INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IRISH BRANCH)

2011 ANNUAL FIELD TRIP

Managing Karst

Welcome to the IAH Annual Fieldtrip 2011

On the first day of this years fieldtrip we will be in the Ballinrobe area, County Mayo, where we will visit one of the catchments studied in the Teagasc led Agricultural Catchments Programme. The Agricultural Catchments Programme aims to encourage productive agriculture while protecting water quality, and is based on partnership with farmers and other stakeholders. We will be visiting the Cregduff catchment area, which is a large karst spring catchment. We will be looking at the issues facing agriculture and karst, such as land management in shallow limestone areas and doline fields.

Following an overnight stop in the Galway area, will be visiting some karst spring catchments in East Galway. These springs were studied as part of a larger project to establish groundwater protection zones, led by the Environmental Protection Agency.   We will be looking at the complexities of delineating spring catchments in low-lying landscapes such as the karst lowlands west of the Shannon. Members of a CDM Ireland team will take us around some of the key sites.

Acknowledgements

On behalf of the IAH (Irish Group) I would like to thank all the contributors and field guides for taking the time to show us around the sites and for preparing this field guide document. I would like to thank members of the Teagasc Agricultural Catchment Programme, especially Ger Shortle and Phil Jordan for allowing us to look at one of their catchments. I would like to thank Robert Meehan, Coran Kelly, Henning Moe for all their help and effort in the preparation of this fieldtrip. I would also like to thank Paul Johnston, Pamela Bartley and Michal Smietanka for their contributions. Finally, I would like to thank the GSI and the Groundwater Section for their support.

Cover Image - Land-spreading at a sinkhole, Glenamaddy, Co. Galway. Courtesy Brian MacDomhnaill

Site Visits:

Saturday 1st October

1. Cregduff Springs
2. Caher Quarry
3. Ardkill or Kilglassaun Turlough
4. Lissatava Swallow Hole and Epikarst Window
5. Pollbaun Doline Field
6. Knockroe Swallow Hole / Spring Couplet

Sunday 2nd October

1. Barnaderg GWS
2. Pollifrin
3. Nalsaragh Turlough
4. Caltra

Karst Mapping Programme at Cregduff Spring, Ballinrobe, County Mayo

Robert Meehan and Coran Kelly

Acknowledgements

There are many people that we wish to thank for their input into this project work.

The entire Teagasc Agricultural Catchments Team contributed massively to the entire work package in so many ways. Specifically, Dr. Avril Rothwell needs to be thanked for her immense patience and endurance, having sampled fourteen springs in the catchment for three weeks, twice daily. Noel Meehan did huge work in helping in liaison with landowners throughout the project work. David Ryan operated the drilling rig during the drilling work, having driven it from Wexford to Ballinrobe !

As well as this, we thank ACP Team Members Phil Jordan and Per-Erik Mellander for lots of stimulating discussion and guidance throughout the project, as well as Ger Shortle for co-ordinating much of the tasks. Other ACP Team Members David Wall, Alice Melland, Sarah Mechan and Oliver Shine are thanked for discussion in the field and office about developments during the project.

We would like to thank the landowners and farmers across the catchment who facilitated access to their fields and for their local knowledge on their land.

Mr. Donal Daly of EPA is thanked for his input, particularly in the initial suggestion of the phosphate susceptibility map for the catchment, and Anthony Mannix and Ellen Carvill of EPA who helped in the tracing injection work. As ever, Dr. David Drew of Trinity College Dublin is acknowledged for his endless knowledge of and suggestions on karst, and Caoimhe Hickey and Tom McIntyre from the Geological Survey of Ireland are thanked for assistance on the dyes and analysis. Declan Kavanagh also contributed to sampling analysis in GSI.

The area around Lough Mask and the River Robe

The hydrogeology of the area has been detailed in David Drew and Donal Daly's publication of 1993. An outline of the region's hydrogeology can be seen on the Figure 1 below.

To the north of the River Robe the density of stream channels is much greater than the south (Drew and Daly, 1993), as thicker drumlin-forming tills overlie the limestone bedrock. This increase in stream channels also coincides with the occurrence of impure limestone bedrock north of the river. South of the river and to the east of Lough Mask, an area of over 200km^2 occurs, with no surface drainage other than man-made arterial drainage channels (Drew and Daly, 1993). Turloughs are common here, and in general they have not been drained. All of this area is underlain by pure bedded limestones, with thick glacial deposits in the east of the area and much bare rock or thin soil close to Lough Mask.

