Environmental Protection Agency

Establishment of Groundwater Source Protection Zones

Kilmaine Public Water Supply Scheme

May 2014

Prepared by:
Coran Kelly TOBIN

With contributions from:
Henning Moe, Michal Smietanka (CDM Smith), Dr. David Drew, Consultant Geologist; Dr. Caoimhe Hickey (GSI)

And with assistance from:
Mayo County Council, Teagasc, and local farmers

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).

TABLE OF CONTENTS

Tables

Figures

1 Introduction

Groundwater Source Protection Zones have been delineated for the Kilmaine Public Water Supply Scheme according to the principles and methodologies set out in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999) and the GSI/EPA/IGI training course on Groundwater Source Protection Zone Delineation, as well as EPA Advice Note No. 7 (EPA, 2011).

The objectives of the report are as follows:

- To outline the principal hydrogeological characteristics of the area surrounding the source.
- To delineate source protection zones for the Kilmaine Public Water Supply Scheme.
- To assist the Environmental Protection Agency and Mayo County Council in protecting the water supply from contamination.

Groundwater protection zones are delineated to help prioritise the area around the source in terms of pollution risk to groundwater. This prioritisation is intended as a guide in evaluating the likely suitability of an area for a proposed activity prior to site investigations. The delineation and use of groundwater protection zones is further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

The maps produced are based largely on the readily available information in the area, extensive field walkovers, water tracing, water level measuring, flow measurements 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

It is acknowledged that the technical standard to be achieved within Source Protection Zone (SPZ) delineation is that of the Geological Survey of Ireland, both in terms of implementation and reporting. The primary guidance documents are:

- Groundwater Protection Scheme Guidelines (DELG/EPA/GSI, 1999); and,
- GSI Guidelines for the Assessment and Mapping of Groundwater Vulnerability to Contamination (Fitzsimons *et al.*, draft 2003).

As such the methodology consisted of a desk study, site visits, walk over surveys, investigative field work, data analysis, interpretation and reporting.

A dye tracing programme comprising 5 separate dye injections was conducted in conjunction with the GSI during 2012 and 2013. Subsequent analysis of the collected water samples, cotton wool and charcoal detectors was conducted in the GSI.

3 Location, site description and well head protection

The Kilmaine Public Water Supply comprises two springs: one approximately 700 m northeast of Kilmaine village in the townland of Killernan and the other approximately 2 km southwest of the village in the townland of Frenchbrook South (**Figure 1**).

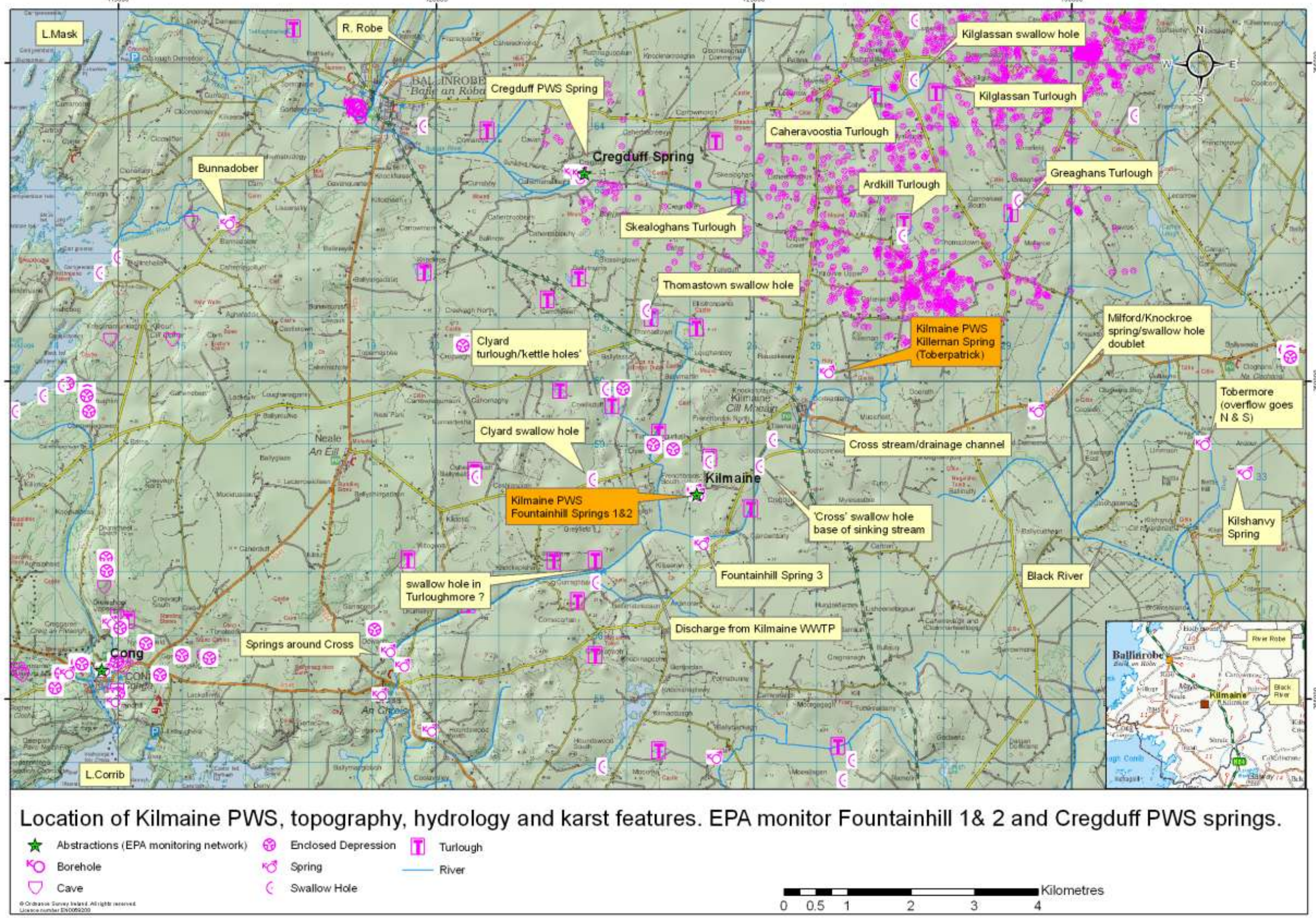

Figure 1 Location of Kilmaine PWS springs, turloughs, springs, streams in the study area.

Two distinct springs issue from the ground at Frenchbrook South approximately 90 m apart, though only one is used for abstraction (Fountainhill Spring 1) – the one nearest the pump house (**Figure 2, Figure 3**), which is within a covered cylindrical concrete chamber. These springs are known locally, and by Mayo County Council, and by Meehan and Kelly (2011) as Fountainhill springs and therefore this naming will be used herein. The springs are included in the national groundwater monitoring points, sampled and monitored by the EPA for water quality and flow. A third spring is located approximately 800 m to the south, in the townland of Fountainhill – Fountainhill 3 in this report (Meehan and Kelly, 2011).

The spring at Killernan, northeast of the village, is known as Tober Patrick and issues from an uncovered concrete chamber (**Figure 5**).

Fountainhill spring 1 provides over 90% of the water for the scheme. Both Fountainhill and Killernan are chlorinated and feed directly into the mains network.

4 Summary details

Table 4-1 provides summary details of the springs at Frenchbrook South and Killernan.

Table 4-1 Summary of Kilmaine source details

	Fountainhill Spring 1	**Fountainhill Spring 2**	**Tober Patrick Spring (Killernan)**
EU Reporting Code	IE_W_G_0019_16_015	IE_W_G_0019_16_015	Not applicable
Drinking water code	2200PUB1016	Not applicable	2200PUB1016
Grid reference	E124112 N258221	E124060 N258287	E126275 N260200
Townland	Frenchbrook South	Frenchbrook South	Killernan
Source type	Spring	Spring	Spring
Elevation (Ground Level)	Approximately 28 mOD	Approximately 29 mOD	35–40 mOD
Depth to rock	Unknown, assumed 1-3 m	Unknown, assumed 1-3 m	Unknown, assumed 1-3 m
Static water level	Ground level	Ground level	Ground level
Average abstraction rate	500–550 m^3/day (~ 6 l/s)	0	30–40 m^3/day
Estimated Discharge including pumping	Average: 97 l/s (8,400 m^3/day) Range (min–max): 7–250 l/s		Unknown

The average quantity of water abstracted from Fountainhill Spring 1 is currently 500–550 m^3/d (5.7–6.4 l/s). The overflow from Fountainhill Spring 1 issues diffusely from around the base of the spring chamber and joins the overflow from Fountainhill Spring 2. The combined overflow is measured using time of flight technology (**Figure 4**) and a discharge hydrograph is presented in **Figure 6** which shows the daily maxima and rainfall (Teagasc data for the Cregduff catchment, some 2 km north).

During the monitoring period, which is continuous apart from June 2011 to June 2012, the combined overflow ranged from virtually zero (no overflow) during the prolonged dry weather conditions in the summer of 2010 to approximately 250 l/s (21,500 m^3/d) in January 2013. The plot also illustrates that the flow from Fountainhill responds rapidly to rainfall. Analysis of the spring flow characteristics indicates that it is moderately karstified, with a high Q50:Q90 ratio that indicates low storage/baseflow (Drew, D., 2013, *pers. comm*.). A flow duration curve is depicted in **Figure 7**. A plot of cumulative rainfall and cumulative discharge is depicted in **Figure 8** and both are closely correlated.

Including pumping, the total mean combined discharge from Springs 1 and 2 is approximately 97 l/s (8,400 m^3/d). Except during prolonged dry weather conditions, the abstracted quantity is relatively small compared to the total estimated mean discharge.

Figure 2 Kilmaine PWS (Fountainhill)

Figure 4 EPA instrumented overflow channel

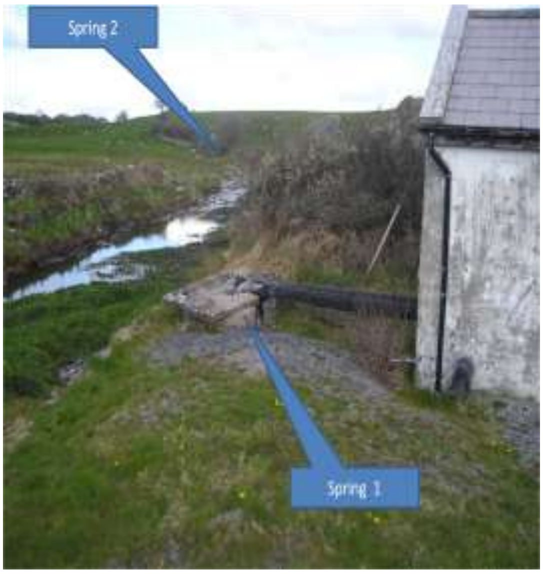

Figure 3 'Fountainhill' Springs

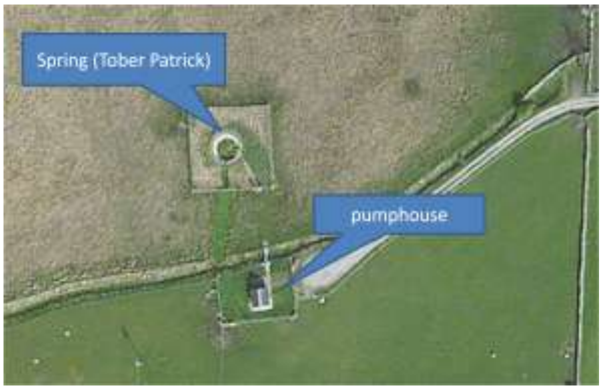

Figure 5 Kilmaine PWS (Tober Patrick, Killernan)

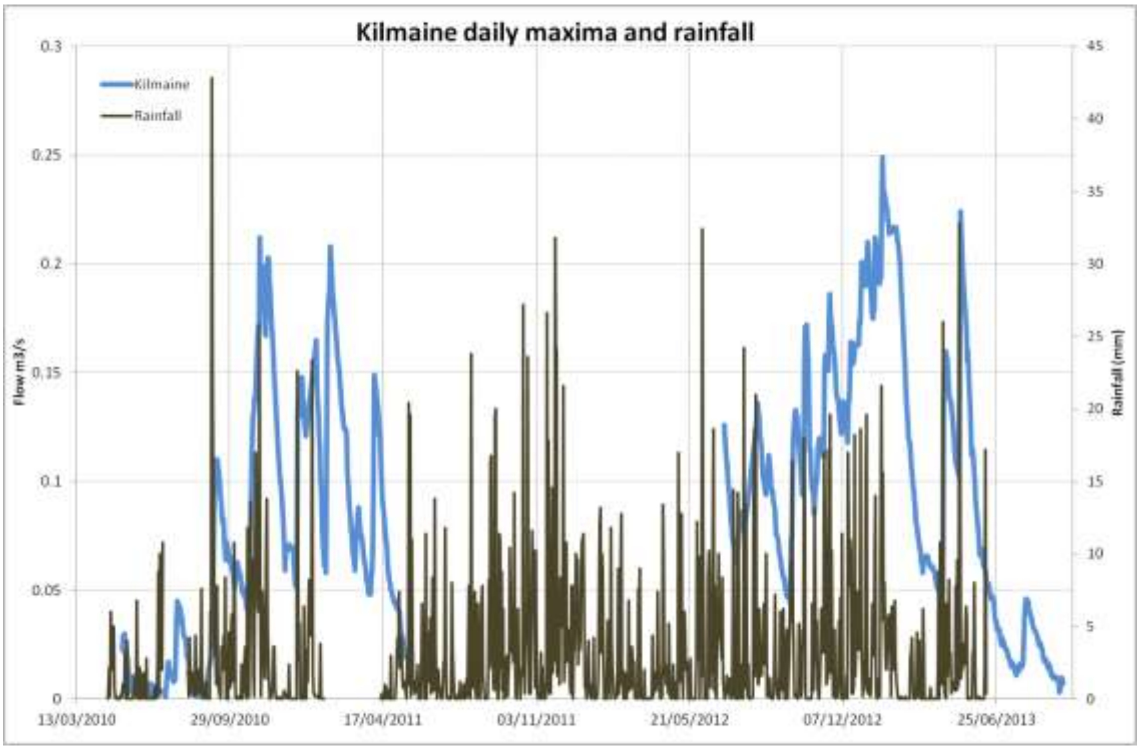

Figure 6 Estimated Overflow (Daily maxima) at Fountainhill (EPA dataset), and rainfall (Teagasc Data for Cregduff)

