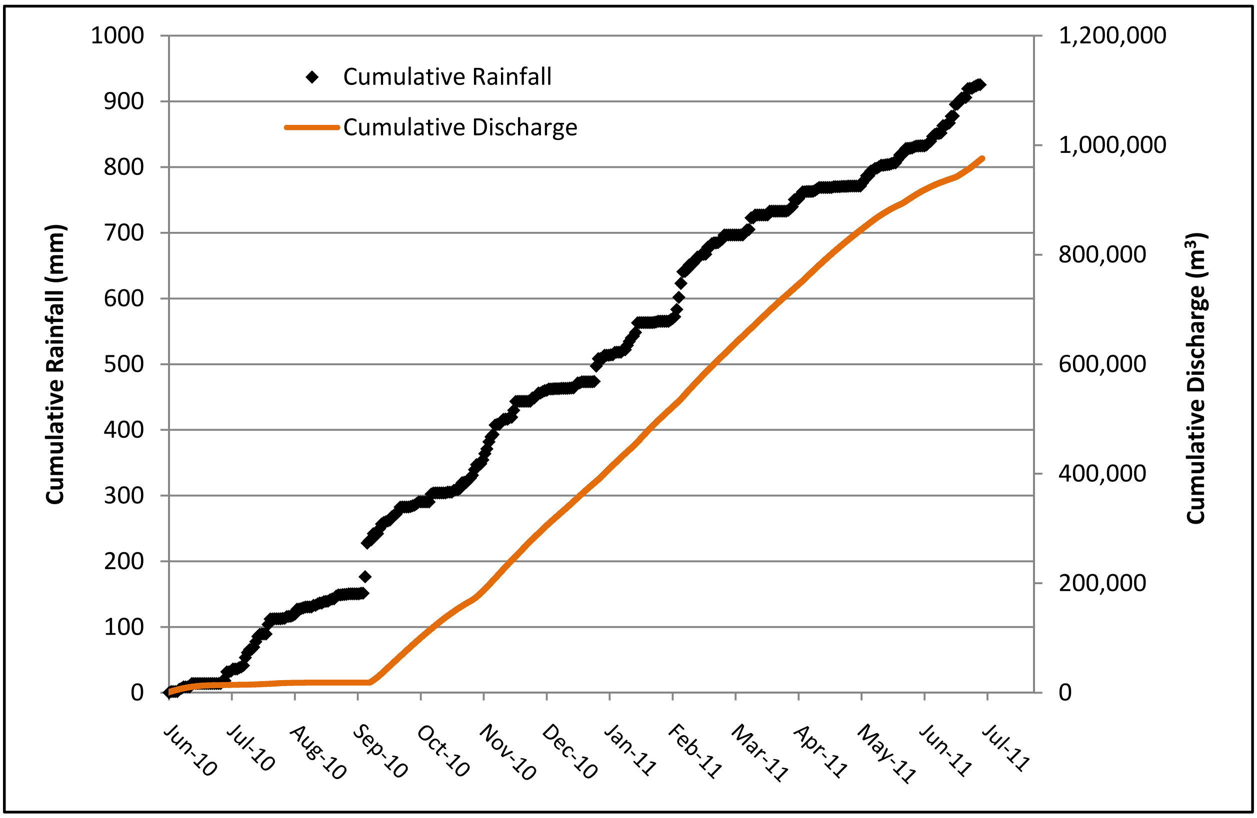



**Figure 4: Cumulative Rainfall (Glenamaddy) and Cumulative Discharge (Marganure Spring)**

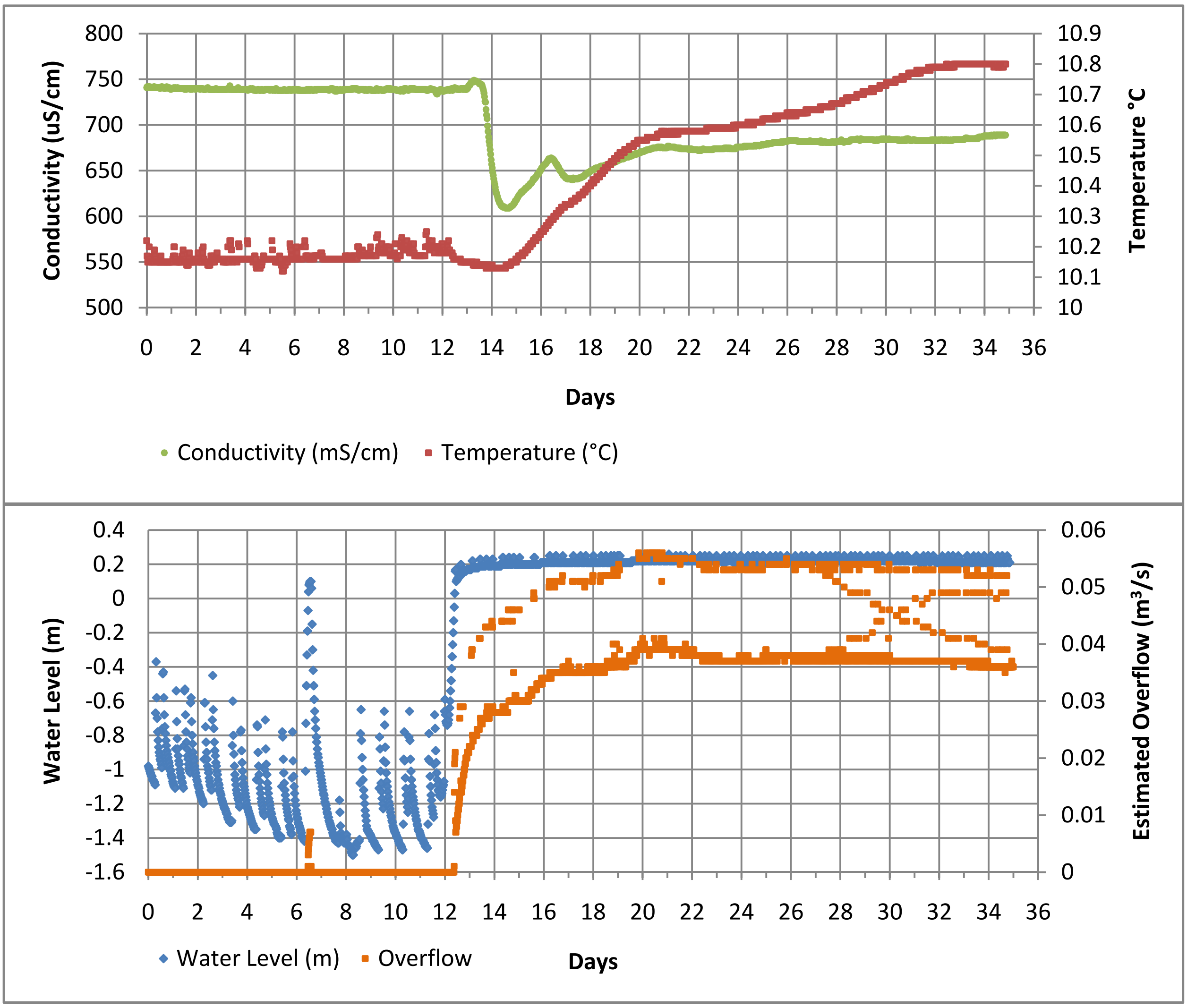



**Figure 5: Detailed Measured Response to Rainfall Event on September 6th, 2010**

The electrical conductivity (EC) of the water in the spring chamber decreased quickly approximately 24 hours after the resumption of overflows, and represents the moment that the main flood pulse from the September 6th rainfall event reached the spring. In this 24-hour period, an estimated 1,672 $m^3$ of water passed through the V-notch weir. Combined with the 1,150 $m^3$/d pumped (on average) from the chamber, the total spring discharge over the same duration was approximately 2,822 $m^3$, and represents (roughly) the volume of water that was flushed out of storage prior to the arrival of the actual flood pulse.

The EC subsequently dropped from a maximum 749 µS/cm to a minimum 609 µS/cm over a 28 hour period, and then increased gradually to approximately 680 µS/cm over a 12-day period, where it remained relatively constant for several days. The instant decrease in EC marks the arrival of the flood pulse through the karst system (*i.e.* the actual water that fell as rain in the September 6th storm event). Over the remainder of the continuous monitoring period, the EC did not recover back to the same value that was measured prior to the arrival of the flood pulse. The temperature of the water in the spring chamber shows a change that follows the initial water level rise and resumption of overflows. Interestingly, the temperature increased with the arrival of the flood pulse, and also did not recover back to pre-flood pulse conditions during the continuous monitoring period. A similar behaviour was measured at the Meelick spring near Mountbellew (CDM, 2011) and is, therefore, not believed to be caused by instrumentation error.

### 4.1 Topography, Surface Hydrology, Landuse

The Marganure spring is located in the Shannon River Basin District near the border with the Western River Basin District. The overflow from the Marganure spring is directed to an unnamed tributary of the Shiven River which flows to the southeast and is a headwater of the Suck River. The surface water catchment of the spring is to the north, where land rises gently from Marganure to Slieveroe, before rising sharply towards Rockfield hill, at a maximum elevation of 126 mOD. Rockfield hill forms a gentle sloping, rocky, plateau with no significant drainage features and few signs of water retention. Further to its north, a wide NE-SW trending valley drains water towards the Lehinch Turlough. Shown in **Figure 1** and **Appendix A**, the turlough collects runoff (and shallow groundwater flow) and forms a prominent surface water body for several months each year (in some years, reportedly all year around). The turlough has a distinct swallow hole at its southern margin, at an approximate elevation of 86 mOD, which is 18 m higher than the main Marganure spring. An overflow channel from the turlough has been constructed at its southwestern margin to alleviate flooding during extreme wet weather events (e.g. November 2009).

The Marganure spring is surrounded by forested and agricultural (pasture) land. To the south, areas of cut peat border the banks and tributaries of the Shiven River, and drainage density is high. Six-inch Ordnance Survey (OS) maps indicate the historical presence of several other seeps (“rises”) that are no longer evident, probably due to land and drainage alterations in the Marganure area generally.

## 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) only 5 km away from Kilkerrin village, 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. For the study period between June 2010 and June 2011 (see **Figure 3**), the effective rainfall would be less, at 400 mm, assuming the same evapotranspiration loss.

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

The bedrock in the entire Kilkerrin study area has been mapped by the GSI as Dinantian Pure Bedded Limestones. There are several outcrops of bedrock on and near Rockfield hill that consist of pale grey, thin bedded (<1 m) limestones that dip gently (<5 degrees) to the northeast. A borehole drilled and logged by the GSI near the Gortgarrow spring (approximately 6.5 km to the NW of Kilkerrin village) indicate that the limestone in the study area may be part of the Knockmaa Formation which is a karstified bioclastic fossiliferous limestone (Pracht, personal communication). Faulting is not directly evident from rock exposures in the immediate study area, but the inferred trace of a GSI-mapped NE-SW trending fault passes less than 400 m to the south of the Marganure spring. Whether or not such a fault could influence groundwater levels and flow patterns in the Kilkerrin area is not known.