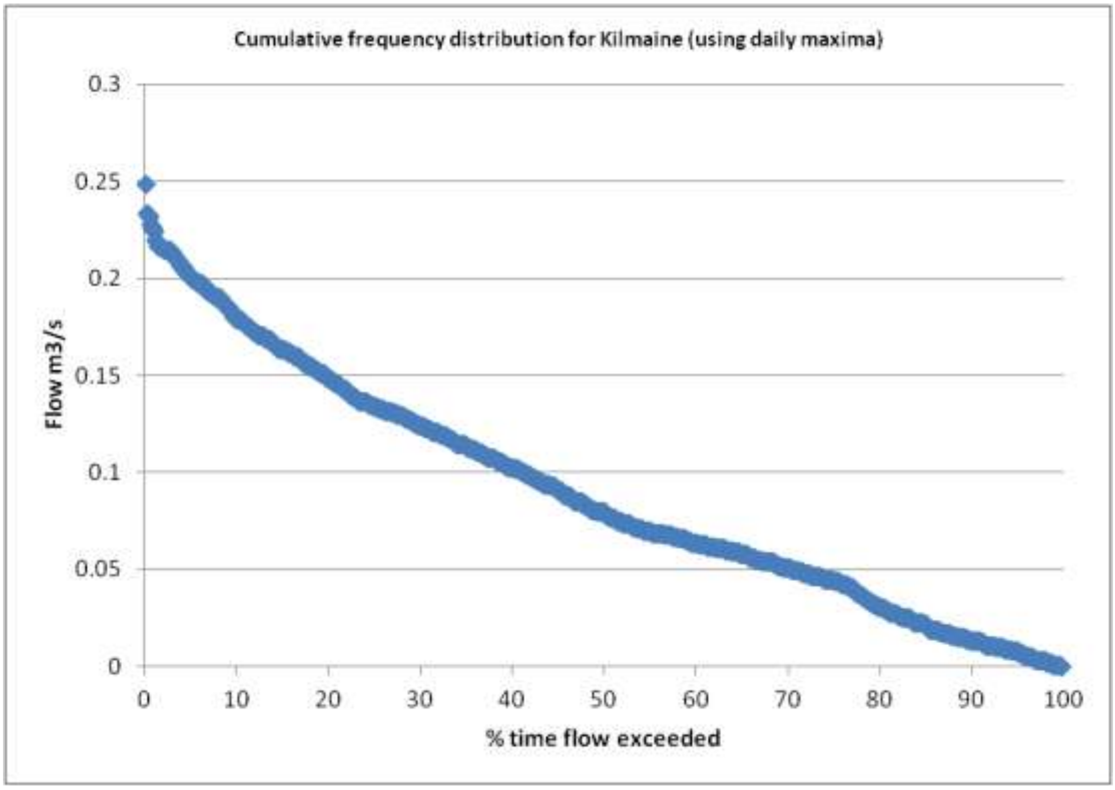

Figure 7 Flow duration curve for Fountainhill Springs (daily maxima)

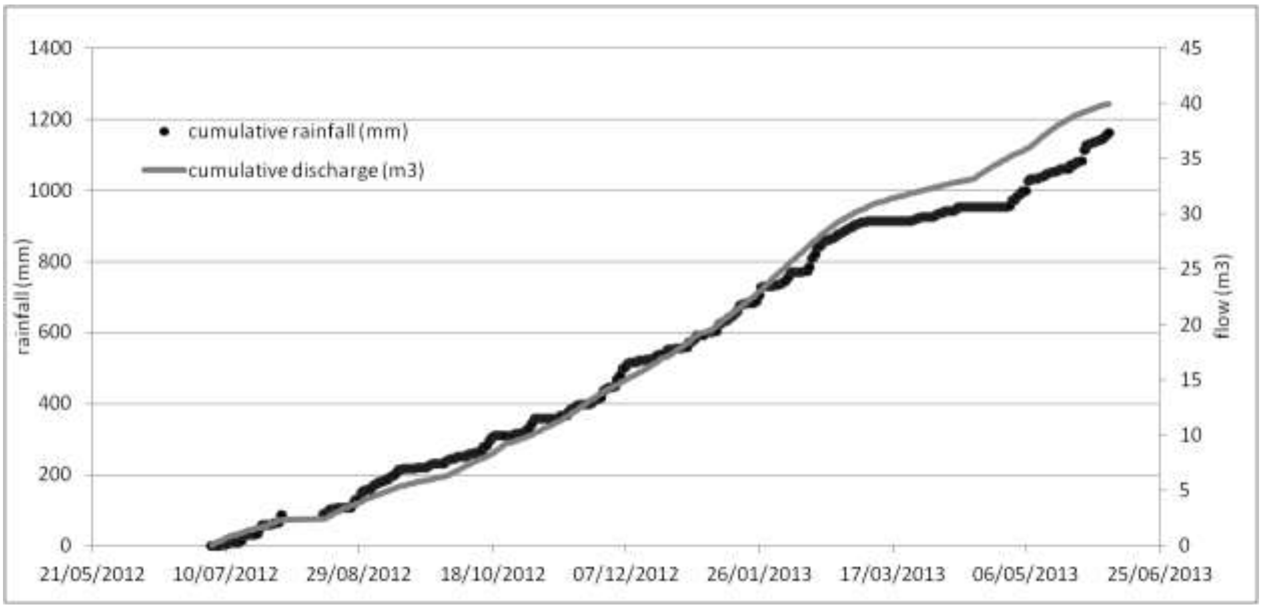

Figure 8 Cumulative rainfall and cumulative discharge (Fountainhill)

5 TOPOGRAPHY, SURFACE HYDROLOGY AND LANDUSE

The regional topography shown in **Figure 1** depicts a relatively low-lying subtle landscape that gradually slopes to the west, southwest and south. There is a plateau north and west of Kilmaine along which the N84 to Ballinrobe is located. The N84 is likely to have been purposefully built on the margin of the plateau where there are drier conditions. The topographic elevation ranges from 45–50 mOD in the northern and northeastern parts of the study area to 20 mOD in the south and southwest, towards Lough Corrib. The terrain is hummocky in the vicinity of Frenchbrook South, Fountainhill, Clyard and Coollisduff and Cross. Present within this area are the Kilmaine springs, a number of turloughs, depressions, and a mapped water course running between Kilmaine and Cross (referred to as the 'Cross River' in some literature, for example in the Kilmaine waste water discharge license application (Mayo County Council, 2010).

The following key points relate to the surface hydrology:

- The surface hydrology as shown on the OSi maps (**Figure 1**) indicates a number of water courses present in the area. The inset map in **Figure 1** shows the Robe and Black rivers, which are the main rivers that flow to Lough Mask and Lough Corrib. Lough Mask and Lough Corrib some 10 km to the west are the regional base levels. However, it is useful to examine the pre-arterial drainage map (**Figure 9**) which contrasts greatly with the current OSi map as it indicates virtually no water courses/features apart from numerous turloughs across the area (Coxon, 1986, Drew and Daly, 1993).

- Extensive arterial drainage works were carried out through the construction of several deep, large drains to alleviate flooding conditions occurring in the turlough areas (owing to high water table, a finite ability to accept recharge, and swallow holes being the primary natural means of draining). It is the artificial drains which are the principal water courses depicted on the current OSi maps (**Figure 1**).

- The OPW drainage works started in 1846 in the Kilmaine area (Coxon, 1986) drained the major turloughs in the area preferentially with the construction the 'Cross River', which routes discharge from the area southwest of Kilmaine toward Cross village.

- There are other imposed arterial drains routed to the Cross water course via Ballymartin, Turloughagurkall and Clyard. Only following high-intensity rainfall events and/or prolonged wet weather periods do the water courses depicted in **Figure 1** flow; witnessed during the course of the hydrogeological mapping for this study.

The most notable turloughs are present in the northern part of the study area, namely – Caheravoostia, Ardkill, Skealoghans, and Greaghans. They have been the subject of several studies over the last 30 years[1], due to the fact that this group of turloughs are considered to be natural functioning turloughs (Coxon, 1986). In contrast, the large number of turloughs present around Kilmaine, particularly to the west and southwest have been extensively modified.

Karst features are shown in **Figure 1**. The large number of enclosed depressions present in the northern part of the area were mapped as part of a field scale study on the Cregduff catchment (Meehan and Kelly, 2011). The enclosed depressions are largely located on the plateau area to the north of Kilmaine. In contrast, there are far fewer features mapped around Kilmaine and south of the N84, particularly enclosed depressions. Several field days were conducted around Kilmaine and karst features and enclosed depressions were noted. Thus, it is considered that this apparent contrast is not simply due to the different field programmes and mapping scales.

The springs tend to occur in clusters. For instance, the Fountainhill group (springs 1, 2 and 3) occur at approximately the same elevation: 27 to 29 m OD. The group of springs around Cross occur at approximately 19 to 20 m OD. This pattern suggests two spring lines that may be related to topographical and/or geological controls.

Also present in the study area 2.8 km west of Kilmaine village are a group of depressions named the ‘Clyard Kettle holes’ (NPWS, SAC site code 00480, Goodwillie, 1979). Recent water level observations indicate that the most northerly pond of the group is a turlough drained by a single swallow hole, and it responds rapidly to rainfall (Johnston, P., 2013, *pers comm*.).

Landuse in the vicinity of the sources is dominated by grazing for cattle (mostly beef) and sheep. Kilmaine village is serviced by mains sewerage which discharges to the Cross river (information from Kilmaine Waste Water Discharge License, Mayo County Council) approximately 1.1 km southwest of the Fountainhill springs [E123219 N257504] (**Figure 1**). There is a quarry 1 km west of the Fountainhill springs at Ballynacarragh. There is a dense road network with one-off housing and farm yards distributed along the network, the majority of which are served by domestic waste water treatment systems.

[1] Selected references: Coxon, 1986; Drew and Daly, 1993; Tynan et al, 2007; Gill et al, 2013; Naughton et al, 2012; Meehan and Kelly 2011; Mellander et al, 2012, 2013)

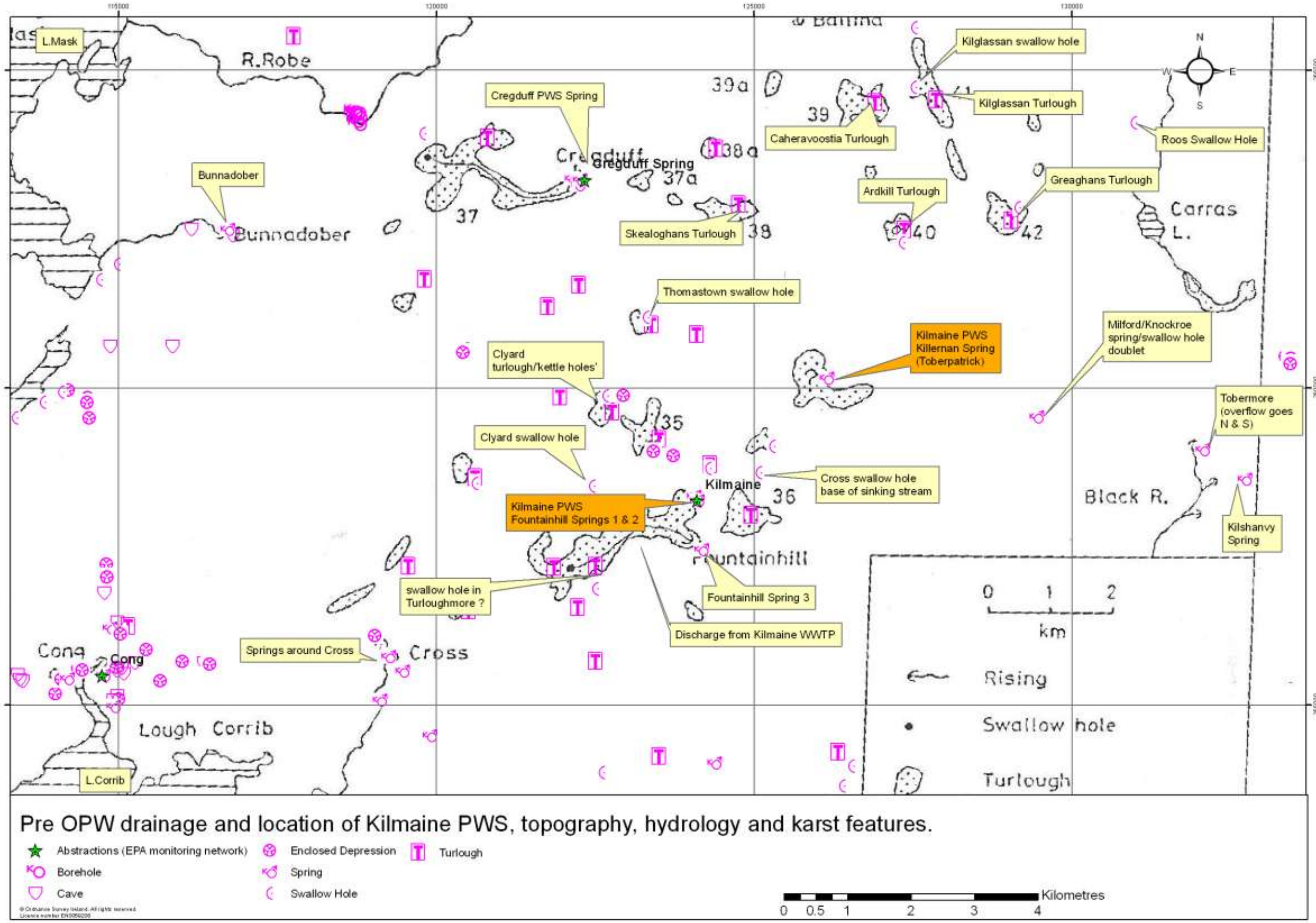

Figure 9 Pre OPW arterial drainage after Drew & Daly (1993).

6 Hydro–meteorology

Establishing groundwater source protection zones requires an understanding of general meteorological patterns across the area of interest. The data source is Met Éireann.

Annual rainfall: The contoured map of rainfall data in Ireland (Met Éireann website, data averaged from 1981–2010) shows that the source and study area are located between the 1400 mm and 1200 mm average annual rainfall isohyets: decreasing west to east. This compares favourably with annual recorded rainfall data for the Cregduff catchment: 1174 mm for 2011 and 1462 mm for 2012, (Mellander, *et al.,* 2013). For the purposes of the report the rainfall is taken from the 1981-2010 30–year average.

Annual evapotranspiration losses: taken to be 443 mm. Potential evapotranspiration (P.E.) is estimated to be 540 mm/yr (based on data from Met Éireann). Actual evapotranspiration (A.E.) is estimated as 82% of P.E., to allow for seasonal soil moisture deficits (Hunter Williams *et al.*, 2011 & in press).

Annual Effective Rainfall: 885–948 mm. The annual average effective rainfall is calculated by subtracting actual evapotranspiration (443 mm) from rainfall (1328–1390 mm).

Reference is made in **Section 10.3** to recharge which estimates the proportion of effective rainfall that enters the groundwater system.

7 Geology

7.1 Introduction

This section briefly describes the relevant geological characteristics of the study area. It provides a framework for the assessment of groundwater flow and delineation of the source protection zones.

The desk study data included the following:

- Geology of Connemara and South Mayo. Bedrock Geology 1: 100,000 Map series, Sheet 11, Geological Survey of Ireland (Long, *et al.,* 1995);
- Forest Inventory and planning system – Integrated Forestry Information System (FIPS-IFS) Soils Parent Material Map, Teagasc (Teagasc, 2006);
- Meehan and Kelly, 2011. Karst Mapping Programme at Cregduff Spring, Ballinrobe, County Mayo IAH field trip;
- Coxon, C, 1986. A study of the hydrology and geomorphology of turloughs. Unpublished PhD Thesis, Trinity College Dublin, 428 pp.;
- Drew, D. and Daly, D., 1993. Groundwater and Karstification in mid-Galway, South Mayo and North Clare. Joint Report by Department of Geography, TCD and Geological Survey of Ireland, Report Series RS 93/3(Groundwater), 86pp; and,
- Mapping and field observation from walk-over surveys.

7.2 Bedrock geology

The regional bedrock map shown in **Figure 10** indicates that the area is principally underlain by the Cong Limestone Formation, described as a pure limestone, and the Ardnasillagh Limestone Formation, described as a dark cherty (impure) limestone with thin shale. The regional rock unit map, which is a generalised bedrock map indicates that the limestones are generalised into two main types, a pure bedded limestone (DPBL) underlain by an impure limestone (DLIL) corresponding to the formations named above (**Figure 11**). The Fountainhill spring group (1, 2 and 3) are located in the Ardnasillagh Limestone Formation (DLIL) and the Cross spring group occur in the Cong Limestone Formation (DPBL) (**Figure 10**).

7.3 Soils, subsoils and depth to bedrock

The mapped soils and subsoils indicate a mix of materials present (**Figure 12**, **Figure 13**). In general, shallow soils, outcrops and rock close to the surface dominate the eastern portions of the study area, whilst deeper predominantly 'dry' soils, tills (boulder clay) derived from limestone and peat dominate the central and western portions of the study area. Poorly drained soils (AminPD) are more extensive to the west, occurring alongside peat. There are gravels present in the vicinity of Kilmaine village and Fountainhill springs.

In general the depths of soil and subsoil increase from west to east and north to south, deepening off the plateau occurring to the north and west of Kilmaine along which the N84 to Ballinrobe is located. The gravels are located off the plateau. Arterial drainage works indicate deep subsoils in places. A review of the aerial photographs indicate excavated material almost along the entirety of the Cross water course and its associated tributary drains. The cutting is some 10 m deep in the vicinity of Turloughmore and Curraghbaun, approximately 2.3 km southwest of the Fountainhill Springs.

8 Groundwater vulnerability

Groundwater vulnerability is dictated by the nature and thickness of the material overlying the uppermost groundwater 'target' – in this case the bedrock aquifer supplying the springs. 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 has been developed for County Mayo by the GSI and a portion of the map which encompasses the study area is given in **Figure 14**.

In general, the subsoil cuttings, particle size data and auger drill holes indicate '**moderately'** permeable subsoils over the majority of the area, becoming dominated by '**low'** permeability subsoils in the eastern part of the study area, where the poorly drained soils and peat dominate. The areas occupied by gravels are '**highly'** permeable. The groundwater vulnerability ranges from extreme to low. The '**High**' vulnerability is based on the presence of '**moderate**' permeability tills that are 5-10m thick and '**high**' permeability gravels in the vicinity of the source. The '**Moderate'** vulnerability is based on the presence of thick moderate permeability subsoil. The areas of '**Low**' vulnerability are areas of '**low**' permeability tills that are greater than 10 m thick. Areas of '**Extreme**' vulnerability comprise outcrops, areas of rock close to the surface and areas of less than 3 m of soil and subsoil. Areas mapped as having as rock at/or close to surface, are denoted as **'X'** on the map.

The large number of enclosed depressions present in the northern part of the area were mapped as part of a field scale study on the Cregduff catchment (Meehan and Kelly, 2011). The enclosed depressions are largely located on the plateau area to the north of Kilmaine. In contrast, there are far fewer features mapped around Kilmaine and south of the N84, particularly enclosed depressions. Several field days were conducted around Kilmaine and karst features and enclosed depressions were noted. Thus, it is considered that this apparent contrast is due to greater depths of soil/subsoil, presence of gravels and that the greater density of features occur on the plateau areas.