## 6.2 Karst Features

As indicated in **Figure 6**, numerous karst features are present within the study area. Some of these had previously been recorded in the GSI Karst Database, but new features were surveyed and recorded as part of this study. Mapping of karst features (see **Appendix B**) was conducted during walkover surveys to identify potential recharge areas and injection points for the purpose of dye tracer testing (see Section 8.2). Only areas at a higher elevation than Marganure spring were surveyed. Surprisingly few features outside the catchment of Lehinch Turlough were identified, but the limestone is close to the surface and the epikarst appears to be well developed.

## 6.3 Depth to Bedrock

Bedrock is exposed or is close (<3 m) to the ground surface across Rockfield hill and the catchment of the Lehinch Turlough. In the flatter terrain to the S and SW of Kilkerrin village and surrounding the Marganure spring, the depth to bedrock increases in a southerly direction.

## 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 (cut and BminPDPT) on lower ground. Mapped subsoils, see **Figure 8**, consist of cutover peat (cut) and glacial till (TLs) derived from the underlying limestones. The cutover peat primarily occupies low-lying areas surrounding and south of the Marganure spring. However, the low-lying area at Marganure also includes sand and silt deposits that overlie the marls described in Section 6.1. Hand-augering to 1.0-1.5 m depth in vicinity of the Marganure spring indicated a mix of clay, sand and silt. Alluvial sediments have been mapped by the GSI in a small area immediately south of Kilkerrin village, and their presence could explain the appearance of shallow seeps in some of the fields surrounding Marganure during significant rain events (i.e. the sands and silts become periodically saturated).

Between the Marganure spring and Slieveroe, white-grey and yellow marls are visible along the bottom of some drainage ditches (see **Appendix A)** and at the surface where they form “stepping stones” on 6-inch OS maps. The geological context of these marls is not well understood, but they probably represent Holocene lake sediments.