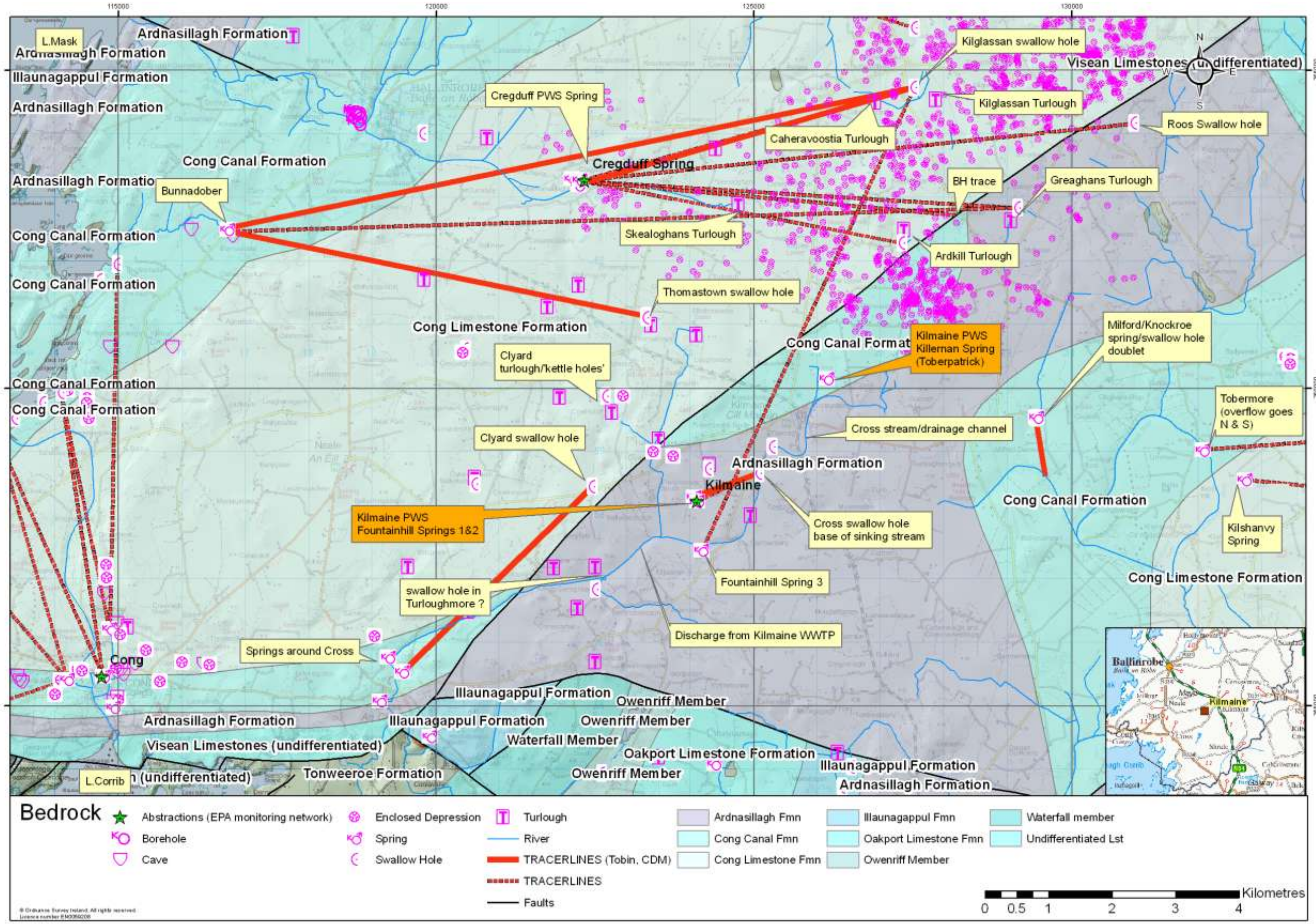

Figure 10 Geological Bedrock Map

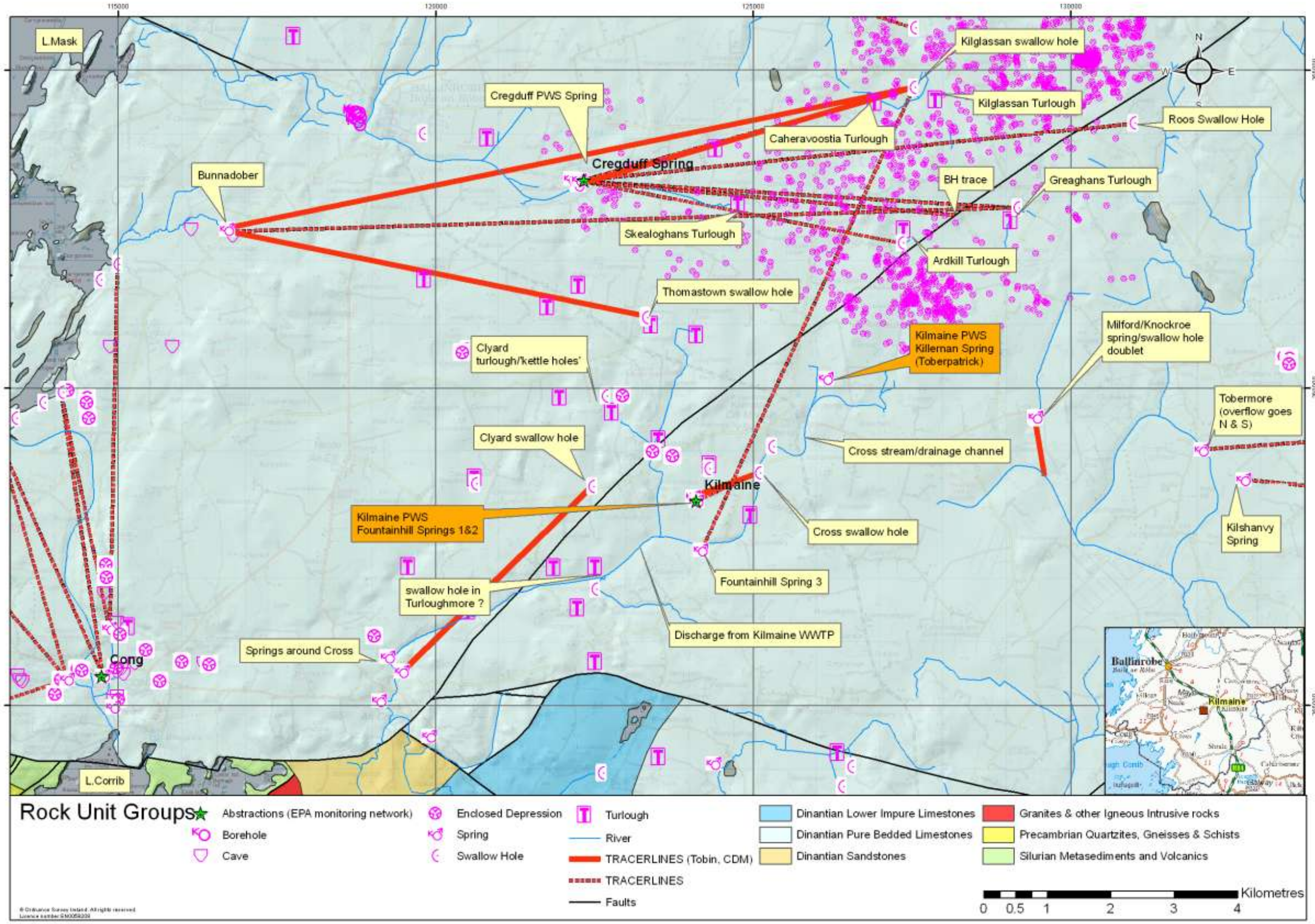

Figure 11 Rock Unit Map

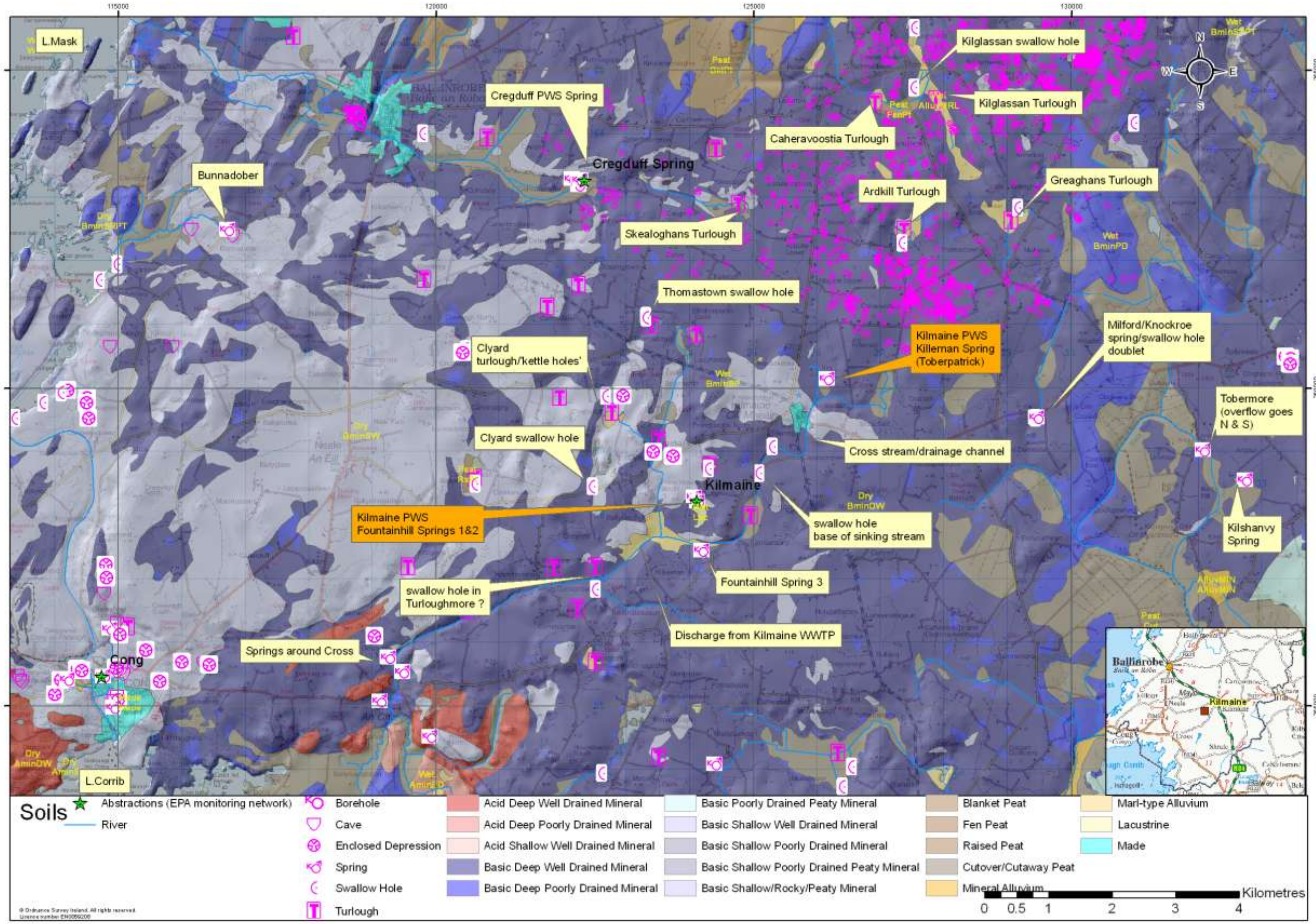

Figure 12 Mapped soils types across study area

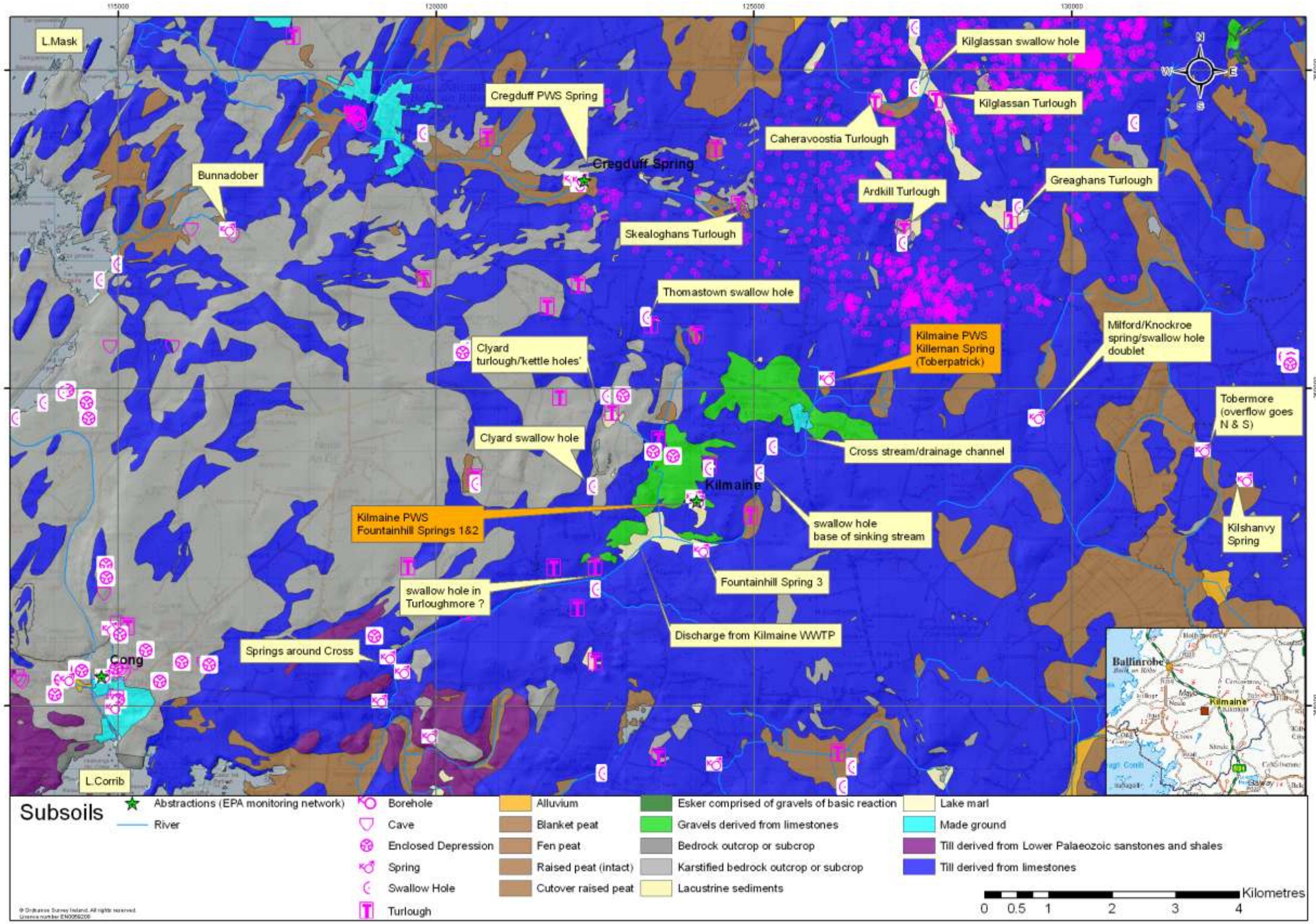

Figure 13 Mapped subsoils across study area

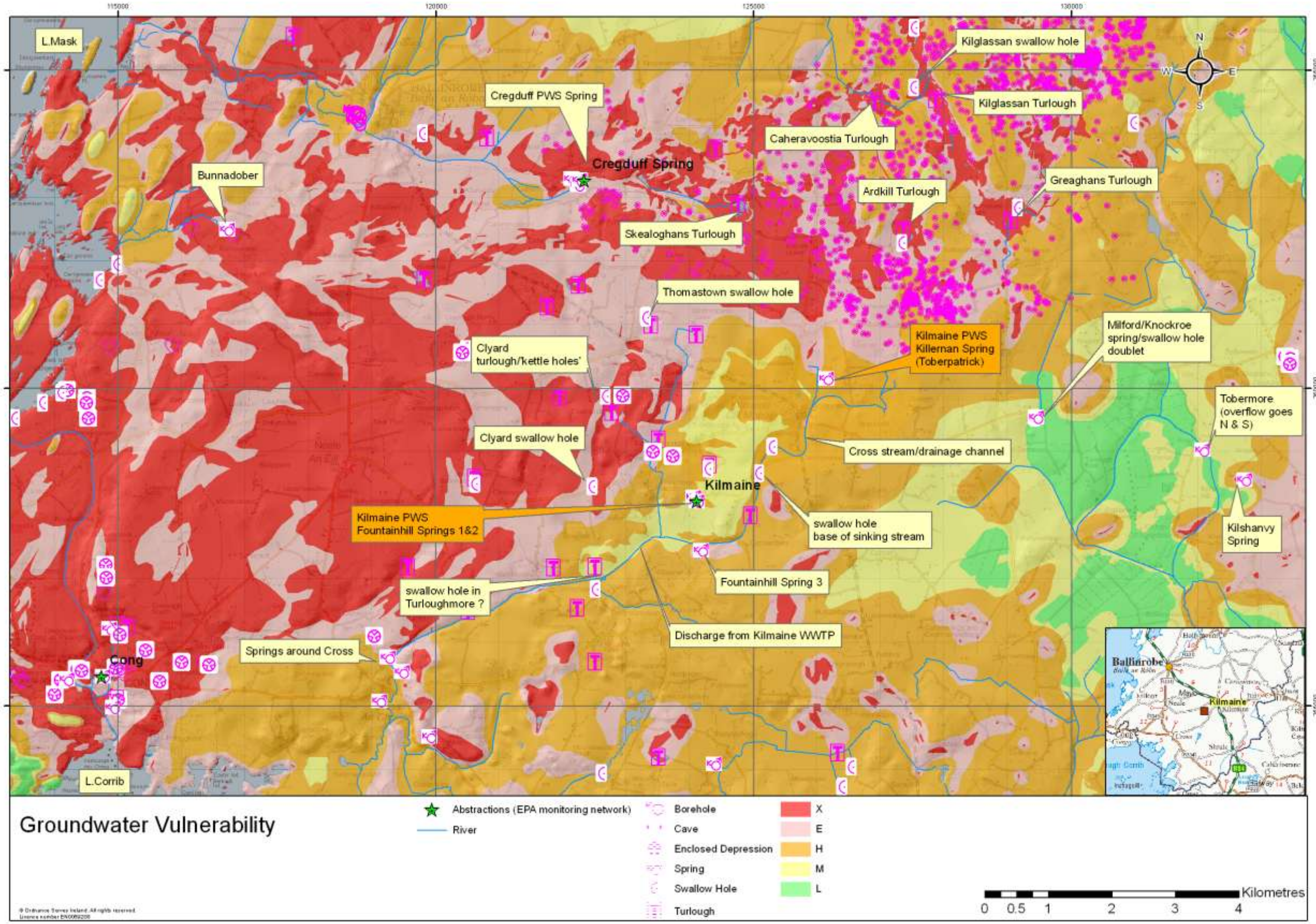

Figure 14 Mapped Groundwater vulnerability across study area

9 Hydrogeology

9.1 Introduction

This section describes the current understanding of the hydrogeology in the vicinity of the source. Hydrogeological, hydrochemical and relevant information was obtained from the following sources:

- GSI website (www.gsi.ie) and databases;
- Local Authority drinking water returns and county council staff;
- EPA website (www.epa.ie) and groundwater monitoring database;
- Water Framework Directive website (www.wfdireland.net);
- Coxon, C, 1986. A study of the hydrology and geomorphology of turloughs. Unpublished PhD Thesis, Trinity College Dublin, 428 pp.;
- Drew, D. and Daly, D., 1993. Groundwater and Karstification in mid-Galway, South Mayo and North Clare. Joint Report by Department of Geography, TCD and Geological Survey of Ireland, Report Series RS 93/3(Groundwater), 86pp;
- Gill, L., Naughton, O., Johnston, P., Basu, B., and Ghosh, B. 2013. Characterisation of hydrogeological connections in a lowland karst network using time series analysis of water levels in ephemeral groundwater-fed lakes (turloughs). Journal of Hydrology. 499, 289-302;
- Gill, L., Naughton, O., Johnston, P. 2013. Modelling a network of turloughs in lowland karst. Water Resources Research, Vol. 49, 3487–3503;
- Meehan and Kelly, 2011. Karst Mapping Programme at Cregduff Spring, Ballinrobe, County Mayo IAH field trip;
- Mellander P-E, Wall DP, Jordan P, Melland AR, Meehan R, Kelly C and Shortle G. 2012. Delivery and impact bypass in a karst aquifer with high phosphorus source and pathway potential. Water Research, 46: 2225-2236;
- Mellander P-E, Jordan P, Melland AR, Murphy P, Wall DP, Mechan S, Meehan R, Kelly C, Shine O, Shortle G. 2013. Quantification of Phosphorus Transport from a Karstic Agricultural Watershed to Emerging Spring Water. Environmental Science and Technology;
- Tynan, S., Gill, M., Johnston. 2007. Development of a Methodology for the Characterisation of a Karstic Groundwater Body with Particular Emphasis on the Linkage with Associated Ecosystems such as Turlough Ecosystems. EPA STRIVE Report 2002-W-DS-8-M1;
- Wilson, J., and C. Rocha. 2012. Regional scale assessment of Submarine Groundwater Discharge in Ireland combining medium resolution satellite imagery and geochemical tracing techniques. Remote Sensing of Environment. 119 (2012) 21–34;
- Wilson, J., and Rocha, 2013. Regional-Scale Assessment of Submarine Groundwater Discharge Using Remote Sensing Development of Remote Sensing as a Tool for Detection, Quantification and Evaluation of Submarine Groundwater Discharge to Irish Coastal Waters. EPA STRIVE Report (2008-FS-W-4-S5); and,
- Field mapping, tracer testing and measurements.

9.2 Groundwater body and status

The source and the surrounding areas are located within the Cong–Robe Groundwater Body 2 which is categorised at 'Poor Status' and 'at Risk' (1a)[2] by the EPA due to the risk imposed on the surface water bodies (River Robe, Lough Corrib and Lough Mask) by nutrient loading.

9.3 Groundwater levels, flow directions and gradients

The limestone bedrock in the area is karstic as evidenced by the presence of large springs that react rapidly to rainfall, 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 east to west, northeast to southwest and, in the eastern portion of the study area – north to south. Lough Mask and Lough Corrib some 10 km to the west are the regional base levels. To establish flow directions, travel times, and zones of contribution(s) and to understand the flow regimes, hydrogeological mapping, flow measurements of the streams and springs and dye tracer tests were undertaken.

Tracer tests were conducted for the purposes of this study in 2012 and 2013 to help frame the contributing area to Fountainhill Springs 1 and 2. The tests undertaken take account of and build on the previous tracing studies done in the general Cregduff/Kilmaine area. The dye types, volumes and sampling strategy were prepared in conjunction with the GSI and considered appropriate for this type of study. The sampling network included springs and several stream crossings and comprised both cotton and charcoal detectors and water samples which were analysed at the GSI. The specific traces done for this study and positive results are indicated on **Figure 10, Figure 11, Figure 19**, and summary details are provided in .

The 'Thomastown', 'Clyard' and 'Milford/Knockroe' traces were negative to the Fountainhill Springs (1, 2 and 3) and Killernan. Therefore they assist to frame the contributing area by ruling out areas that do not appear to contribute to Fountainhill Springs or to Killernan springs. The 'Thomastown' and 'Clyard' trace suggest a groundwater divide between drainage to L. Mask and L. Corrib. The 'Milford/Knockroe' trace assists to indicate a divide between drainage to the Black River and to L. Corrib. This trace was a repeat of a trace undertaken by Meehan and Kelly (2011) but the water course that the recent trace links to was not sampled at the time.

The injection point used for the Cross River trace is a swallow hole at the base of a 3–4 m deep cutting, draining the turloughs south of Kilmaine. Field mapping indicates that the 'Cross' River sinks in 3 locations between Kilmaine and the Fountainhill springs (**Figure 1**). One of these sinks was used to trace from. The 'Cross' trace was positive to Fountainhill 1 and 2, and negative to all the other springs. During the summer of 2013 the 'Cross' water course was dry in the vicinity of Kilmaine, with only a very low flow in the vicinity of Cross – the bulk of which was made up of the spring discharges. All of the springs were in very low flow condition during this period with the most northerly of the three springs at Cross (townland of Dowagh) completely dry.

[2] Further information on the groundwater body, risk and status can be obtained at www.gsi.ie and www.wfdireland.net

Table 9-1 Summary details of dye tracer tests conducted in 2011, 2012 and 2013

Input Site/elevation	Coordinates	Date injection	Dye	Summary results
Milford/Knockroe swallow hole 35 mOD	129433 259531	25/10/2012	Optical Brightener 30 litres	Positive at stream/drain (30 mOD), 800m south 1/11/2012, less than 7 days (5 m/hr) Gradient: 0.006
Thomastown swallow hole 40mOD	123302 261137	13/6/2013	Optical Brightener 60 litres	Positive at Bunnadober (22 mOD), 6.6 km WNW 19/6/2013, less than 6 days (47 m/hr) Gradient: 0.003
Kilglassan swallow hole 34 mOD	127521 264731	29/8/2013	Fluorescein 7.5 litres (6 kg @0.8%) Tanker assist 6000 gallons clean water	Positive at Cregduff (30 mOD) 5.5 km SW, and Bunnadober (spring and cave), 11km SW 14/9/2013 (less than 9 days to Cregduff, 9–16 days to Bunnadober (30 m/hr) Gradient 0.001
Cross river sink @ Kilmaine 30 mOD	125081 258662	14/9/2013	Optical Brightener 30 litres Tanker assist 6000 gallons clean water	Positive at Fountainhill Springs 1, 2 (29, 28 mOD), 1km SW 16/9/2013, approx 2 days (20 m/hr) Gradient: 0.001–0.002
Clyard swallow hole 30 mOD	122461 258454	29/11/2012	Optical Brightener 30 litres	Positive at Cross Springs (18–20 mOD), 4 km SW 6/12/2012, less than 7 days (30 m/hr) Gradient: 0.002–0.003
Cregduff Tracing in 2011 (Meehan and Kelly 2011)				
Roos swallow hole 56 mOD	130982 264166	2nd June 2011	Rhodamine 20 litres (4 kg @ 0.2%)	Positive at Cregduff 8.6 km SW 30 days later (12 m/hr) Gradient: 0.003
Lugatallin swallow hole 35 mOD	127531 265670	2nd June 2011	Optical brightener 40 litres	Positive at Robe Spring 1.5 km NW Less than 7 days (9–15m/hr) Gradient: 0.001
Lissatava 50 mOD	129940 267193	2nd June 2011	Fluorescein 10 litres (8 kg @ 0.8%)	Positive at Kilrush, 3.5km NW Less than 7 days (21 m/hr) Gradient: 0.003

The Kilglassan trace is a repeat trace of one that was originally conducted in 1983 in 'medium' flow conditions, which is reported to be positive to Cregduff (2–5 days, 47–123 m/hr) and 'weakly' positive to Fountainhill Spring 3 (9–14 days, 24–37 m/hr) (Coxon, 1986). Fountainhill 1 and 2 were not sampled at the time. The recently conducted trace from Kilglassan was conducted in low flow conditions and was positive to two of the individual springs at Cregduff (the other two springs were not flowing) and to both Bunnadober spring and Bunnadober Cave. The connection to the cave is based on anecdotal evidence by cavers who reported a green tinge to water in the cave (Drew, D., 2014, *pers. comms.*). The travel time to Cregduff at the time of testing was less than 9 days and the travel time to Bunnadober was less than 15 days. The recent trace was unsuccessful in re-affirming the link to Fountainhill 3 established in the original trace and did not appear at any of the other sampling points, including Fountainhill 1 and 2.

In the Greaghans trace conducted by Coxon (1986) there were positive detections at Cregduff and Bunnadober, however, they were regarded with caution as it was unclear if it was a direct link or an indirect link from Cregduff via overflow entering a swallow hole. However, the overflow is now directed to the Bulkan river and so it appears that the positive from the recent trace from Kilglassan, provides support that there is a direct link from Greaghans to Bunnadober. No other links from the swallow hole at Greaghans turlough were established in 1986 trace. A repeat of this trace conducted by Coxon (1986) was scheduled for this study but could not be conducted due to unfavourable conditions.

Gradients calculated for each of the traces range from 0.001–0.006 (**Table 9-1**). Drew and Daly (1993) report the general groundwater gradients to be in the order of 0.0008–0.0018 which broadly fit with those given in **Table 9-1**. The gradients are considered to be relatively flat, mirroring the regional topographic gradient.

Contoured groundwater level data for the Cregduff area broadly indicate an east to west groundwater 'trough' with a strong component converging at Cregduff springs (Drew and Daly, 1993; Coxon, 1986). The interpreted water levels indicate that groundwater elevations are in the order of 36–40 mOD in the southern part of the Cregduff area, coinciding with the plateau north of Kilmaine, and north of the main road from Kilmaine to Ballinrobe. Killernan spring (Tober Patrick) is approximately 35 mOD, The Fountainhill spring group (1, 2 and 3) are approximately 29–29 mOD, and the springs at Cross are at approximately 15 mOD. Therefore the water levels based on the general topographic and drainage patterns and the spring elevations are less than 30–35 mOD and suggest groundwater flow direction from northeast to southwest in the vicinity of Kilmaine and Cross and east to west in the vicinity of Cregduff.

Wilson and Rocha (2012, 2013) have conducted recent work in mapping radon activity and thermal image analysis to locate potential groundwater discharges in near–off–shore and lake environments and indicate that there are "*large*" "*cool groundwater discharges from the eastern shorelines of Lough Mask clearly visible in the temperature maps*". "*The spatial distribution of radon matched the results from the thermal image analysis and areas of elevated radon activities along the north and eastern margins of the lake coincided spatially with the presence of large cold water plumes confirming the presence of submarine groundwater discharge*" (Wilson and Rocha, 2013). The zone extends 1–2 km north and south of the location where the River Robe enters Lough Mask. The estimated flow is approximately 4 m^3/s (Ellison, R., 2011).

From all the tracing results, background information and data, it is inferred that there are three main groundwater directions associated with three main broad groundwater domains in the study area, listed as follows (**Figure 19**):

- An East–West domain that discharges to Lough Mask and includes the springs at Cregduff and Bunnadober.

- A Northeast–Southwest domain that discharges to Lough Corrib and encompasses internal catchments to Cross Springs, Fountainhill (1, 2 and 3), and Killernan (Tober Patrick). The arterial network in the vicinity of Kilmaine and Cross parallels the broad groundwater flow direction and is not considered to be a groundwater divide.

- A North–South domain in the east of the study area that discharges to the Black river. The Black river (inset **Figure 1**) flows south and southwest to Lough Corrib. The traces undertaken by Drew (1993) emerge in the springs (Kilshanvy and Tobermore) at the headwaters of the Black River. The inputs for these traces are not shown: they are some 7/8 km west. It is assumed that the Black River and the springs that were traced are major discharge zones and groundwater does not continue to flow west toward Kilmaine/Cross.

9.4 Hydrochemistry and water quality

Hydrochemical analyses for Fountainhill (25 untreated samples from 2007 to 2012 (EPA data), and data for a few parameters (nitrate, conductivity, hardness, iron and manganese) from Local Authority returns from 2000 to 2007 (30 treated water samples) were examined.

Note that the EPA samples are representative of both Fountainhill 1 and 2.

Note that the Local Authority data represent a mixed sample of water from both Fountainhill springs and Killernan, albeit that Fountainhill spring 1 provides the bulk of the water. These data are still useful to give an indication from the general groundwater quality and chemistry.

The water from Fountainhill is hard to very hard, with total hardness values of 282–437 mg/l, a mean of 369 mg/l (equivalent CaCO3) and electrical conductivity (EC) values of 427–1044 µS/cm, (average 678 µS/cm). The coefficient of variance of electrical conductivity is 17%, indicating that the flow is predominantly conduit flow (Doak, 1995). The groundwater has a calcium bicarbonate hydrochemical signature. Alkalinity ranges from 280–444 mg/l $CaCO_3$. Samples are generally within acceptable levels for colour and turbidity. The Local Authority drinking water return data (mixed sample) is quite similar with respect to conductivity (mean 680 µS/cm) and hardness (mean of 389 mg/l, n=3).

Figure 15, Figure 16, Figure 17, Figure 18, show the data for the key indicators of contamination and the main points are as follows:

- Nitrate concentrations from the EPA data (2007 to 2012) range from 3–14 mg/l with a mean of 9 mg/l and the trend is declining. The mean is less than the groundwater threshold value of 37.5 mg/l (S.I. No. 9 of 2010) and less than the drinking water limit of 50 mg/l (S.I. No. 278 of 2007). The mean from the drinking water returns is 12 mg/l, though this data are from 2002 to 2007. Ammonia concentrations range from 0.009 to 0.08 mg/l and the mean is 0.026 mg/l, which is below the groundwater threshold value (0.175 mg/l) (S.I. No. 278 of 2007). However, the data for 2007 and 2009 indicate slightly higher concentrations.

- Chloride is a constituent of organic wastes, sewage discharge and artificial fertilisers, and concentrations higher than 24 mg/l (Groundwater Threshold Value for Saline Intrusion Test, S.I. No. 9 of 2010) may indicate contamination, with levels higher than 30 mg/l usually indicating significant contamination (Daly, 1996). Chloride concentrations range from 13–26 mg/l with a mean of 18 mg/l.

- The average concentration of Molybdate Reactive Phosphorous (MRP) is 0.018 mg/L P (EPA data: 2007–2013), which is below the groundwater threshold value (S.I. No 9 of 2010) of 0.035 mg/L P. The range is from 0.0015 to 0.042 mg/l. Whilst below the groundwater threshold value there is a very slight inclining trend. In addition, the variability is high, i.e., the distribution about the mean is quite wide, with a standard deviation of 0.01. A similar mean is observed for Cregduff springs (0.017 mg/l P), though the range is greater: 0.0045 – 0.055 mg/l. An inclining trend is also observed in the data, though slightly greater than that for Kilmaine. Mellander *et al*., 2012, 2013, conducted high resolution monitoring of MRP and spring discharge at Cregduff and report a mean of 0.014 mg/l P from September 2010–September 2011 and 0.022 mg/l P from September 2011 to September 2012. Mellander et al., 2012, 2013 also indicate that:

- Peak concentrations in MRP coincide with storm events (both winter and summer);
- MRP concentrations broadly decrease in the winter months due to dilution; and,
- the overall annual MRP load increases with greater annual rainfall totals.

The higher MRP concentrations for both Cregduff and Kilmaine in the EPA data, which is quarterly, tend to be in the autumn and winter and coincide with rainfall events.

- Iron and manganese concentrations are generally low, though on one occasion they were elevated in 2010 but still below drinking water limits. The Local Authority data indicate occasionally elevated iron and manganese in the bulk water samples.
- The ratio of potassium to sodium (K:Na) is used to help indicate if water has been contaminated, along with other parameters, and may indicate contamination if the ratio is greater than 0.35 to 0.4. The ratio exceeded or equalled 0.35 on six occasions, all in 2007, apart from once in 2009. The concentrations of potassium were elevated on those occasions, generally in excess of 4 mg/l.
- Faecal coliform counts exceeded 0 counts per 100ml on every occasion from 2007 to 2012 in the EPA untreated samples. On thirteen of those occasions the counts exceeded 100 counts per 100ml, which is indicative of gross contamination. Total coliform counts were exceeded on every occasion. The magnitude of the counts in the Cregduff springs parallels the counts at Fountainhill. Further, the higher counts generally occur on the same days that MRP concentrations are elevated and coincide with rainfall events.
- The concentrations of trace metals are generally below laboratory limits of detection with the exception of silver which exceeded the drinking water limit once in September 2008 with a concentration of 46 µg/litre.
- There has been one confirmed detection 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, bacteriological contamination is persistent, with gross faecal contamination occurring more than 50% of the time, between 2007 and 2012. Potassium sodium ratios were persistently elevated in 2007. The contamination may indicate contamination from organic wastes.

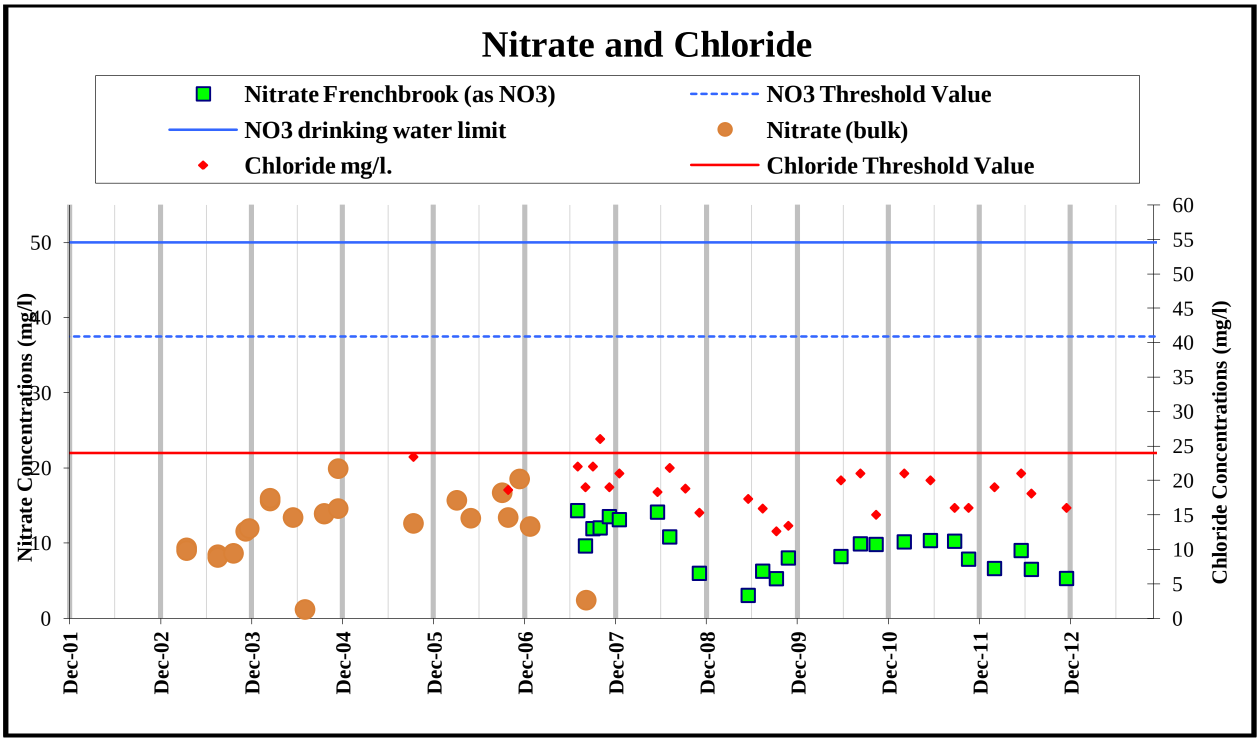

Figure 15 Key indicators of contamination (Nitrate, chloride)