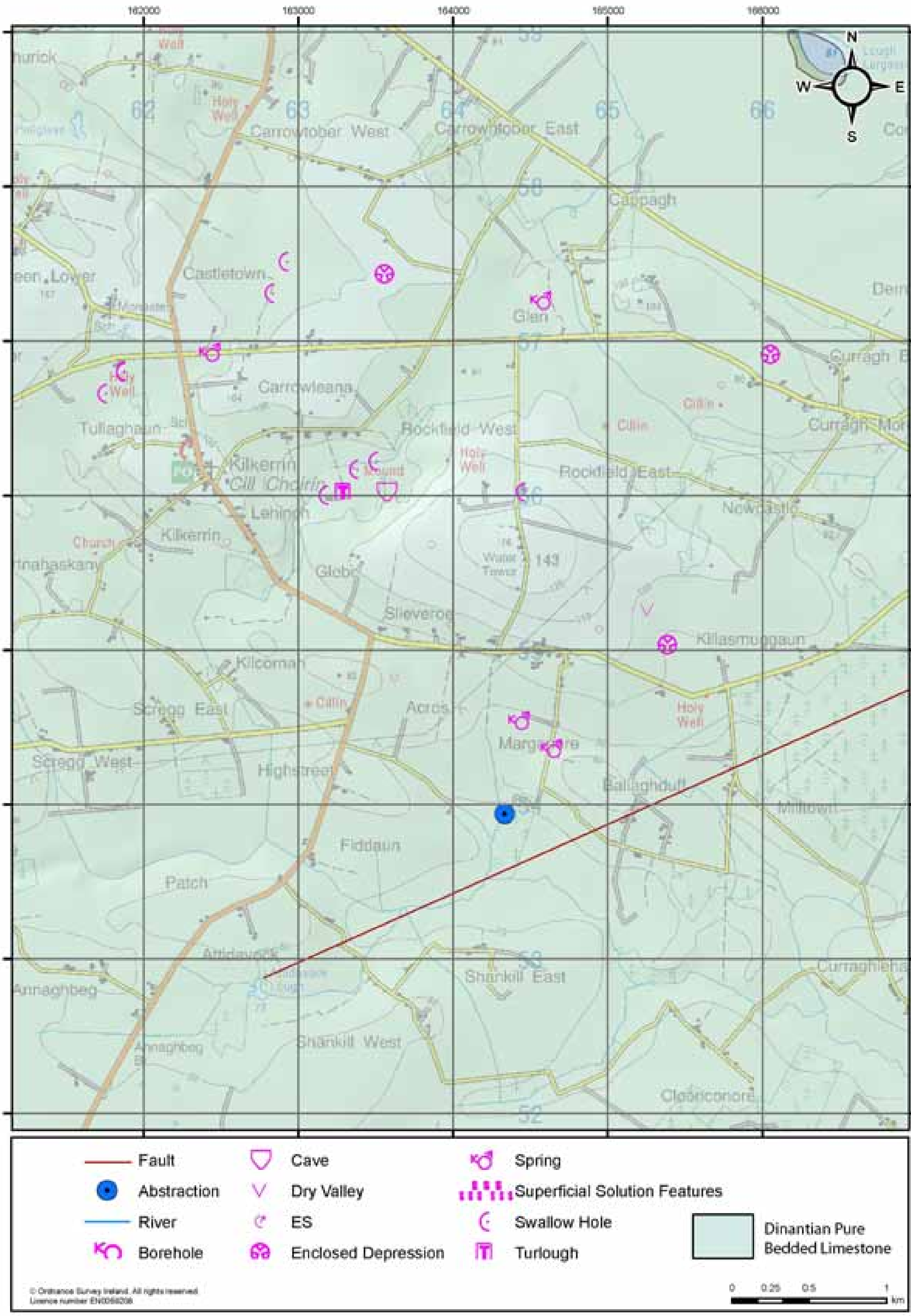



**Figure 6: Bedrock/Rock Unit and Karst Features Map**

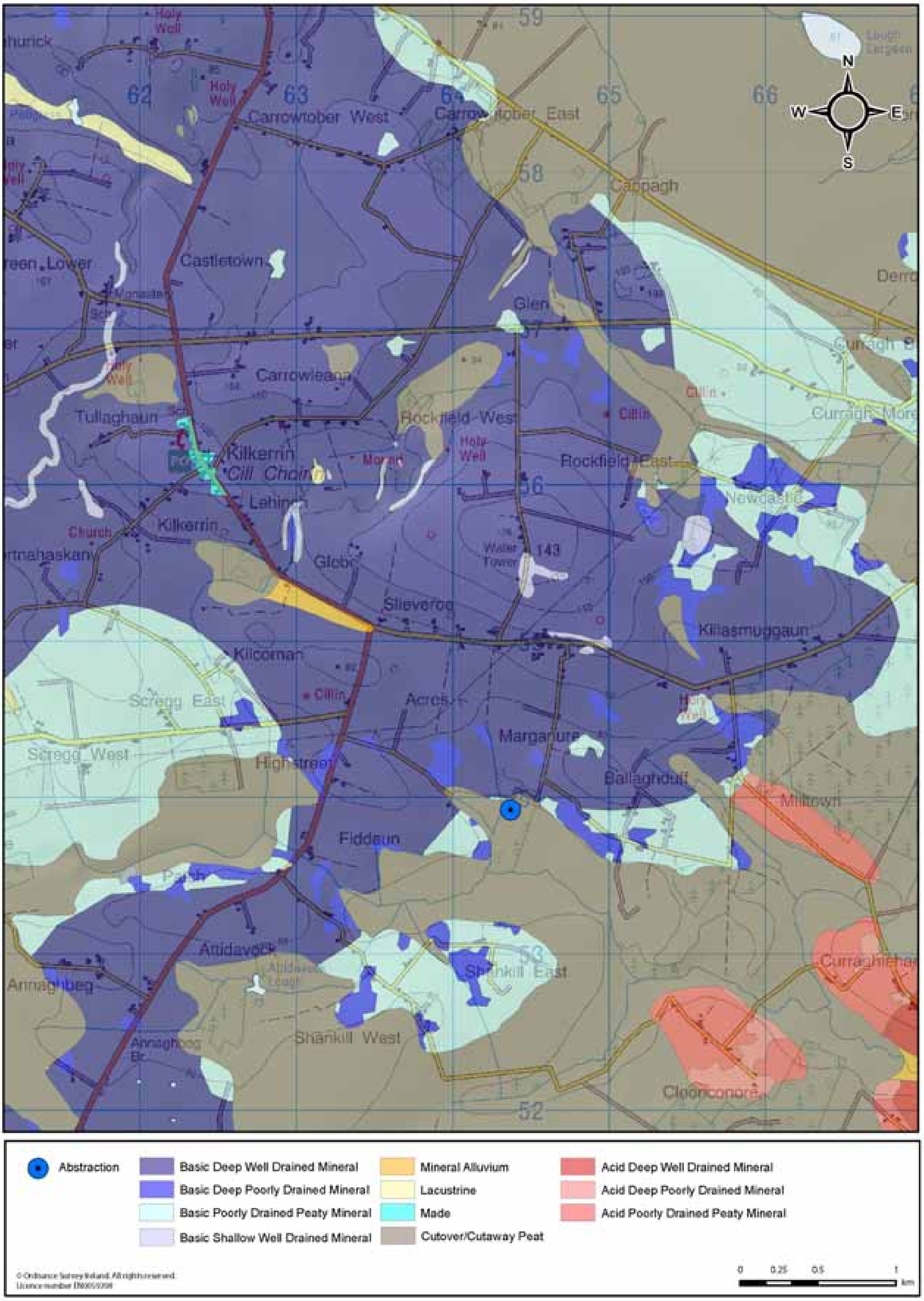



**Figure 7: Soils Map**

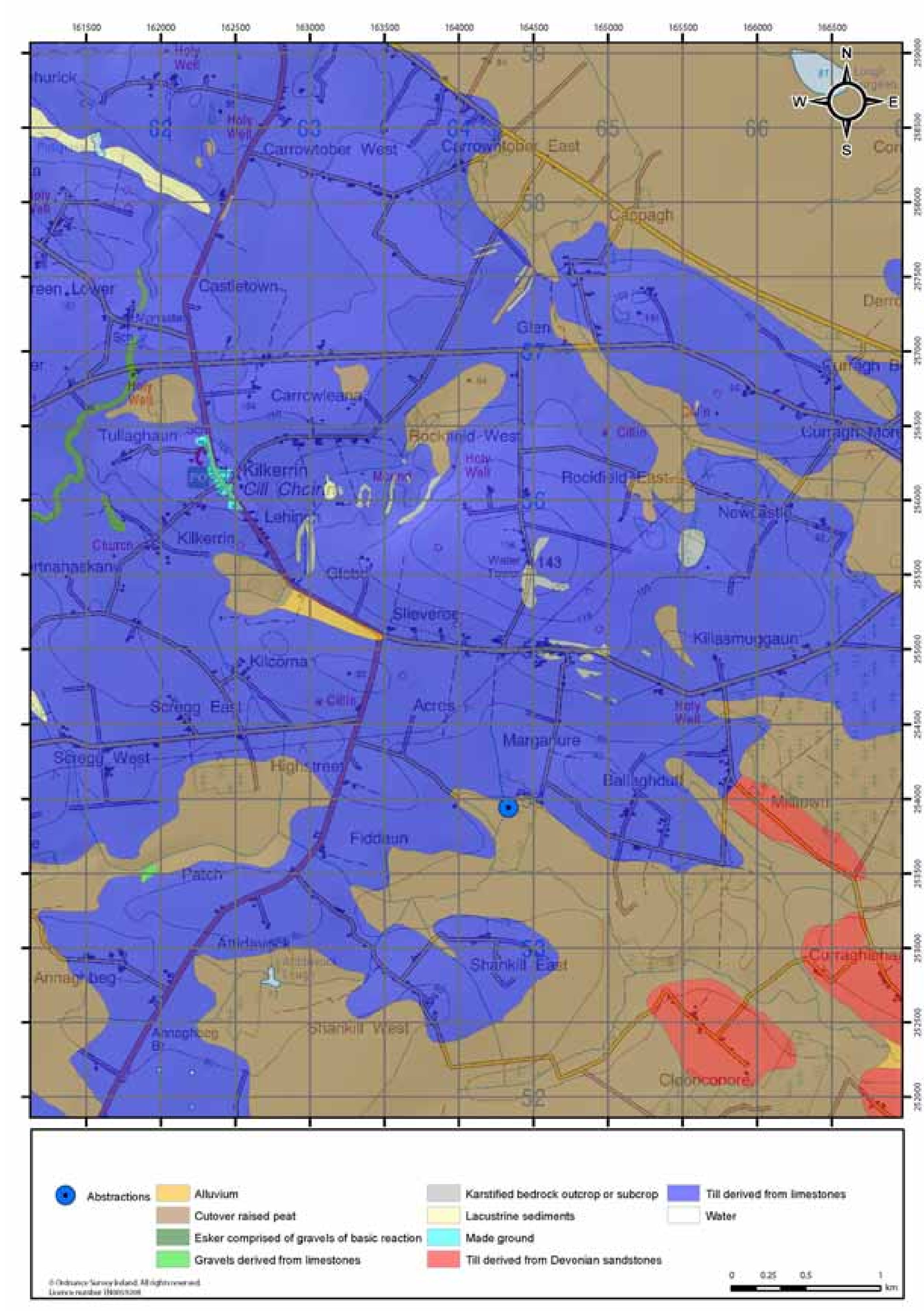



**Figure 8: Subsoils Map**

# 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 Kilkerrin PWS means that vulnerability relates primarily to the permeability and thickness of the 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**, bedrock is exposed or is close (<1 m) to the ground surface across Rockfield hill. Accordingly, vulnerability across the hill is mapped as Extreme. Bedrock is also exposed along some streambeds that otherwise occur in areas with a subsoil cover, and accordingly, streambeds are assigned extreme vulnerability and assumed to be losing water to the underlying aquifer. The vulnerability in lower-lying areas ranges from High to Low, reflecting the greater thickness and distribution of subsoil materials as well as the presence of peat. In the immediate vicinity of the main spring, vulnerability is mapped as Moderate and Low.

# 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 at Kilkerrin is distinctly karstic, and as such, fissures and conduits are expected to influence flow patterns, directions and rates. The flow characteristics are expected to vary in space and time in line with different hydrometeorological conditions, although general topographic and drainage considerations suggest that groundwater flow will generally be from north to south.

To establish flow directions, travel times, and zones of contribution(s), 11 dye tracer tests were conducted from 6 dye injection locations between June 2010 and April 2011, specifically targeting the Marganure spring. As summarised in **Appendix C** (and in Figure 14), only one test, from the swallow hole at Lehinch Turlough, was positively traced to the main spring at Marganure. The other tests are summarised as follows:

- Two tests from an old quarry on the southern slope of Rockfield hill resulted in confirmed traces to Springs A and B, but not Marganure.
- One test in a shallow, NW-SE trending dry valley at Killasmuggaun resulted in a very short trace to Spring C only.

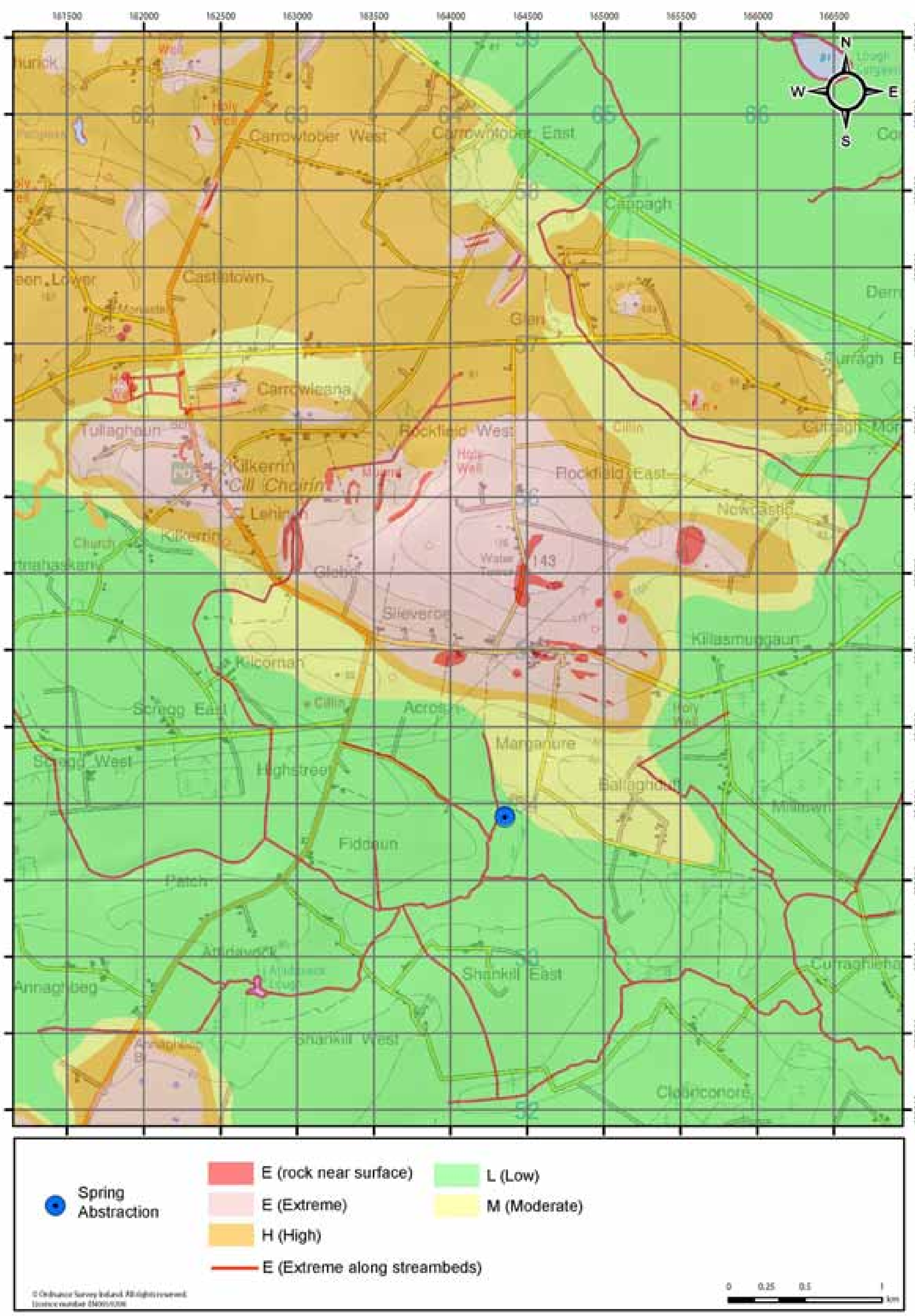



**Figure 9: Groundwater Vulnerability Map**

- Two tests from a small swallow hole at the top Rockfield hill did not result in any detections at any of the locations sampled.
- One test from Castletown just N of Kilkerrin village resulted in a positive trace to the Gortgarrow PWS, approximately 6.5 km to the NW of Kilkerrin village.

From these results, it has been established that the Lehinch Turlough, and its associated catchment, is a major source of water to the Kilkerrin-Moylough PWS. As a result, the turlough catchment is included in the inferred zone of contribution (ZOC) to the Marganure spring (see Section 9). Demonstrated travel times through the karst system range from approximately 11 m/hr to more than 40 m/hr (at the times of testing).

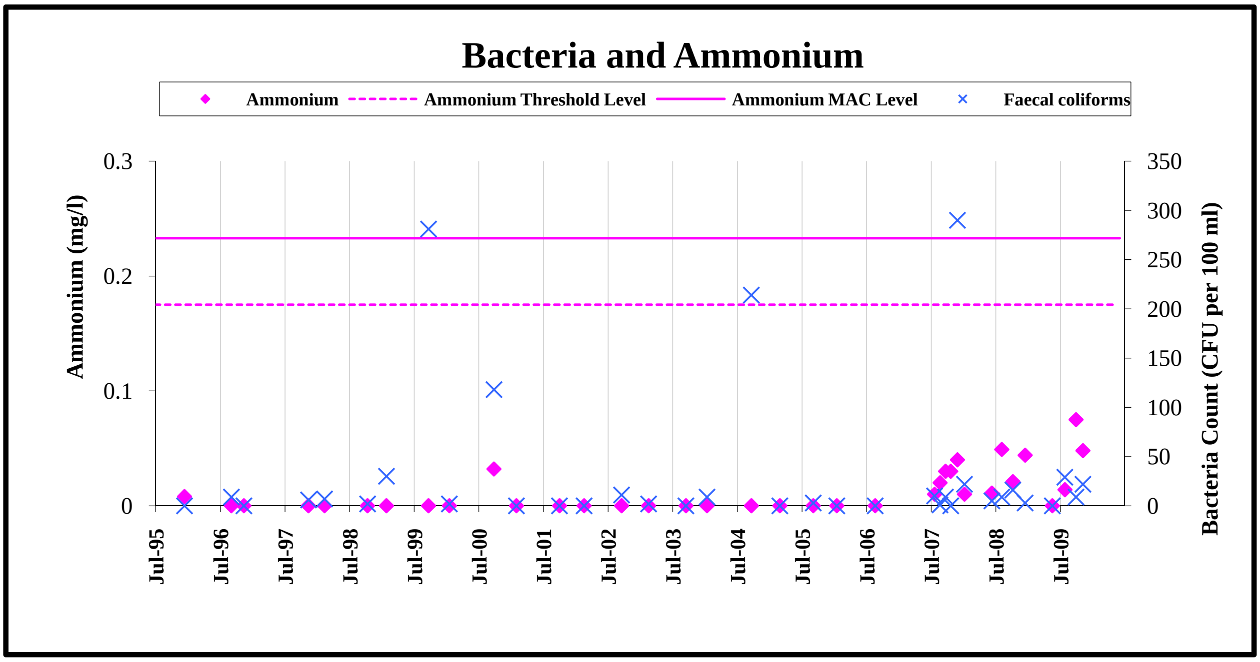
Surprising results were: a) the apparent absence of positive traces to the Marganure spring from the old quarry on the southern slope of Rockfield hill; and b) the absence of any positive traces from the small swallow hole at the top, eastern part of Rockfield hill. These tests testify to the difficulty in determining groundwater flow paths in karst aquifers. There may have been circumstances surrounding each test that would explain why they were not detected at Marganure and it is recommended that these specific tests be repeated (see Section 13).