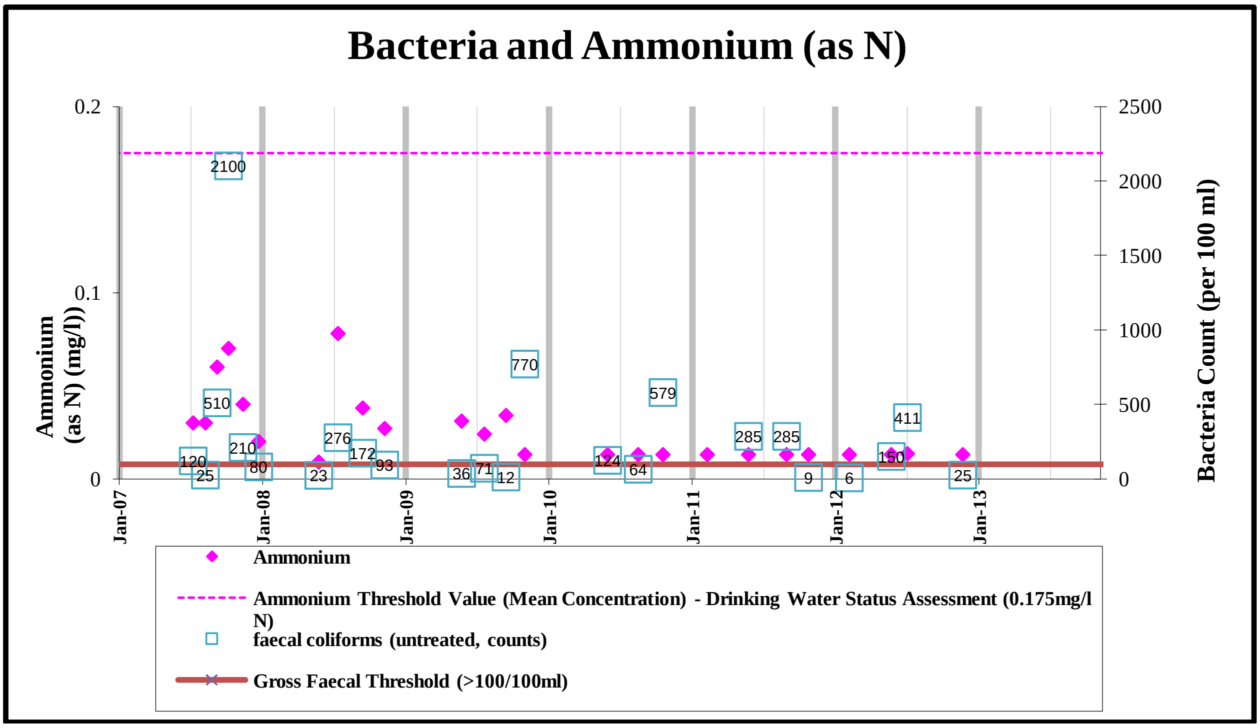

Figure 16 Key indicators of contamination (bacteria, ammonia)

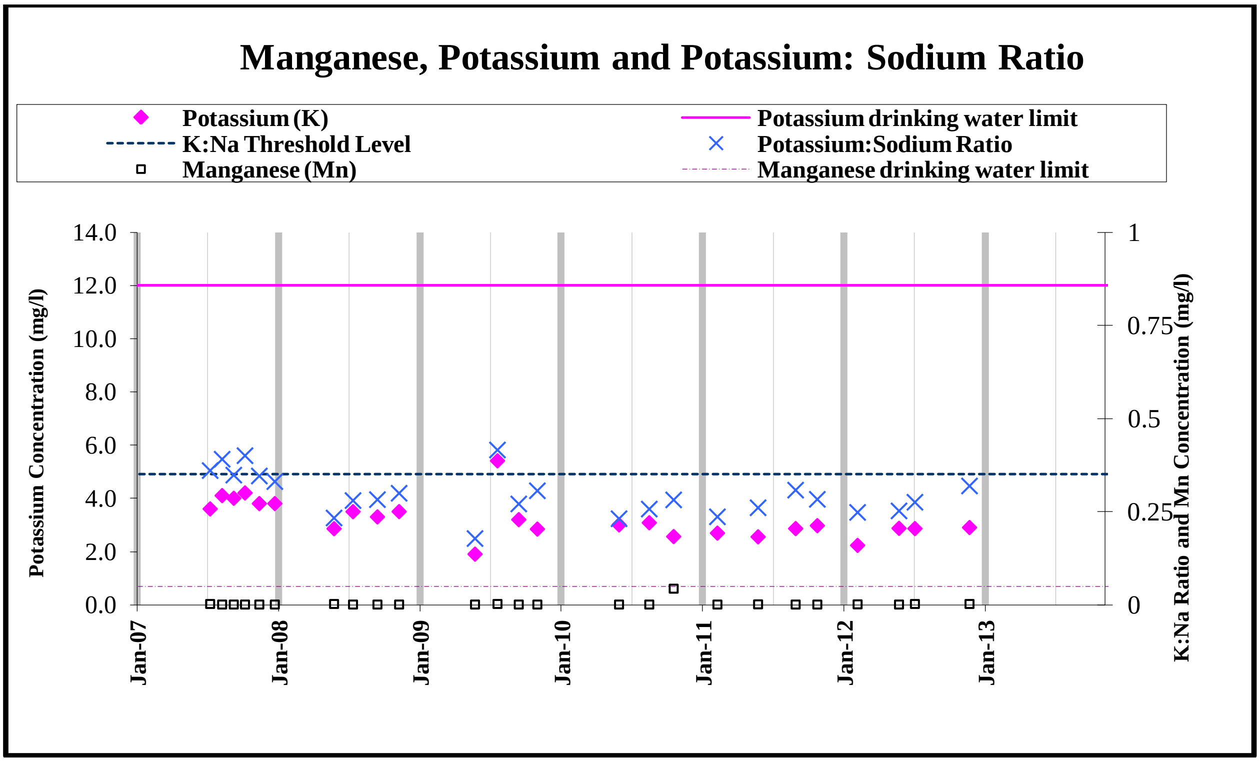

Figure 17 Key indicators of contamination (Mn, K, K:Na)

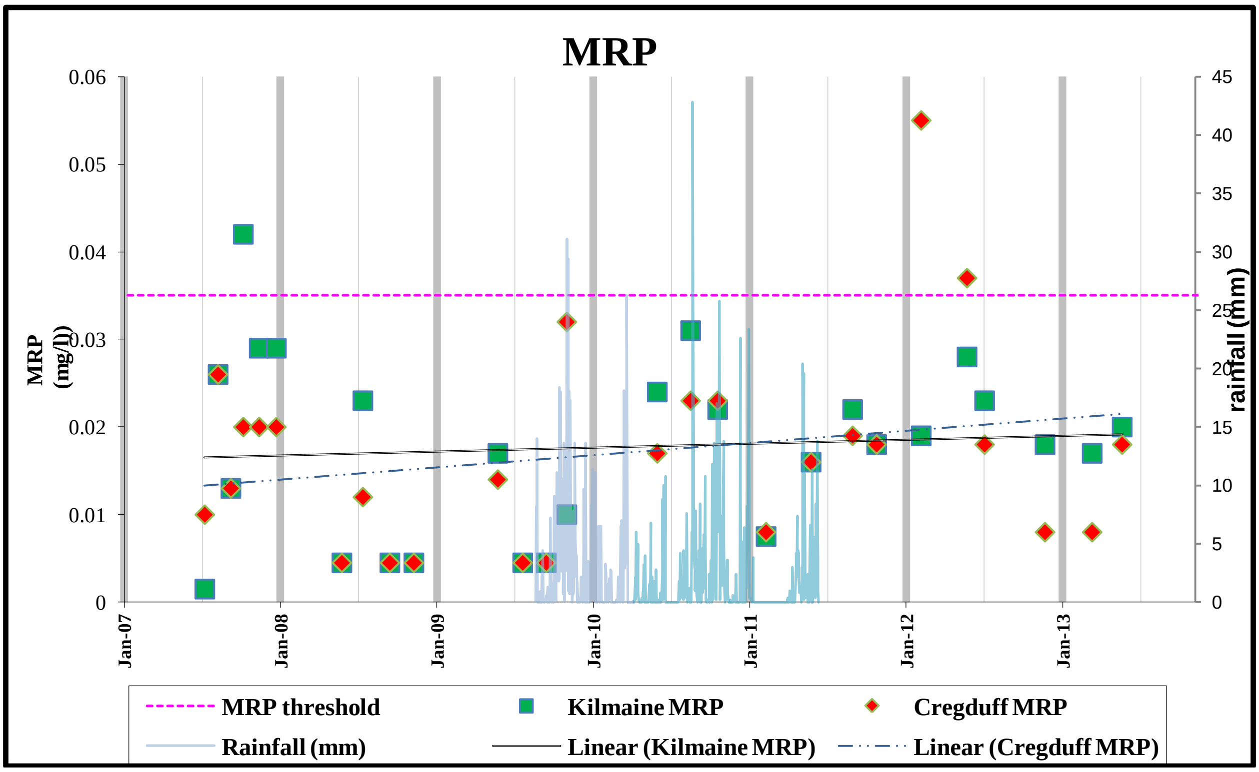

Figure 18 Key indicators of contamination (MRP)

9.5 Aquifer characteristics

The presence of karst features within the study area provides evidence for karstification of the limestone aquifer that supplies groundwater to the Kilmaine PWS. The established trace links are characteristic of a regional aquifer system that stretches across much of the area around Ballinrobe, Kilmaine and Cross, which gives rise to numerous springs, several 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 (***Figure 19)***.*

The established flow rates from the recent trace work are in the order of 5–47 m/hr (120–1100 m/d) and associated flow gradients are in the order of 0.002–0.003. Recent flow rates established for the traces done within the Cregduff catchment range from 12–21 m/hr (Meehan and Kelly, 2011). The flow rates established fit the broad ranges of 5–120 m/hr and 10–100 m/hr (Coxon, 1986; Drew and Daly, 1993). The traces conducted in 2011, 2012 and 2013 were conducted in relatively 'dry' hydrological conditions. Therefore the rates indicated for the recent work are probably indicative of rates at the lower end of the spectrum. Drew and Daly (1993) suggested that the traces being conducted from swallow holes in turloughs probably represented zones of higher permeability in the aquifer. The majority of the recent traces are also associated with swallow holes in turloughs, for instance, Thomastown and Clyard. However, the Milford/Knockroe trace is not associated with a turlough and neither are the two conducted to the north of the Cregduff catchment: Roos and Lissatava (Meehan and Kelly, 2011).

The spring hydrograph (**Figure 6**) illustrates the rapid response of the discharge to rainfall and indicates that the spring flow is very 'flashy' – an indication of how karstified the bedrock aquifer is. The coefficient of variation of electrical conductivity is 17% which also indicates that the flow nature of the spring is 'flashy', corresponding to a quick response to rainfall. Mellander *et al.*, 2013, illustrate how turbidity correlates to rainfall and increases in spring discharges at Cregduff and interpreted the hydrographs to indicate conduit, large fissure and small–medium fissure flow components. Analysis of the spring flow characteristics and statistical indices of Fountainhill (1, 2) and Cregduff spring indicates that whilst they both respond rapidly to rainfall, they behave differently: the Cregduff spring is distinctly flashier (Drew, D., 2013, *pers. comm*.).

The Fountainhill spring group (1, 2 and 3) occur at approximately the same elevation: 27 to 29 m OD. The Cross spring group around occur at approximately 19 to 20 m OD. This pattern suggests two spring lines that may be related to geological controls. Lough Mask and Lough Corrib some 10 km to the west are the regional base levels.

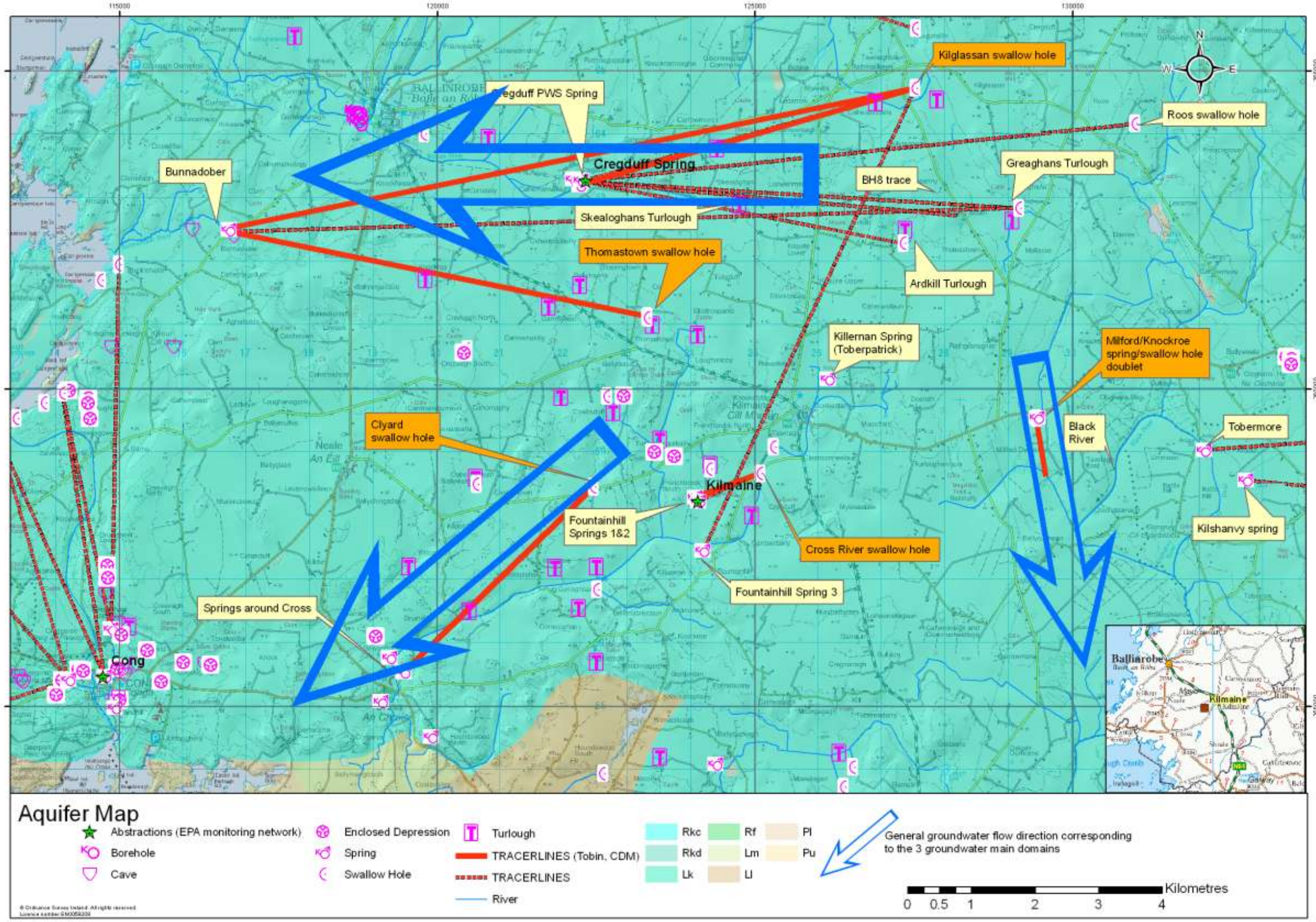

Figure 19 Bedrock Aquifer Map

10 Zone of contribution (ZOC)

10.1 Conceptual model

The current understanding of the geological and hydrogeological situation around Kilmaine, Cross and Cregduff is given as follows:

- Lough Mask and Lough Corrib are the regional base levels. It is inferred that there are 3 main broad groundwater catchments as follows:

    - An East–West domain that discharges to Lough Mask and includes the springs at Cregduff and Bunnadober.

    - A Northeast–Southwest domain that discharges to Lough Corrib and encompasses internal overlapping catchments to the springs at Cross, Fountainhill (1, 2 and 3), and Killernan (Tober Patrick).

    - A North–South domain in the east of the study area that discharges to the Black river. This catchment feeds south and southwestwards toward Lough Corrib.

  The boundaries between these groundwater catchments are subtle and indistinct and there is likely to be overlap. The generalised groundwater flow directions are shown in **Figure 19**.

- Principally due to the lack of natural surface drainage it is considered that the majority of effective rainfall descends to the water table diffusely, although there is a proportion of point recharging occurring also via swallow holes etc. There is an imposed arterial drainage network which is preferentially routed between Kilmaine and Cross connecting a number of turloughs. It conveys water during wet weather periods when the water table is high and above the base of the bed. During dry periods it sinks between Kilmaine and the Fountainhill springs, gaining thereafter. The arterial network in the vicinity of Kilmaine and Cross parallels the broad groundwater flow direction and are not considered as hydraulic divides.

- All the springs in the area discharge from a karst system and groundwater flows via fissures, fractures and karst conduits. The springs around Kilmaine – particularly the Fountainhill group (springs 1, 2 and 3) occur at approximately the same elevation: 27 to 29 m OD. The group of springs around Cross occur at approximately 19 to 20 m OD. This pattern suggests two spring lines that may be related to topographical and/or geological controls .

- As evidenced by continuous flow monitoring of Fountainhill springs (1, 2) 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 (120–1,100 m/d), and because of the combination of high flow velocities and the areas of extreme vulnerability including the sites of concentrated recharge (swallow holes), both the aquifer generally and the Fountainhill springs specifically are susceptible to pollution, with little or no attenuation potential for contaminants in the subsurface (other than by dilution).

- There are several swallow holes – sites of concentrated recharge, which are usually associated with turloughs, and traces from some of these demonstrate definitive links to a number of the springs.

Only one trace conducted in a swallow hole in the artificial bed of the Cross river was traced to Fountainhill 1 and 2.

- Limitations to the conceptual model mainly lie with a lack of greater information on groundwater flow directions. The tracing programme attempted to define and distinguish the zones of contribution to Fountainhill springs. There remains uncertainty with the boundary zones between drainage to L. Mask and to L. Corrib and toward the Black River. There is also a lack of detailed groundwater vulnerability south of Kilmaine toward Cross.

A schematic cross section is given in **Figure 20**.

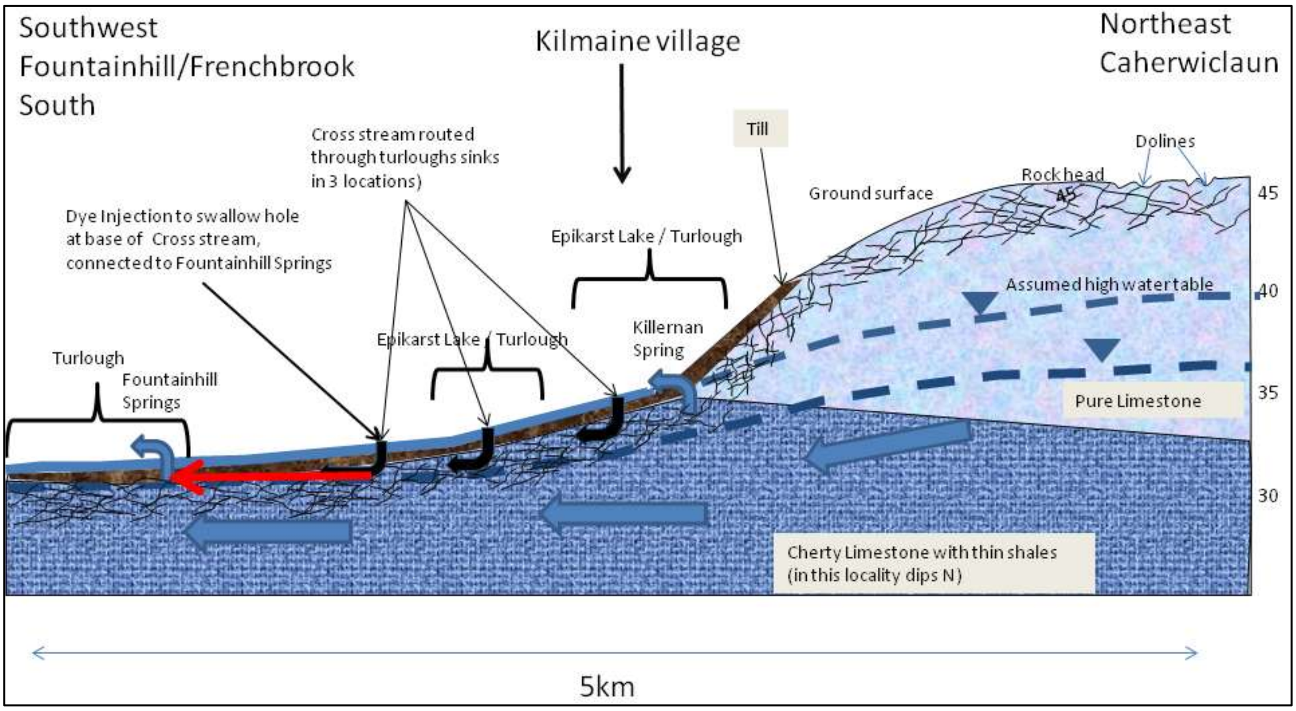

Figure 20 Schematic cross section from northeast of Kilmaine village to Fountainhill Springs (1, 2)

10.2 Boundaries

The boundaries of the area contributing to the source (Zone of Contribution (ZOC)) are based on the considerations and limitations described above.

The size of the ZOC is a function of:

- the total outflow
- the recharge in the area.

The location of the ZOC is a function of:

- the groundwater flow direction and gradient
- the subsoil and rock permeability.

The shape and boundaries of the ZOC were determined using hydrogeological mapping, dye-tracing, water balance estimations, and conceptual understanding of groundwater flow. The boundaries are described below along with associated uncertainties and limitations.

The boundaries are broadly based on topography; the broad groundwater flow directions defined by the tracing results, i.e., the 3 broad groundwater domains; and, that the Cross river is not a hydraulic divide. In addition the zone of contribution delineated for Fountainhill springs also captures Killernan spring (Tober Patrick). The 'Cross' tracing results show that dye went to both Fountainhill springs (1, 2). Therefore the zone of contribution has to be delineated for both springs as one. The boundaries are very difficult to define due to the uncertainties of groundwater flow.

The **northern** boundary is constrained by a broad topographic ridge and water tracing. This area is a relatively broad flat plateau. General topographic and drainage patterns and established groundwater water level maps indicate it to be a divide. Analysis of the spring flow characteristics of Cregduff and Kilmaine indicate that whilst they both respond to rainfall, Cregduff is distinctly flashier. This suggests that the Kilmaine catchment is different, i.e., groundwater flow is not derived from the Cregduff catchment. There is no established link from Greaghans turlough to Fountainhill spring 3 (Coxon, 1986). The recently conducted Kilglassan trace did not appear at any of the Fountainhill springs (1, 2, 3). With the information supporting differing regional flow patterns and in light of subsequent work and data, the weight of evidence suggests that any link from Kilglassan to Fountainhill spring 3 is likely to be tenuous. On balance, it would not be appropriate to use this tracer test alone to link the Kilmaine flow pattern to the Cregduff flow pattern. However, these results should be borne in mind if additional investigations are undertaken in the future and there is the opportunity to repeat these tracer tests under differing flow conditions.

The more recent trace evidence relating Kilglassan & Fountainhill is summarised as follows:

1. Kilglassan (recent) negative to FH 1, 2 & 3 and positive to Cregduff and Bunnadober.
2. Cross trace negative to FH 3 and positive to FH 1 & 2.
3. Milford traces negative to FH 1, 2 & 3, (in fact negative to all sampling points except for stream south).
4. Roos trace negative to FH 1, 2 & 3 and positive to Cregduff (unknown to Bunnadober – wasn't sampled).
5. Clyard negative to FH 1, 2 & 3, positive to Cross spring.
6. Thomastown negative to FH 1, 2 & 3, positive to Bunnadober.

The Greaghans trace (1986) was negative to FH 3 (FH 1 & 2 were not sampled).

The **eastern** boundary is currently constrained by topography, and is the apparent divide between drainage to the Black river and drainage to L. Corrib. The recent tracing from the Milford/Knockroe doublet was definitively traced to the water course to the south and did not appear in the Fountainhill springs (1, 2, 3) or Cross springs. This trace was also conducted in 2011 and it did not appear in any of the springs (Meehan and Kelly, 2011).

The **southeastern** boundary – extending from the springs to the eastern boundary is difficult to define. It is constrained by topography and crosses the 'Cross' water course, which is assumed not to be a groundwater divide and across the northern end of a turlough. Further east, where the boundary crosses the main road is also constrained by topography though is more definitive based on the tracing that also constrains the eastern boundary.

The **southwestern** boundary is based on the location of the Fountainhill springs 1 and 2; it is assumed that groundwater cannot flow back up to the springs. An arbitrary buffer of 30 m is applied. Joining this boundary with the western and southern boundary is based on topography and is uncertain.

The **western** boundary is constrained by tracing and topography; the ‘Clyard’ and ‘Thomastown’ traces delimit the boundary to be east of the injection points. The boundary extends along the plateau north of the Fountainhill springs (1, 2), assumed to be groundwater divides and the boundary is extended to meet the northern boundary in the area of Loughanboy and Rausakeera – the plateau marked by the extremely vulnerable groundwater areas. The swallow hole at the northern end of the Clyard turlough / ‘Kettle Holes’ remains untraced though it is considered due to its lower elevation that it is unlikely to go to the Fountainhill springs (1, 2).

10.3 Recharge and water balance

The term ‘recharge’ refers to the amount of water replenishing the groundwater flow system. The recharge rate is generally estimated on an annual basis, and assumed to consist of input (*i.e.*, annual rainfall) less water loss prior to entry into the groundwater system (*i.e.*, annual evapotranspiration and runoff). The estimation of a realistic recharge rate is critical in source protection delineation, as it will dictate the size of the zone of contribution to the source (*i.e.*, the outer Source Protection Area).

The main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient (Groundwater Working Group 2005; Hunter Williams *et al.,* 2011, & in press). The Geological Survey of Ireland have prepared a recharge coefficient map and a portion for the Kilmaine area is depicted in **Figure 21**.

These calculations are summarised as follows:

Average annual rainfall (R)	1330 – 1390 mm
Estimated P.E.	540 mm
Estimated A.E. (82% of P.E.)	443 mm
Effective rainfall (Potential recharge)	885 – 948 mm
Bulk recharge coefficient	65 – 85%
Recharge	**475 – 622 mm**

Water balance: The water balance calculation states that the recharge over the area contributing to the source should equal the discharge at the source. Current GSI guidance states that ZOC delineation should conservatively account for 150% of the abstraction volume if the hydrogeological conditions allow.

The area described above and shown in **Figure 22** is 7.9 km^2, and the area required to provide the estimated total mean discharge (8,400 m^3/d) is approximately 5 km^2, thus the area delineated allows for over 160% of the mean discharge. The area allows for varying groundwater flow directions and associated uncertainties. It also accommodates for discharge at Killernan spring and the water that flows via the Cross River.

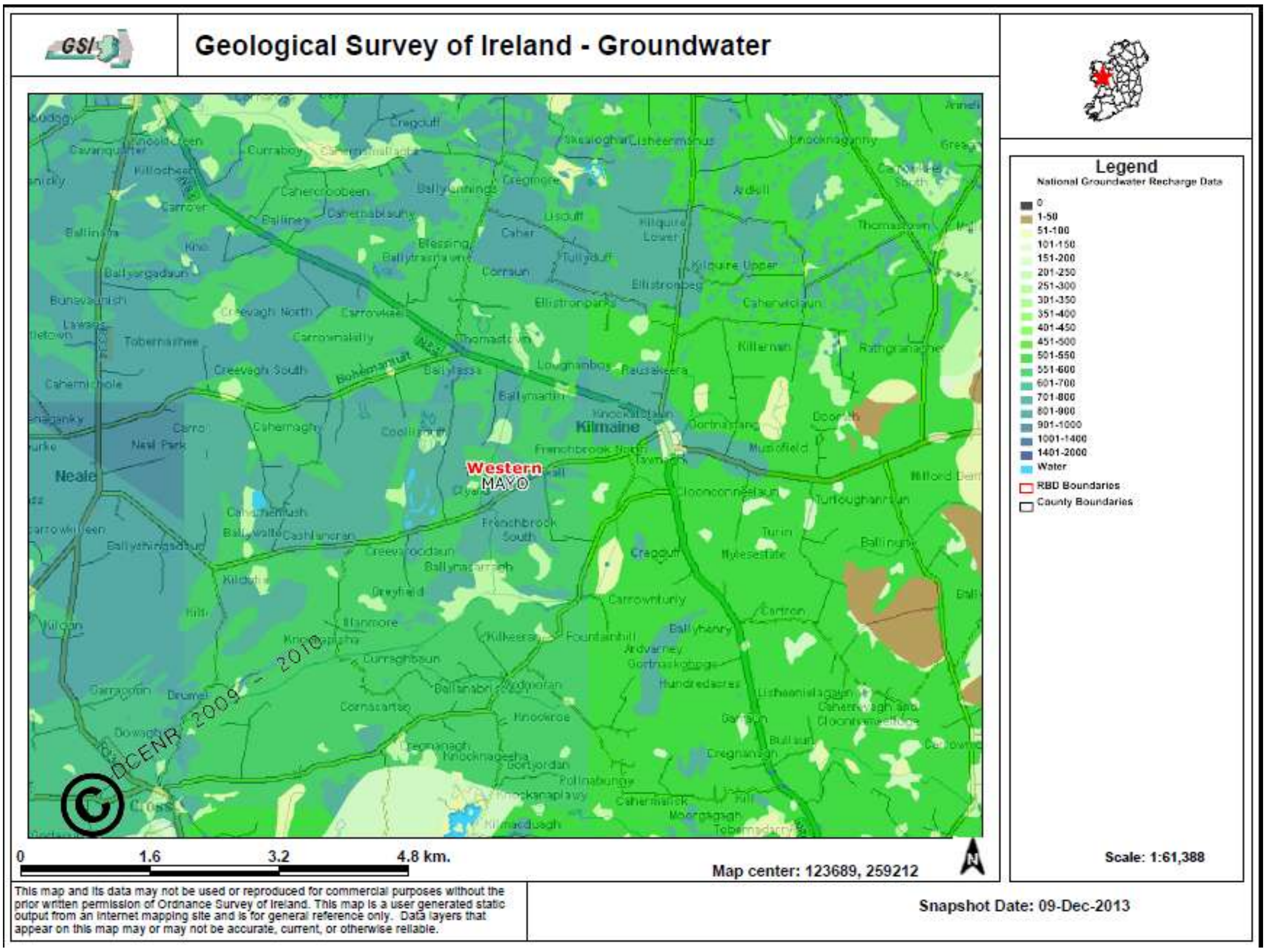

Figure 21 Recharge Coefficient Map (GSI)

11 Delineation of Source Protection Zones (SPZ)

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 the source protection areas (also the Zone of Contribution) and the aquifer vulnerability. The source protection areas represent the horizontal groundwater pathway to the source, while the vulnerability reflects the vertical pathway. The Source Protection Areas are subdivided into an Inner Protection Area and the Outer Protection Area.