## 8.3 Hydrochemistry and Water Quality

The Kilkerrin PWS has been monitored by the EPA since 1995, and was included in the EPA operational chemical network in late-2006. The sample point is at 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 36 samples in total, and results are highlighted as follows:

- The water is hard (average 350 mg/l $CaCO_3$). The average field conductivity is 718 µS/cm with a range between 530 and 802 µS/cm. The average field pH is 7.0 and the hydrochemical signature of the water is calcium bicarbonate.
- Faecal coliforms are detected periodically with gross contamination (>100 CFU per 100 ml) on 4 occasions in the available dataset, all occurring in the months of September and November.
- There are no ammonium concentrations greater than EPA's status Threshold Value of 0.175 mg/l. The general apparent absence of ammonium pre-2007 reflects the use of higher detection limits at the time – EPA's analytical protocols changed with the introduction of the Water Framework Directive related monitoring programme at the end of 2006, and detection limits were generally lowered for some substances.
- Concentrations of nitrate (as $NO_3$) range from 1.3 mg/l to 12.4 mg/l with a mean of 7.5 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 9 mg/l to 23 mg/l with a mean of 17 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).




*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**

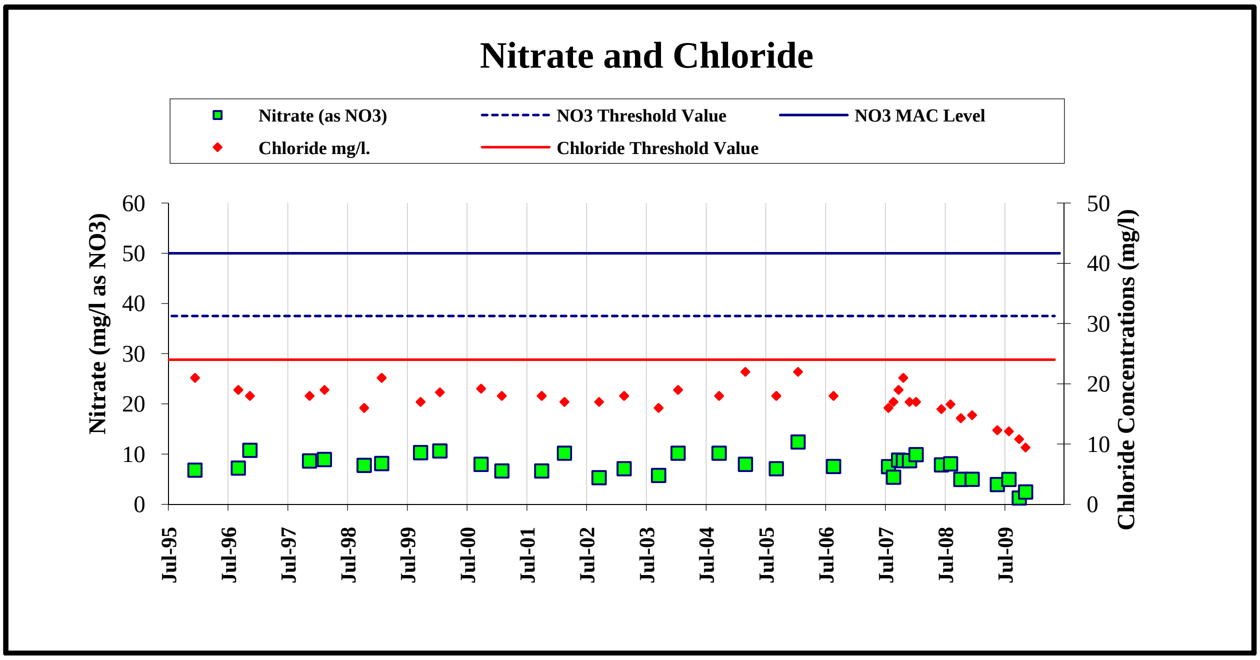
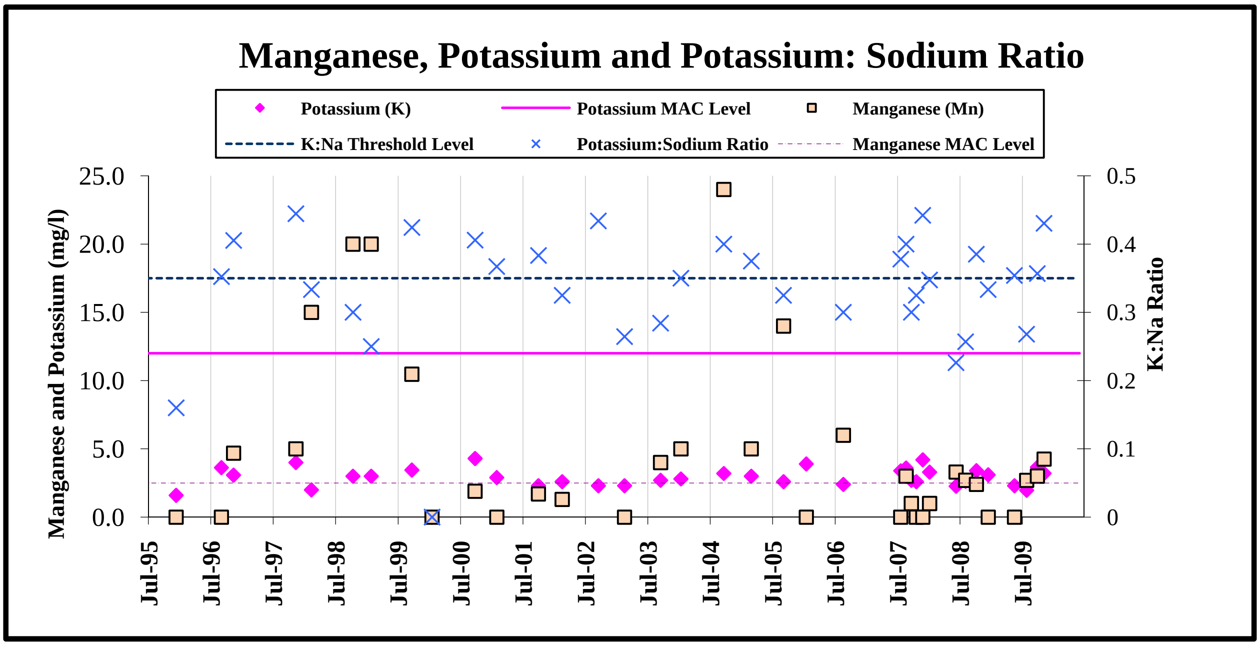
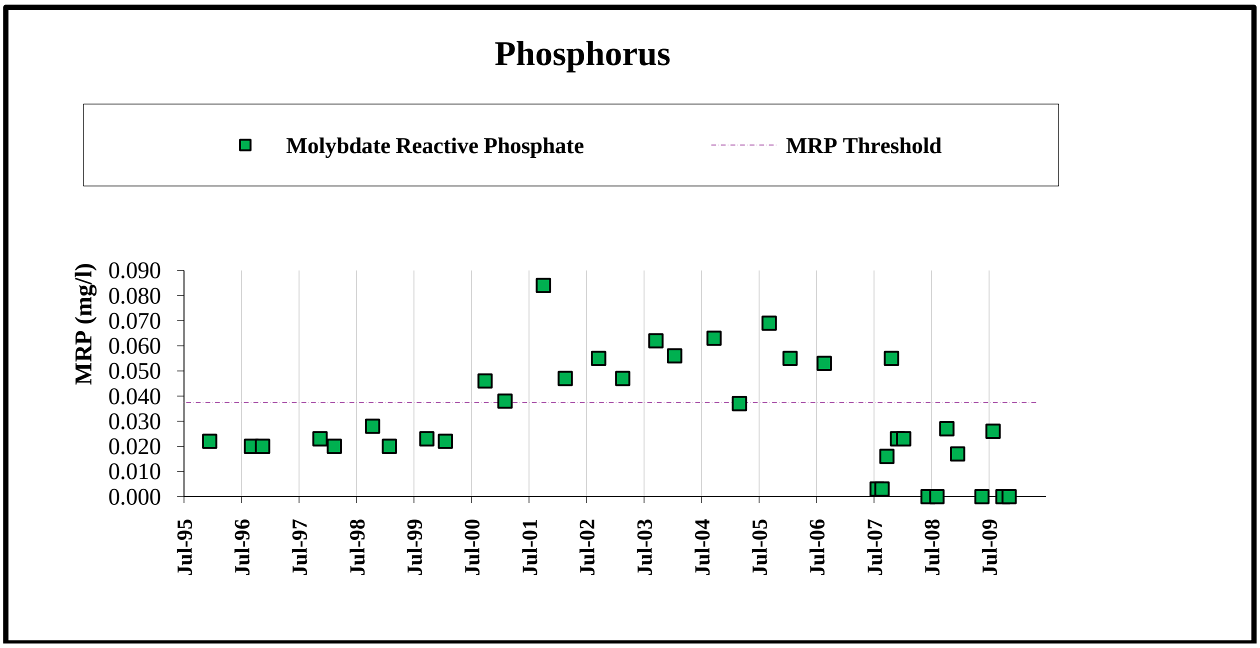



**Figure 11: Nitrate and Chloride Concentrations**




*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**

- There have been several exceedances of relevant threshold values for both iron and manganese, particularly in the period 2000 through 2006. Since then, there has been a marked decrease in related concentrations.
-
- 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 concentration of all other trace metals are low and/ or below laboratory detection limits.

- There have been two confirmed detections in 2007 of MCPA and mecoprop (active ingredients in herbicides), but concentrations were both below drinking water standards. The concentrations of all organic compounds to date are also below respective laboratory limits of detection.

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. Alternatively, the improvement may be linked to the construction of the wastewater treatment plant at Kilkerrin and/or the implementation of the Good Agricultural Practice regulations (e.g. changes in farmyard or slurry spreading practices) in the catchment area of the Lehinch Turlough.

## 8.4 Aquifer Characteristics

The presence of numerous karst features (enclosed depressions, dolines, swallow holes and turloughs) within the study area provides ample evidence for significant karstification of the limestone bedrock aquifer that supplies groundwater to the Kilkerrin-Moylough PWS. The established linkages between swallow holes, turloughs and springs at Kilkerrin (and Gortgarrow further north) 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 $Rk_c$ aquifer – a *regionally important karstic aquifer, dominated by conduit flow.* As indicated by outcrops on Rockfield hill, the epikarst appears to be well developed with prominent fissuring and widening of joints, which facilitates vertical percolation of rainwater. Although the limestone bedrock channels groundwater to all of the springs mapped near Kilkerrin, their respective flow and discharge characteristics show variation that is related to local geological characteristics, hydrometeorological conditions and a complex network of karst conduits. Rockfield hill, where bedrock is exposed or near ground surface, is considered to be the most significant groundwater recharge area associated with the Kilkerrin-Moylough PWS.

Flow rates through the karst system have been established from tracer tests, and range from 270 m/d to more than 1 km/d. These flow rates are similar to those reported for the Gortgarrow spring system (Meehan, 2009). Flow gradients between established point sources of recharge and springs at Kilkerrin range from <0.01 to 0.04.

# 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 the Kilkerrin springs are provided in **Figures 14 and 15.** The PWS is sourced from a single spring that discharges from a karstified limestone aquifer that is fed by water draining to and from a conduit system that is associated with Lehinch Turlough. The turlough receives water from surface runoff and streamflow, as well as shallow groundwater pathways, notably the epikarst (the upper, more fractured and weathered zone in karstified rocks). Numerous small seeps exist around the base of Rockfield hill, along the boundary between the epikarst and till (where the latter is present), and groundwater flow in the epikarst will generally follow topographic gradients. Soils are thin, and a high proportion of effective rainfall will infiltrate, facilitated by the epikarst. Overall, the aquifer system is characterised by:

- Rapid hydraulic responses to rainfall (with respect to spring discharges, water levels and chemistry)
- High groundwater flow velocities;
- Both diffuse and point recharge mechanisms;
- Extreme vulnerability to contamination;
- Little or no attenuation potential for contaminants, other than by dilution.