The **Inner Protection Area (SI)** is designed to protect the source from microbial and viral contamination and it is based on the 100-day time of travel to the supply (DELG/EPA/GSI 1999). This is based on the velocities given in the Aquifer Characteristics. All the limestone area in the ZOC is within the 100 day time of travel as indicated by the demonstrated flow rates from the tracing results. The **Outer Protection Area (SO)** encompasses the entire zone of contribution to the source, described in the previous section. It is based on hydrogeological mapping and tracing and is large enough to match 160% of the total mean discharge. As the entire ZOC is within the 100 day time of travel, the SO is the same as the SI, thus the entire ZOC is termed SI.

The **Source Protection Zones** are shown in **Figure 22** and are listed in **Table 11-1**.

Table 11-1 Source Protection Zones

SPZ	Area m^2	%
SI/X	204707	2.6%
SI/E	1126318	13.8%
SI/H	528128	67%
SI/M	1261055	16%
	7873360	100%

12 Potential pollution sources

The water quality reflects susceptibility of the source due to the persistent faecal and total coliform counts. The Source Protection Zones (SI) encompasses the entire ZOC which ranges from '**extreme'** to '**moderate**' vulnerability to contamination. Land use in this area is mainly grazing cattle. There are a number of houses and farms upgradient of the springs which pose a risk to the source. Kilmaine village is served by a municipal treatment plant discharging to the Cross water course outside the ZOC. However, there are many houses outside the sewered area that are assumed to be on domestic wastewater treatment systems. There are several roads present in the ZOC and there is a low to moderate risk of contamination from this source.

13 Conclusions

- Fountainhill springs issue from Pure Bedded limestones which is a Regionally Important Karstified Aquifer.

- The Source Protection Zone has been delineated using hydrogeological mapping techniques and water tracing and is considered to represent the most likely contributing area. There are inherent uncertainties with the boundaries.

- Due to the rapid groundwater velocities, it is considered that groundwater in any part of the ZOC could potentially reach the source within 100 days. Therefore the entire ZOC is classified as the Inner Protection Area.

- The groundwater vulnerability is '**extreme'** to '**moderate**' and there is a significant proportion with rock at or very close to the surface and areas of concentrated recharge (enclosed depressions and swallow holes, portions of the water courses that 'lose' water to the aquifer. There are likely to be additional areas of where the depth to bedrock is shallower that have not been mapped due to the mapping scale.

- Available data shows the persistent presence of faecal coliforms in the untreated water. This suggests contamination from an organic waste source, and also provides evidence on the extreme vulnerability and rapid velocities and lack of natural attenuation.

- The Source Protection Zones delineated in this report are based on the current understanding of groundwater conditions and on the available data. Additional data obtained in the future might indicate that amendments to the boundaries are necessary, and the conclusions should not be used as the sole basis for site-specific decisions. Sources of error are due to limited discharge data, lack of trace data and groundwater level data.

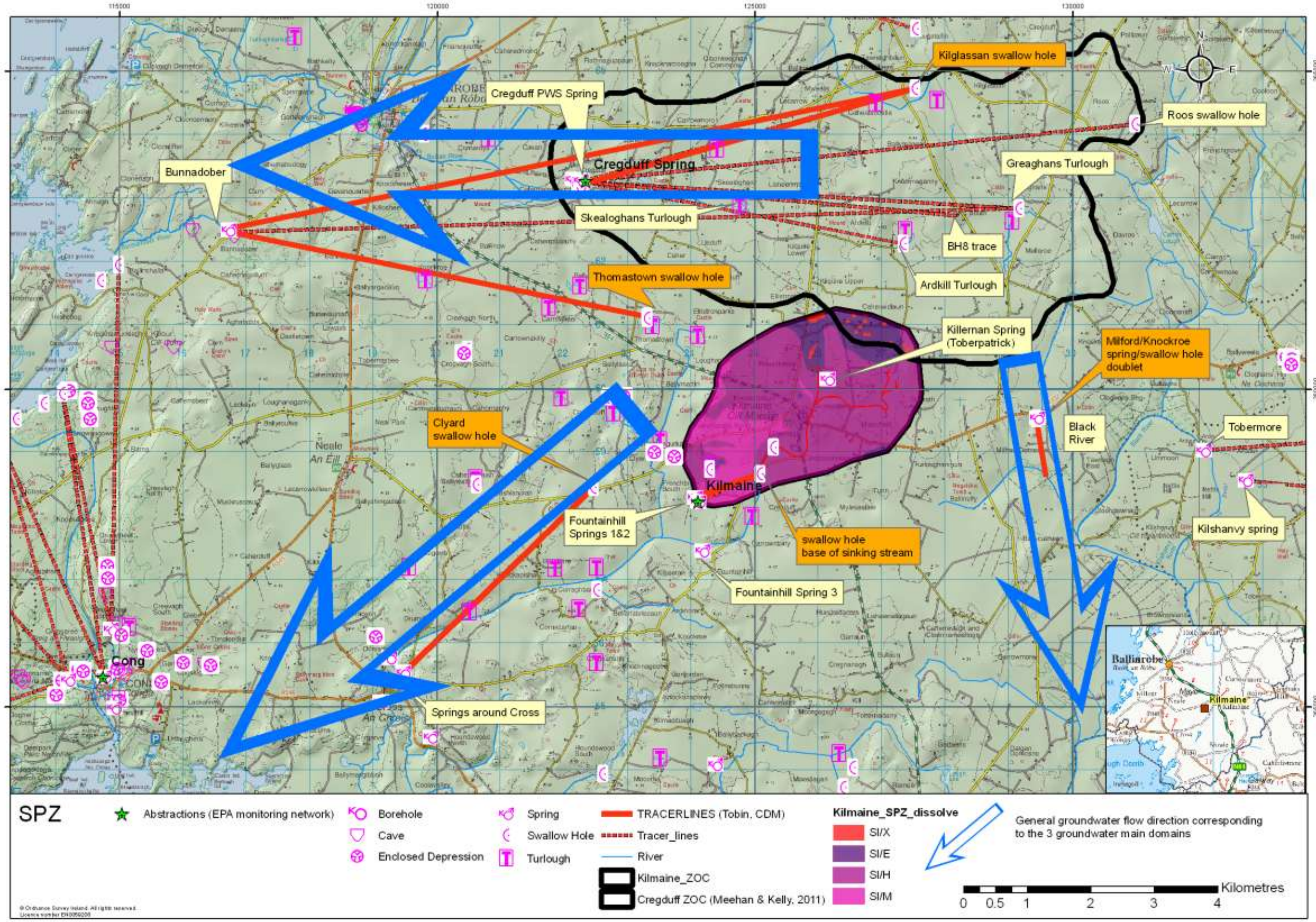

Figure 22 Source Protection Zones

14 Recommendations

1. Continued measuring of flow data should be carried out to develop a real-time database of hydrogeological information allowing better estimates of representative discharge. More generally there is very little information on the discharges from the other springs (Tober Patrick, Fountainhill, Cross and Bunnadober).

2. Further tracing (and in different hydrological flow conditions) would be useful to establish the groundwater flow patterns. Potential traces could be carried out from swallow holes in the Ardkill, Greaghans and Clyard turloughs, and potentially from a swallow hole 500 m northeast of the Fountainhill Springs (1, 2). It may also be possible to trace from some of the enclosed depressions mapped in the northern part of the zone of contribution and from further upstream along the ‘Cross’ water course. It is also suggested to repeat the Kilglassan trace at higher flow conditions.

    a. The main reasons for tracing from Ardkill and Greaghans is because the Fountainhill Springs (1, 2) were not sampled in the original traces (Coxon, 1986) and it would provide further information on the two broad catchments. It would also help in validating or otherwise the omission of the Kilglassan trace to Fountainhill 3.

    b. Similarly a trace from the Clyard turlough would give further information on the divide between L. Mask and L. Corrib.

    c. Traces from the swallow hole 500 m north of the springs or further up the ‘Cross’ water course would improve the certainty on the zone of contribution.

3. Water level mapping from boreholes could be useful to establish watertable maps.

4. High resolution depth to bedrock mapping would be useful to better define the vulnerability boundaries, particularly the ‘Moderate’ and ‘Extreme’ (both the ‘X’ and ‘1 to 3m’) categories.

5. Higher resolution water quality sampling of the **untreated** water could be carried out.

6. It is recommended that an adequate barrier to Cryptosporidium be installed as part of the water treatment system for the supply.

7. The potential hazards in the ZOC should be located and assessed, especially given the number of farmyards and houses up-gradient of the source in the ZOC.

8. An assessment of setback distances in accordance with EPA Advice Note No. 11 (EPA, 2011) is recommended

9. Particular care should be taken when assessing the location of any activities or developments which might cause contamination at the springs or adversely affect the springs.

15 References

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

Drew and Daly, D. 1993. Groundwater and Karstification in Mid-Galway, South Mayo and North Clare. Joint Trinity College Dublin and Geological Survey of Ireland report. Report Series, 93/3. Geological Survey of Ireland.

Doak, M. 1995. The Vulnerability to pollution and hydrochemical variation of eleven springs (catchments) in the karst lowlands of the west of Ireland. M Sc. Thesis, Sligo RTC, 52 pp.

Ellison, R. 2011. Study of groundwater inputs into Lough Mask using a spatio-temporal assessment survey of non-supported 222Rn activities. Unpublished MSc thesis, School of Natural Sciences (Environmental Science), TCD.

EPA, 2011. Advice Note No. 7. EPA Drinking Water Advice Note No. 7: Source Protection and Catchment Management to protect Groundwater Supplies.

EPA, 2011. Advice Note No. 11. EPA Drinking Water Advice Note No. 11: Technical Assessments and Prior Investigations.

Fitzsimons, V., Daly, D. and Deakin, J. (2003). GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination. Geological Survey of Ireland.

Geological Survey of Ireland, Cong–Robe GWB: Summary of Initial Characterisation. www.gsi.ie

Gill, L., Naughton, O., Johnston, P., Basu, B., and Ghosh, B. (2013). Characterisation of hydrogeological connections in a lowland karst network using time series analysis of water levels in ephemeral groundwater-fed lakes (turloughs). Journal of Hydrology. 499, 289-302.

Gill, L., Naughton, O., Johnston, P. (2013). Modelling a network of turloughs in lowland karst. Water Resources Research, Vol. 49, 3487–3503.

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

Goodwillie, R. (1979). A Preliminary Report on Areas of Scientific Interest in County Mayo. The National Institute for Physical Planning and Construction Research.

Hunter Williams, N.H., Misstear, B.D., Daly, D., Johnston, P., Lee, M., Cooney, P., Hickey, C. (2011) A National Groundwater Recharge Map for Ireland. National Hydrology Conference, Athlone, November 2011.

Hunter Williams, N.H., Misstear, B.D., Daly, D. and Lee, M. (in press) Development of a national groundwater recharge map for the Republic of Ireland. QJEGH.

Long, C.B., McConnell, B., and J.B. Archer (1995). Geology of Connemara and South Mayo: A geological description of Southwest Mayo and adjoining parts of Northwest Galway. Geological Survey of Ireland. 1:100,000 Map series.

Mayo County Council. 2010. Kilmaine waste water discharge license. D0361-01 - KILMAINE

Meehan R., Kelly, C. (2011) Karst Mapping Programme at Cregduff Spring, Ballinrobe, County Mayo. IAH Field Trip.

Mellander P-E, Wall DP, Jordan P, Melland AR, Meehan R, Kelly C and Shortle G. (2012). Delivery and impact bypass in a karst aquifer with high phosphorus source and pathway potential. Water Research, 46: 2225-2236.

Mellander P-E, Jordan P, Melland AR, Murphy P, Wall DP, Mechan S, Meehan R, Kelly C, Shine O, Shortle G. (2013). Quantification of Phosphorus Transport from a Karstic Agricultural Watershed to Emerging Spring Water. Environmental Science and Technology.

S.I. No. 278 of 2007. Statutory Instrument. European Communities (Drinking Water) (No. 2) Regulations 2007. The Stationary Office, Dublin.

S.I. No. 9 of 2010. Statutory Instrument. European Communities Environmental Objectives (Groundwater) Regulations 2010. The Stationary Office, Dublin.

Tynan, S., Gill, M., and P. Johnston (2007). Development of a Methodology for the Characterisation of a Karstic Groundwater Body with Particular Emphasis on the Linkage with Associated Ecosystems such as Turlough Ecosystems. EPA STRIVE Report 2002-W-DS-8-M1.

Teagasc, 2006. County Mayo Subsoils Map. Map produced as part of Teagasc/EPA Soils and Subsoils Mapping Project. Teagasc, Kinsealy, Dublin.

Wilson, J., and C. Rocha, (2012). Regional scale assessment of Submarine Groundwater Discharge in Ireland combining medium resolution satellite imagery and geochemical tracing techniques. Remote Sensing of Environment. 119 (2012) 21–34.

Wilson, J., and Rocha, (2013). Regional-Scale Assessment of Submarine Groundwater Discharge Using Remote Sensing Development of Remote Sensing as a Tool for Detection, Quantification and Evaluation of Submarine Groundwater Discharge (SGD) to Irish Coastal Waters. EPA STRIVE Report (2008-FS-W-4-S5). ISBN: 978-1-84095-510-1