The main Marganure spring appears to be an underflow spring with a finite discharge capacity (approx. 0.05-0.06 $m^3/s$). A tracer test has proven a groundwater flow connection between the Lehinch Turlough and the Marganure spring. When the turlough fills up, this provides the bulk of the higher range discharges measured at the spring.

A hydraulic connection has also been demonstrated between a former quarry on the southern slope of the Rockfield hill to Springs A and B. A connection between the quarry and the Marganure spring was expected and the apparent absence of a connection may have a geological explanation or reflect the very wet climatic conditions under which the related tracer tests were conducted. Two possible explanations are:

- A shallow low-permeability layer is present between the conduit networks that feed the respective springs (i.e., such a layer could have prevented dyed water from reaching deeper conduits feeding the Marganure spring); and/or;

- Alternatively, such a low permeability layer is not present, and an interconnected but “full” conduit network (following the wet weather events in September) could have flushed the dyed water quickly out of the system before the dye had the opportunity to penetrate to deeper conduits that feed the Marganure spring.

Even though they are situated at different elevations, the springs at and near Marganure are inferred to be part of the same groundwater flow system. Recharge takes place diffusively and at points that are represented by enclosed depressions and swallow holes. The bedrock is exposed or close to the surface across most of the higher ground in the study area, and a relatively high proportion of rainfall is therefore able to recharge to the underlying bedrock aquifer. Recharge rates would be considerably lower where peat is present and subsoil is thicker.

Shallow alluvial deposits may contribute nominal quantities of water to the springs, but mostly, these deposits are thin and probably discontinuous, and as such, have a greater role in activating localised seeps during wet weather conditions.

## 9.2 Boundaries

Groundwater flows to the Marganure 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

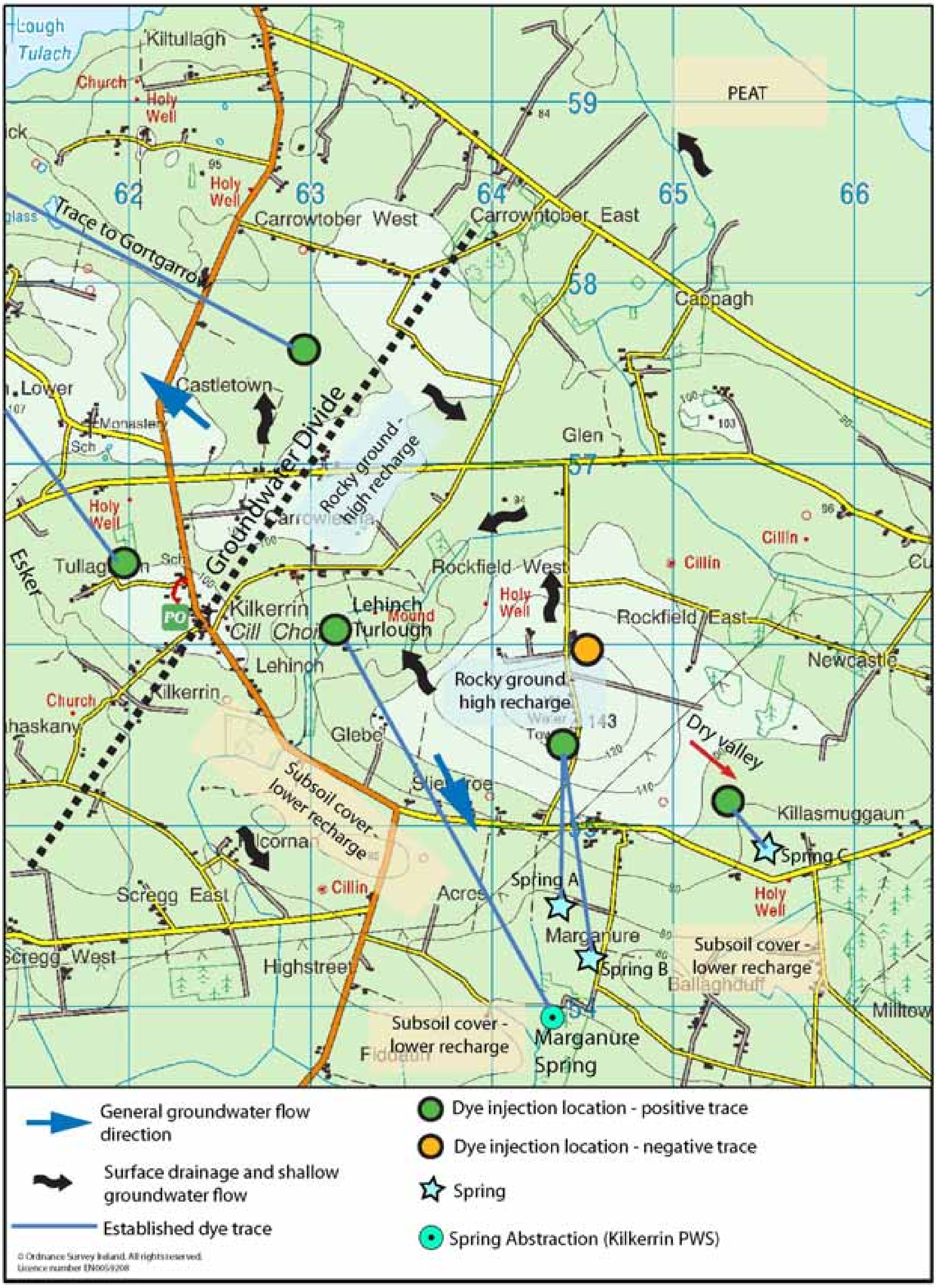



**Figure 14: Conceptual model – plan map**

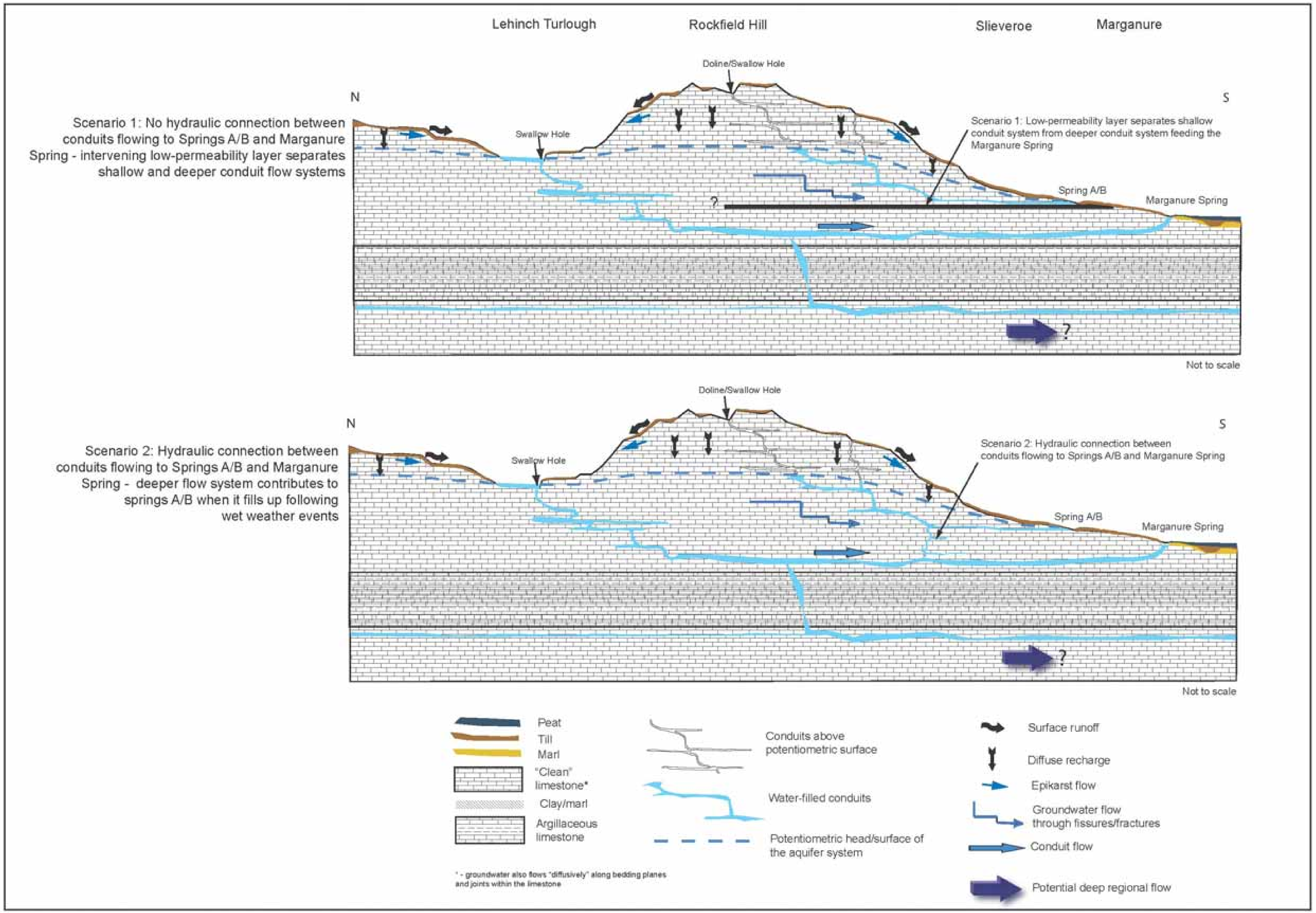



**Figure 15: Conceptual model – cross-section**

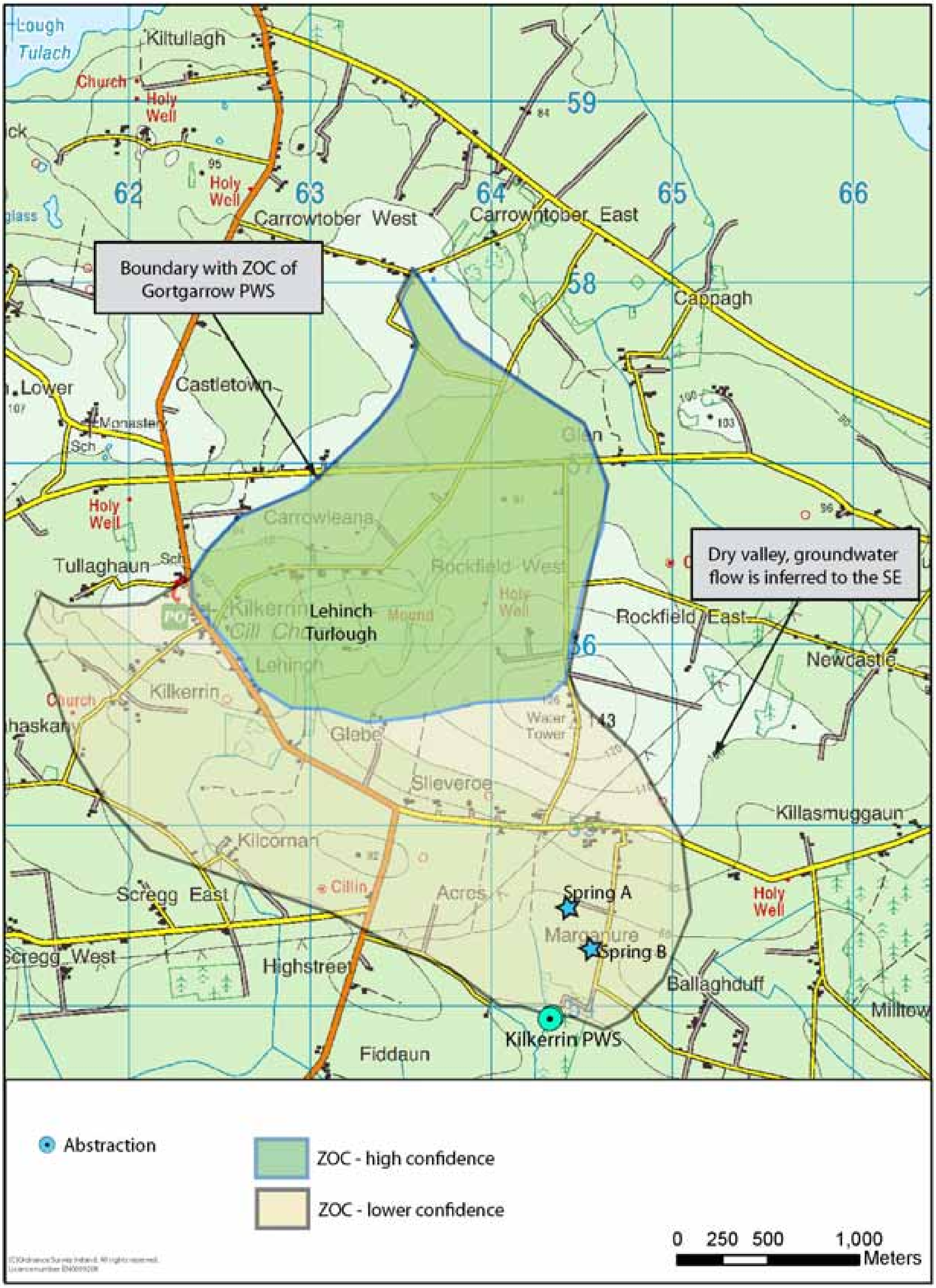



**Figure 16: Estimated Zone of Contribution**

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 Lehinch Turlough, which has been conclusively traced to the Marganure spring. The LC ZOC includes areas that have either been traced to springs A and B (assumed to be part of same groundwater system) or that are otherwise needed to support the highest range of measured discharges at Marganure. Importantly, it includes the southern slope of Rockfield hill (e.g. at Slieveroe).

In **Figure 16**, the **southern boundary** is defined by topography - all areas that are topographically lower than the Marganure spring are excluded from the ZOC. The **northern boundary** is marked by a NE-SW trending topographic ridge that separates the catchment of the Lehinch Turlough from a localised catchment at Castletown where a swallow hole was traced to the Gortgarrow spring in the opposite direction from Marganure. The **eastern boundary** is guided by tracer test results from injection locations at the top of Rockfield hill and at Killasmuggaun, as well as the NW-SE trending dry valley at Killasmuggaun. There is some uncertainty with the delineation of the eastern boundary, and if the recommended repeat tracer test from the top of Rockfiled hill (see Section 13) yields a positive trace to Marganure, then the eastern boundary will need to be adjusted. The **western boundary** extends to Kilkerrin village, and is guided by topography and earlier tracer test results associated with Gortgarrow (Meehan, 2008).

## 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 Marganure 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 Marganure 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 at Rockfield, an $R_c$ of approximately 75% can be expected (*i.e.* 75% of effective rainfall infiltrates into the groundwater system). This $R_c$ is at the lower range for Extreme vulnerability scenarios, but a low-range value is considered appropriate since slopes are quite steep (*i.e.* enhancing runoff). From a water balance perspective, a 2.2 $km^2$ area of Extreme vulnerability would be needed to support the average measured discharge of 2,678 $m^3$/d during the measurement period defined in Section 4. Within the HC ZOC, an estimated 1.5 $km^2$ Extreme vulnerability area 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**.** Given general catchment characteristics, an area-weighted recharge coefficient ($R_c$) of 58% is considered reasonable for the 3.2 $km^2$ area of the HC ZOC. Using the meteorological statistics in Section 5, the average annual recharge over the HC ZOC is estimated to be 352 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 (34% of HC ZOC) | 75% |
| Rc for High vulnerability areas (62% of HC ZOC area) | 50% |
| Rc for Moderate vulnerability areas (4% of HC ZOC) | 35% |
| Bulk recharge coefficient for HC ZOC | 58% |
| Annual recharge rate | 352 mm |

This value is slightly lower than results from a similar study at Gortgarrow (Meehan, 2008) which considered a value of 391 mm/yr. The difference between the two is accounted for by vulnerability categories covering the respective ZOC areas, as these determine the recharge coefficients that are used in the water balance calculations. With a bulk recharge coefficient of 58%, it follows that the remaining 42% of the water balance is represented by surface runoff. Significant quantities of runoff are generated within the catchment, as witnessed during storm events in November 2010 and February 2011, and the rapid flooding of Lehinch Turlough. The runoff flows to the turlough via both natural and artificial drainage channels (see **Appendix A**) and drains underground in the turlough area or leaves then catchment via the overflow channel from the turlough.

A recharge rate of 352 mm/yr equates to 3,084 $m^3$/d over the HC ZOC, which is 15% greater than the average measured discharge at the Marganure spring over the referenced 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**. Unfortunately, spring discharges were not measured during the catastrophic flooding events of November 2009, so the actual high extremes of the Kilkerrin groundwater system have not yet been conclusively quantified. Nonetheless, the available data point to the main spring as having a finite discharge capacity, which implies that the existing data set from the Marganure spring describes both the average and "wet weather discharges" from the spring reasonably well. As such, the available measured data and associated water balance calculations provide reasonable descriptions of the ZOC to the spring.

The above deliberations reflect the Marganure spring only, but not springs A and B. Although springs A and B are located within 1 km of the Marganure spring, they are situated at higher elevations and, as such, represent either overflow springs or a separate localised groundwater flow system. Dye injected from a former quarry on the southern slope of Rockfield hill was traced to springs A and B but not the main Marganure spring. Initial results using Fluorescein were later confirmed by a second test using Rhodamine. The apparent lack of connection between the quarry and the Marganure spring still needs to be conclusively demonstrated by repeating the test from the quarry one more time, but next time under dry, low-flow conditions, ideally when springs A and B are inactive (i.e. to test if the dye could penetrate deeper and reach the Marganure spring). Spot measurements of discharges from the two springs are not sufficiently frequent or accurate to estimate how much of the effective rainfall on Rockfield hill is discharged by these springs. The two springs started to flow later than the overflow observed at the Marganure spring, by several days. On November 22nd 2010, when the overflow from the Marganure spring was measured at 43 l/s, springs A and B were discharging small quantities of water, estimated to be 10 l/s and 3 l/s, respectively. In stark contrast, on January 17th, discharges were measured at 54 and 30 l/s, respectively, compared to 50 l/s at Marganure. However, these measurements must be regarded with caution. Due to spring and drainage configurations, discharges from springs A and B were measured in nearby drainage ditches which also contained additional water from other drainage ditches and shallow seeps from alluvial sediments. The measured flow was fast and turbulent, subjecting the measurements to significant potential error (measurements were conducted with an impeller flow meter). Although the "real" flow at springs A and B and the percent error associated with the measurements are not known, the springs are undoubtedly an important part of the overall groundwater system and water balance at Marganure, especially during wet hydrometeorological conditions. For purposes of this study, values of 50% of the measured discharges are used for further consideration, i.e. 27 and 15 l/s respectively (for a total of 42 l/s).

To account for uncertainties surrounding the relationship between the Marganure spring and the southern slope of Rockfield hill, as well as the discharges from springs A and B, additional contributing area 4.7 $km^2$ has been delineated as a ZOC of lower confidence. To supply the 42 l/s from springs A and B, a minimum area of 2.1 $km^2$ is required for a potential recharge value of 607 mm/yr. Specifically where the additional recharge to springs A and B occurs compared to the Marganure spring has not been conclusively established, but the obvious candidate areas are the southern slopes of Rockfield hill between Killasmuggaun and Glebe, which are mapped as Extreme vulnerability and will therefore accommodate significant additional recharge.

# 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, flow velocities greater than 1 km/d have been recorded from the karst at Kilkerrin, which means that, once in the conduit system, pollutants can reach the PWS within 3 days. 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 Lehinch Turlough.

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 34%) or SI/High (62%), the remainder 4% being SI/Moderate. Within the total combined HC and LC ZOC areas, SI designations are as follows:

- SI/X: 3.2% of total ZOC area
- SI/E: 32.5% of total ZOC area
- SI/H: 31.0% of total ZOC area
- SI/M: 15.9% of total ZOC area
- SI/L: 17.4% of total ZOC area

# 11 Potential Pollution Sources

There are several potential sources of groundwater pollution within the ZOC:

- Farmyards and associated landspreading;
- Septic tanks (although Kilkerrin households were connected to a new sewerage scheme in 2008);
- A wastewater treatment plant (500 population equivalent) located at the immediate western margin of Lehinch Turlough.

As a result, the risk of groundwater pollution of the PWS is considered to be extreme.

# 12 Conclusions

The Kilkerrin springs discharge from a karstified limestone aquifer in which groundwater flows through fissures and open conduits that facilitate rapid transport of water. The primary contributing area to the Marganure spring, which supplies water to the Kilkerrin PWS, is the catchment area of the Lehinch Turlough. Water entering a swallow hole within the turlough has been traced directly to the Marganure spring.

Spring discharges at Marganure are reasonably well quantified, but results from tracer testing have demonstrated that groundwater flow paths are complex with some important outstanding questions. Outside of the catchment of the Lehinch Turlough, there is uncertainty about contributing areas to the spring (system). For this reason, the ZOC defined by this study has been divided into areas of high confidence and lower confidence. High confidence areas have been delineated from conclusive tracer tests. Lower confidence areas represent additional contributing areas that are needed to satisfy water balance calculations. The high confidence ZOC occupies an area of 3.2 $km^2$ whereas the lower confidence ZOC occupies an area of 4.7 $km^2$.

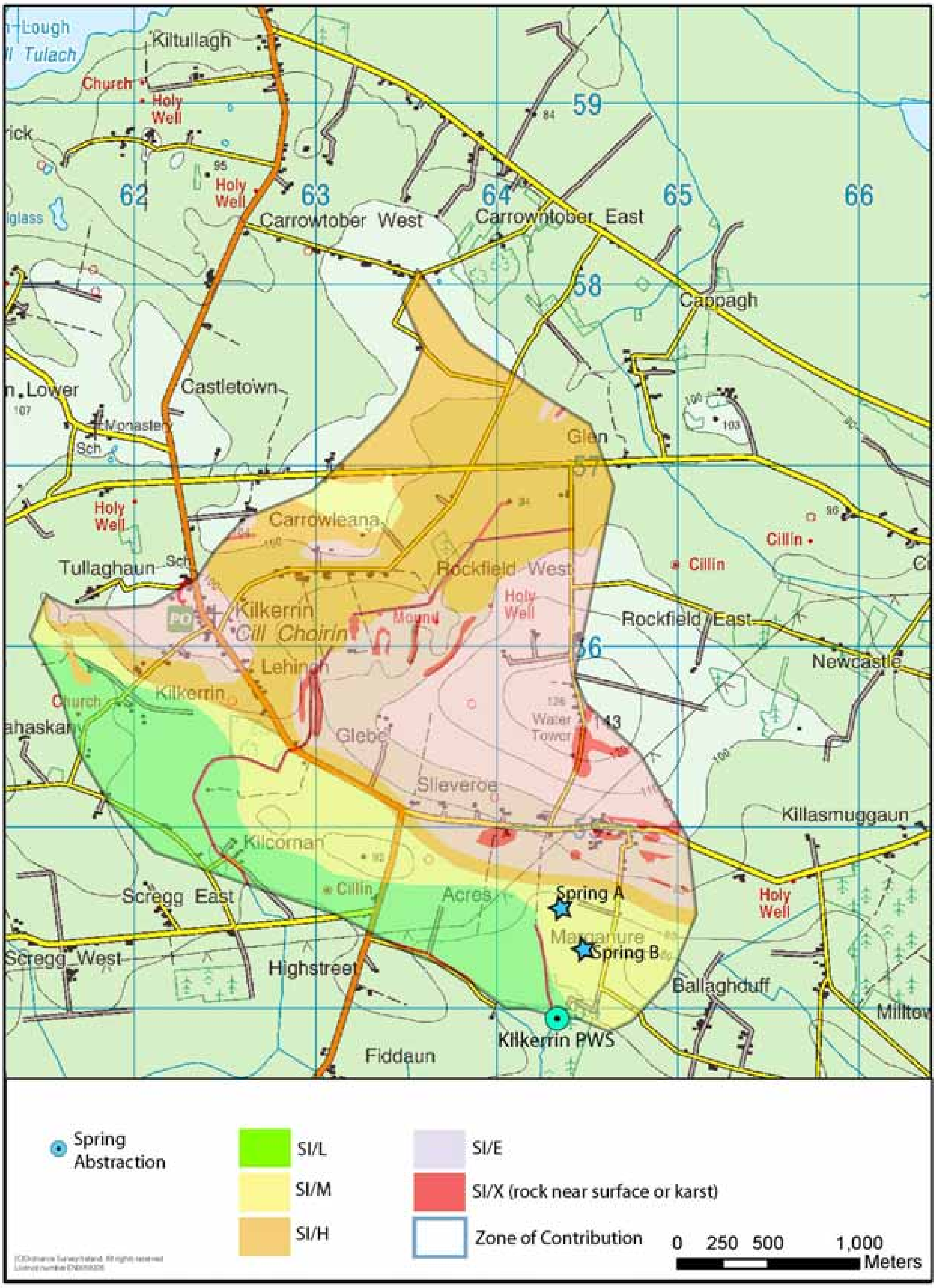



**Figure 17: Source Protection Zones**

The areas within the delineated LC ZOC that actually provide water to the springs have not been conclusively demonstrated, but are in likelihood focussed on the southern slope of Rockfield hill.

Water quality data from the Marganure spring shows historical evidence of contamination by organic waste sources. Groundwater quality is especially vulnerable to pollution in the surface catchment of the Lehinch Turlough, and possibly the southern slope of Rockfield hill. With numerous potential sources of pollution distributed across the entire study area, the overall risk of pollution to the PWS is significant.

# 13 Recommendations

Given the vulnerability of the PWS to contamination, good agricultural practice relating to landspreading and slurry storage must 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.

The proximity of the Kilkerrin wastewater treatment plant to the swallow hole in the Lehinch Turlough requires caution by the operators of the plant to avoid, by all means, discharges of wastewater into the ground, whether directly or indirectly.

Tracer tests should be repeated at two specific injection locations to address uncertainties associated with results to date and, therefore boundaries of the delineated ZOCs, as follows:

1. One injection at the former quarry at Slieveroe to test and verify if there could be a connection between the south slope of Rockfield hill and the Marganure spring during lower-flow (drier climatic) conditions than have been tested to date. As explained in Section 8, test results from the old quarry to date have raised questions about why the dye was (apparently) not detected at the Marganure spring – specifically, was the dye "skimmed" or flushed out through shallow conduits because the groundwater flow system was "full" (due to very wet conditions at the time of testing), or could a shallow low-permeability layer (barrier) be present underground that prevents the dye at this location from reaching deeper conduits that are connected to the Maragnure spring? For the recommended test, dye would be injected at an opportune time, ideally after flows at Springs A and B cease.

2. One injection at the swallow hole at the top of Rockfield hill to test and verify the fate and transport of the dye from this location, as previous tests yielded no positive traces at any of the sampled locations. Again, the test would be repeated during lower-flow (drier) conditions, at an opportune time when the Lehinch Turlough holds little water and is draining actively. The previous tests were carried out during very wet conditions when the turlough was significantly flooded. It cannot be ruled out that previous dye entered and mixed with the surface water, resulting in considerable dilution of the dye and an extended residence time over several weeks/months (and potential retention on vegetation). The test should involve an extended set of sampling locations, including both natural and artificial drainages to the turlough. Given the labour intensive nature of sampling, use of optical brightener with cotton samplers that can be left in place at monitoring points is suggested.

If either test shows a positive trace to the Marganure spring, the ZOC and SPZs defined in this report should be updated. Related drilling at Rockfield would also be helpful to identify the potential presence of any shallow low-permeability layers in the limestone sequence. As well, the discharges from Springs A and B are significant during wet weather conditions, and should ideally be quantified more accurately. This would require the construction of weirs and estimation of respective overflows, in a manner similar to hat has been accomplished at the Marganure spring.

Finally, two dye tracer tests conducted as part of this study from locations north of Kilkerrin village (swallow holes at Castletown and Kiltullagh Turlough) were detected at the Gortgarrow PWS. In the future, these results should be used to update the ZOC and existing SPZ report for the Gortgarrow PWS (Meehan, 2008).

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# APPENDIX A

## Photographs




V-notch weir - early September 2010 (no overflow)


V-notch weir - mid-December 2010 (overflow)

Outcrop of limestone on Rockfield Hill

Limestone bedding near Lehinch Turlough

Outcrop of marl near Marganure spring

Marl at base of drainage ditch by Marganure spring

Swallow hole at Lehinch Turlough
(traced to Marganure spring)

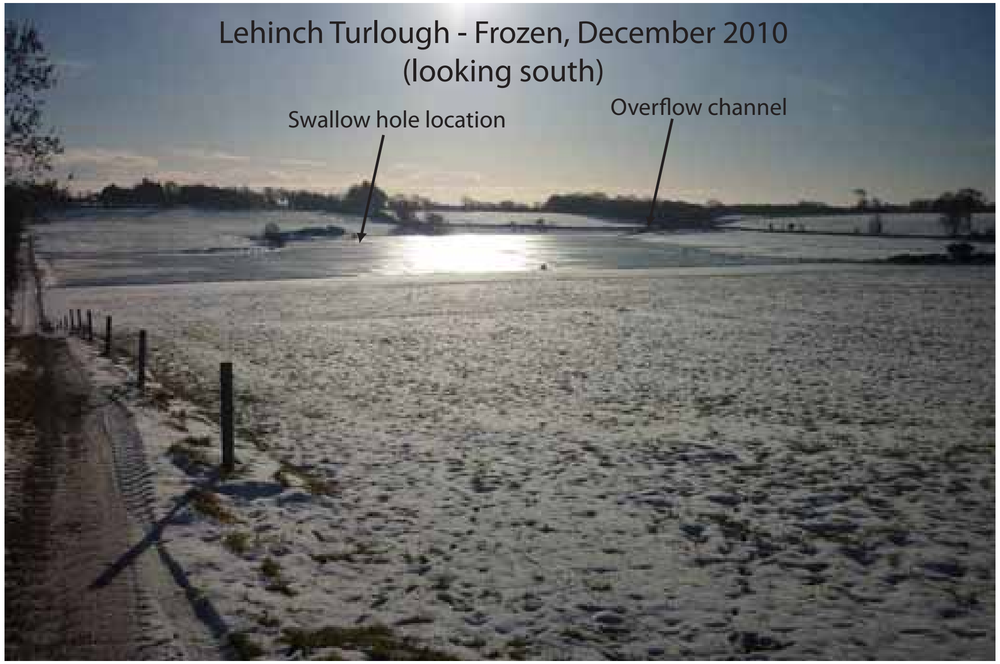
Close-up of swallow hole at Lehinch Turlough



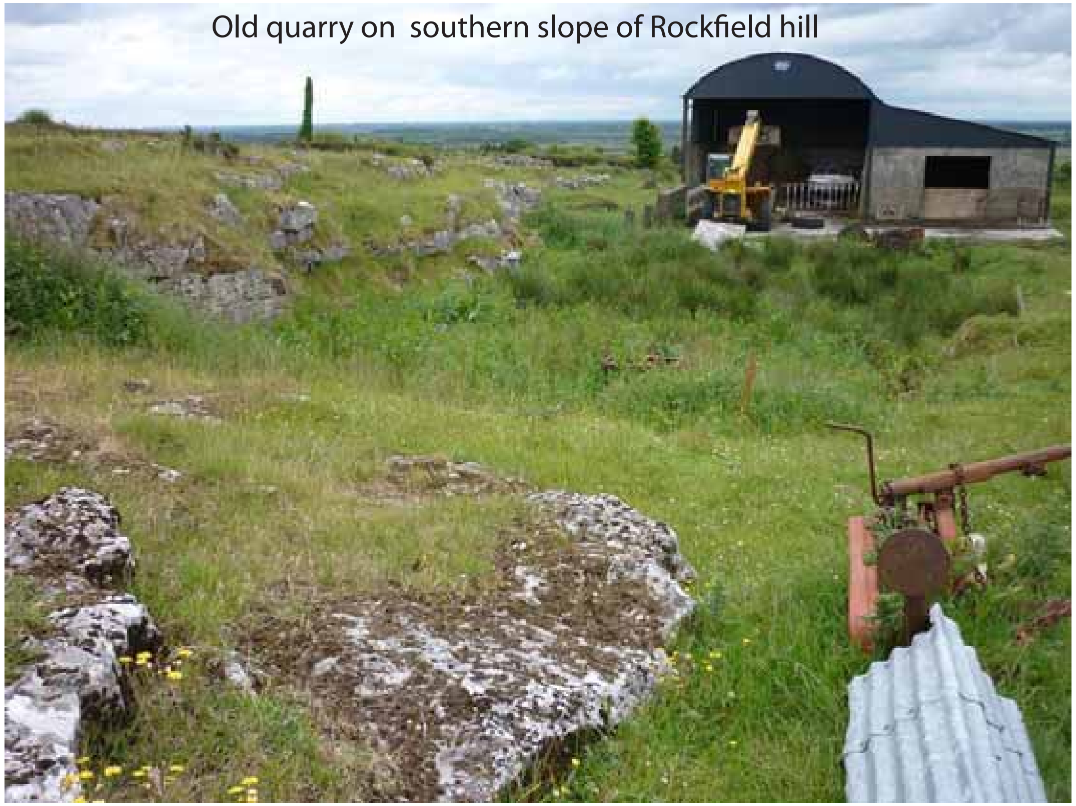
Catchment of Lehinch Turlough
(eastern end of turlough, looking south)


Lehinch Turlough - Dry, July 2010
(western end of turlough, looking north)


Lehinch Turlough - Flooded, November 2010
(looking south)
Swallow hole location
Overflow channel
Rockfield hill


Lehinch Turlough - Frozen, December 2010
(looking south)
Swallow hole location
Overflow channel

Old quarry on southern slope of Rockfield hill



Injection of Rhodamine in old quarry

Injection of Fluorescein from top of Rockfield hill

# APPENDIX B

**Mapped Karst Features**

| Feature Type | Easting | Northing | General Area | Comments |
|---|---|---|---|---|
| Enclosed Depression | 162174 | 251480 | Annaghmore | Field full of enclosed depressions |
| Swallow Hole | 162815 | 257309 | Castletown | Along drainage ditch |
| Swallow Hole | 162905 | 257513 | Castletown | Infilled with large rocks |
| Enclosed Depression | 163556 | 257435 | Castletown | |
| Spring | 162427 | 256928 | Castletown | Dubious - seep? |
| Spring | 164564 | 257263 | Glen | Tiny |
| Enclosed Depression | 166050 | 256912 | Curraghmore | |
| Enclosed Depression | 165385 | 255035 | Killasmuggaun | |
| Spring | 164423 | 254547 | Marganure | Spring A |
| Spring | 164632 | 254364 | Marganure | Spring B |
| Swallow Hole | 164436 | 256022 | Rockfield | Injection site |
| Swallow Hole | 160392 | 259677 | Kiltullagh | Kiltullagh, small swallow hole |
| Swallow Hole | 160424 | 259687 | Kiltullagh | Kiltullagh, main swallow hole |
| Swallow Hole | 161853 | 256805 | Tullaghaun | Traced to Gortgarrow |
| Swallow Hole | 161853 | 256798 | Kilkerrin village | Takes overflow |
| Swallow Hole | 161734 | 256658 | Kilkerrin village | Takes overflow |
| Swallow Hole | 163164 | 256001 | Lehinch | Main Lehinch swallow hole |
| Swallow Hole | 163360 | 256169 | Lehinch | In streambed |
| Swallow Hole | 163486 | 256220 | Kilkerrin village | Appears to sink into bedrock |
| Cave | 163573 | 256022 | Lehinch | May not be a proper cave, unclear if opening at surface continues deep |
| Dry Valley | 165256 | 255260 | Killasmuggaun | SE direction |

# APPENDIX C

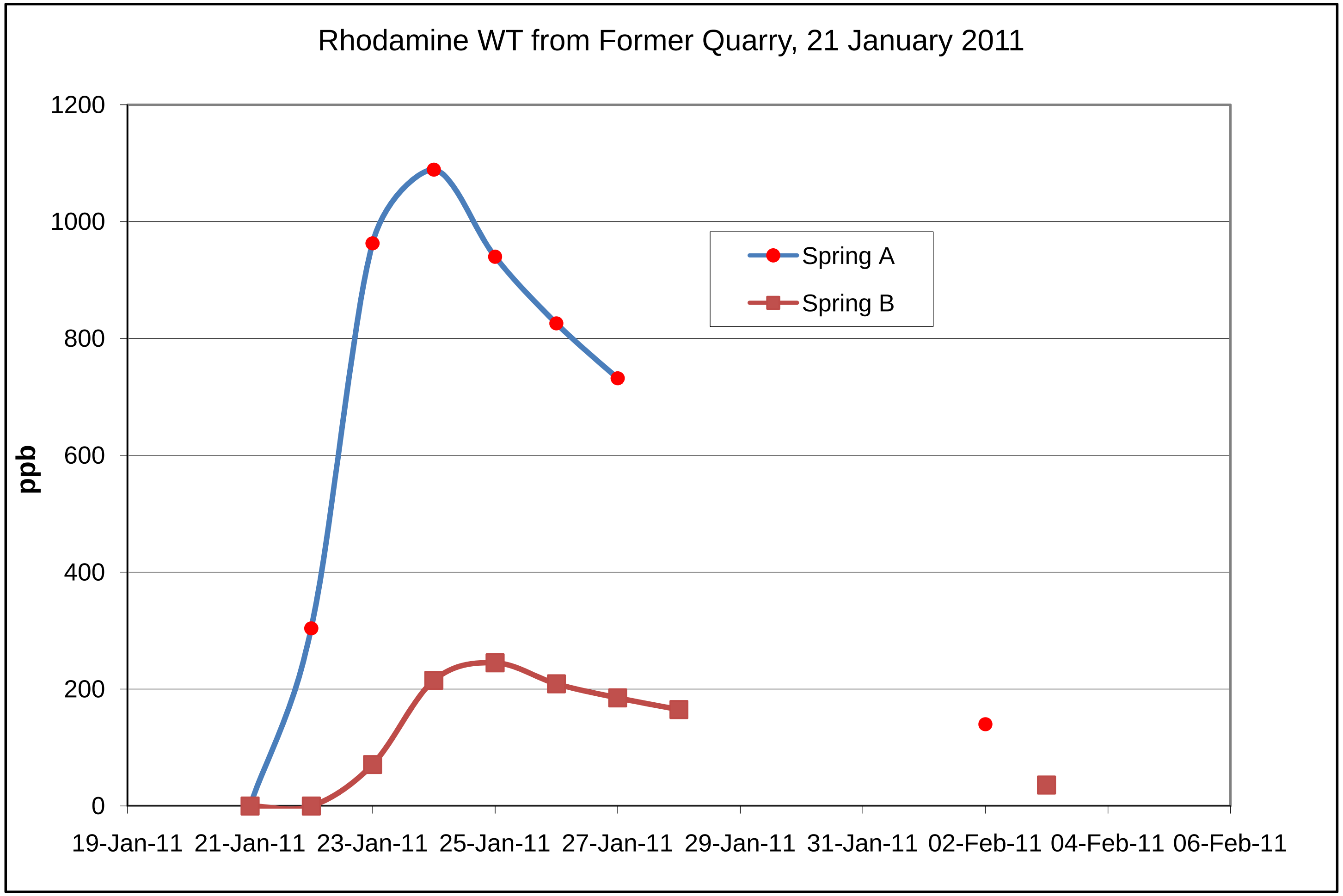
## Tracer Test Results

## Kilkerrin-Moylough PWS - Summary of Dye Tracing

| Injection Date | Injection Site | Description | Input NGR | Tracer Used | Comments | Output site | Output NGR | Result/Flow Velocity |
|---|---|---|---|---|---|---|---|---|
| 18/6/10 | Glenamaddy Road Sink | Depression and channel in field | 162847E 261365N | Rhodamine 1.2 kg / 6 litres | 2000 gallon tanker x 3. Dye injected at start of second tanker load | Lettera Spring | 159540E 262120N | Positive trace. 71.6 m/hr or 1,719 m/d |
| 18/6/10 | Kiltullagh Lough | Swallow hole draining turlough | 160424E 259687N | Fluorescein 8 kgs / 10 litres | Dye was poured into naturally sinking water | Gortgarrow Spring | 157099E 259498N | Positive trace. 23.6 m/hr or 567 m/d |
| 11/10/10 | Lehinch Turlough | Swallow hole into bedrock | 163486E 256220N | Fluorescein 2 kgs / 2.5 litres | Naturally sinking water (last of turlough drainage) to swallow hole after wet weather | Marganure Spring | 164346E 253959N | Positive trace. Between 58-138m/hr or 1382 m/d |
| 19/10/10 | Castletown | Rock-filled depression at swallow hole site | 163053E 257586N | Rhodamine 1.5 kg / 7.5 litres | 2000 gallon tanker x 2. Water and dye ponded slightly, but drained in 30 minutes | Gortgarrow Spring | 157099E 259498N | Positive trace. 11.4 m/hr or 273 m/d |
| 19/10/10 | Slieveroe Quarry | Former quarry beside water tower. Opening in limestone pavement | 164388E 255449N | Optical Brightener 10 litres | 2000 gallon tanker x 2. Water ponded on grass with OB before we found opening in rock. Dye spread on grass – but draining away relatively quickly | Marganure Spring | 164424E 254547N | Negative trace. No UV lamp detection on cotton sampler |
| 19/10/10 | Slieveroe Quarry | Former quarry beside water tower. Opening in limestone pavement | 164388E 255449N | Optical Brightener 10 litres | 2000 gallon tanker x 2. Water ponded on grass with OB before we found opening in rock. Dye spread on grass – but draining away relatively quickly | Spring A | 164410E 254560N | Negative trace. UV lamp detection on cotton sampler left in flowing ditch leading away from spring |
| 19/10/10 | Slieveroe Quarry | Former quarry beside water tower. Opening in limestone pavement | 164388E 255449N | Optical Brightener 10 litres | 2000 gallon tanker x 2. Water ponded on grass with OB before we found opening in rock. Dye spread on grass – but draining away relatively quickly | Spring B | 164595E 254310E | Negative trace. UV lamp detection on cotton sampler left in flowing ditch leading away from spring |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9/11/10 | Killasmuggaun | Swallow hole near old quarry beside 2 small seeps/springs | 165331E 255060N | Fluorescein 2 kg / 2.5 litres | Dye poured directly into sinking stream. Drained immediately | Kilsmuggaun Springs | 165407E 255086N & 165581E 254847N | Positive trace. 150 - 200 m/hr or 3600 - 4800 m/d (200m of that was on surface in stream) |
| 9/11/10 | Slieveroe Quarry | Former quarry beside water tower. Opening in limestone pavement | 164388E 255449N | Rhodamine 1.5 kg / 7.5 litres | 2000 gallon tanker x 2. Dye poured directly into opening in the rock and drained quickly. | Marganure Spring | 164424E 254547N | Questionable positive trace. >40 m/hr or 960 m/d |
| 1/21/11 | Slieveroe Quarry | Former quarry beside water tower. Opening in limestone pavement | 164388E 255449N | Rhodamine 2 kg/ 7.5 litres | 2000 gallon tanker x 2. Dye poured directly into opening in the rock and drained quickly. | Marganure Spring | 164424E 254547N | No detection |
| 1/21/11 | Rockfield hill | Swallow hole by farm, 400 m NNE of water tower | 164460E 256010N | Fluorescein 3 kg/10 litres | 2000 gallon tanker x 2. Dye poured directly into opening in the rock and drained quickly. | Marganure Spring | 164424E 254547N | No detection |
| 2/411 | Annaghmore | Swallow hole in depression | 162170E 251460N | Rhodamine 3 kg | 2000 gallon tanker x 2. Dye poured directly into opening in the rock and drained quickly. | Marganure Spring | 164424E 254547N | No detection |
| 4/5/11 | Rockfield hill | Swallow hole by farm, 400 m NNE of water tower | 164460E 256010N | Optical Brightener 19 litres and Rhodamine 2 kg | 2000 gallon tanker x 2. Dye poured directly into opening in the rock and drained quickly. | Ditch that carries merged water from Springs A and B | Location adjacent to Marganure pump house | Questionable low-level detections (not considered as a confirmed positive trace) |

**Examples of Positive Traces**



## Examples of Positive Traces