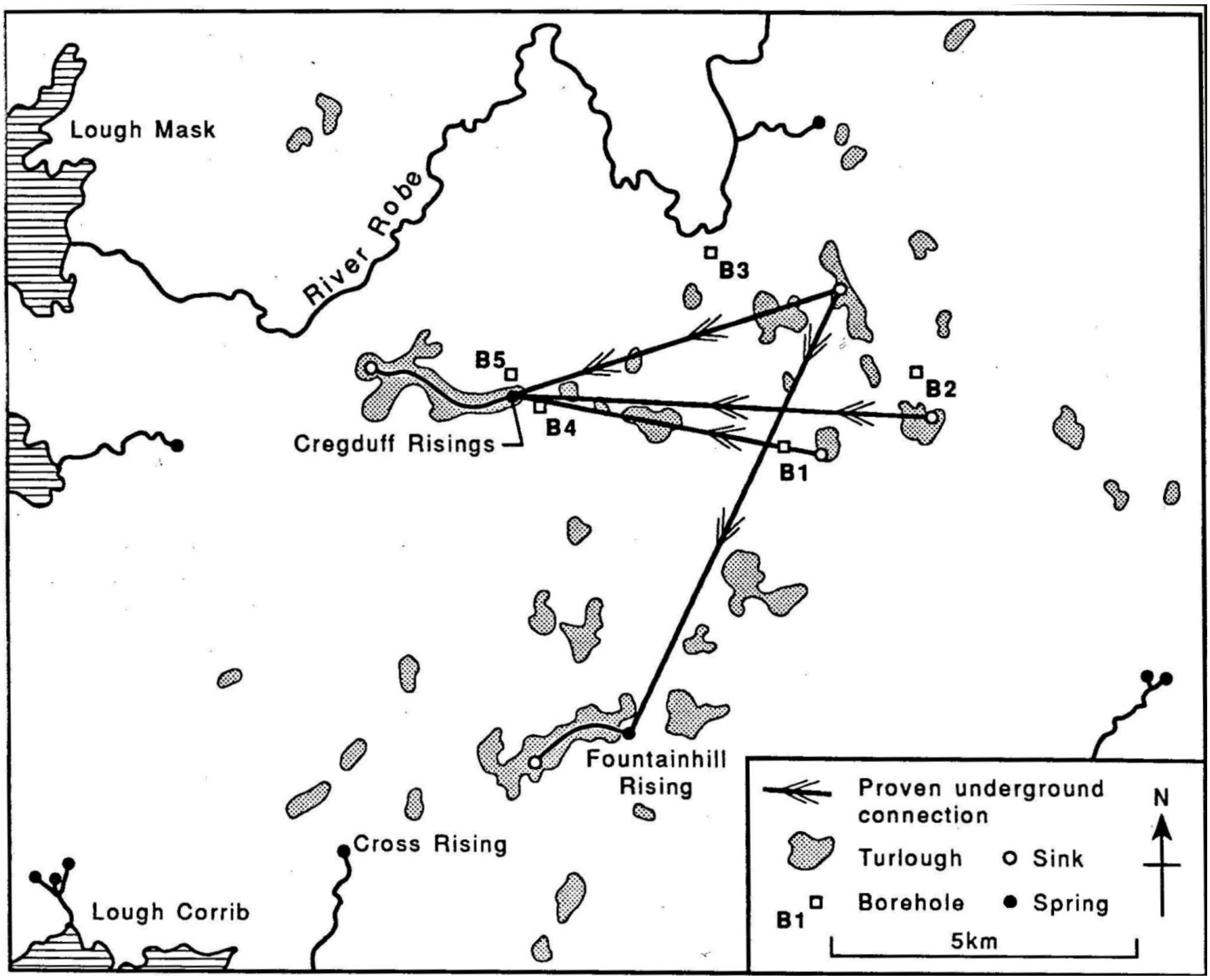

Figure 1: Outline of the hydrology of the Ballinrobe area, County Mayo. From Drew and Daly, 1993.

The River Robe is the only surface water feature of any magnitude here, and there is considerable interaction between river flow and groundwater. Drew and Daly report that for approximately 40% of the year, flows in this river increase downstream roughly in accordance with the increase in area drained. However, from mid-winter to late spring, flows downstream of Kilrush, where the cover of glacial deposits thins, are disproportionately high, up to $3m^3/s$ higher than upstream; thus the river gains significantly from high groundwater table levels. In the summer and early autumn the reverse applies, and upstream discharges are up to 300% of those prevailing further downstream, and a maximum difference of almost $1m^3/s$ has been measured (Drew and Daly, 1993). At this time water is being lost to the stream bed to the deeper body of groundwater beneath. Recent work on the Robe with the use of Radon 'mapping' has revealed additional information on the groundwater discharges to the river (*David Drew*, *pers comm September 2011)*

All of the drainage in this area reaches Lough Mask, either *via* the River Robe or from springs close to the lake. Springs which have been mapped and noted before include Fountainhill (1,500 m^3/d), Cross (12,000 m^3/d) and Bunnadober (5,000 m^3/d). There are also springs which Drew and Daly term 'internal' springs, such as that at Kilrush (1,500 m^3/d), the Loop Spring on the banks of the River Robe (750 m^3/d) and the set of four springs at Cregduff, reported in 1993 to discharge 7,500 m^3/d. Cregduff Spring formerly drained into a turlough but the waters from this feature are now conduited to the River Robe at Ballinrobe *via* the Bulkan River.

The movement of groundwater can be seen to be east to west, from an initial inspection of Figure 1. Hydraulic gradients have been measured as being 0.0008 - 0.00175 (0.8m – 1.75m per kilometre, Drew and Daly, 1993). Flow rates for groundwater have been measured at 10m – 100 m/h but these may represent maximum rates as they were all measured from turlough sinks to springs and these routes may be along zones of higher than average permeability (Coxon and Drew, 1986; Coxon, 1986). A water table map of the area is shown on Figure 2 following. A groundwater trough extends westwards from the region in which many turloughs occur.

Few data are available concerning water yields in wells, but great variation in yield over short distances and vertical localisation of inflows are the norm.

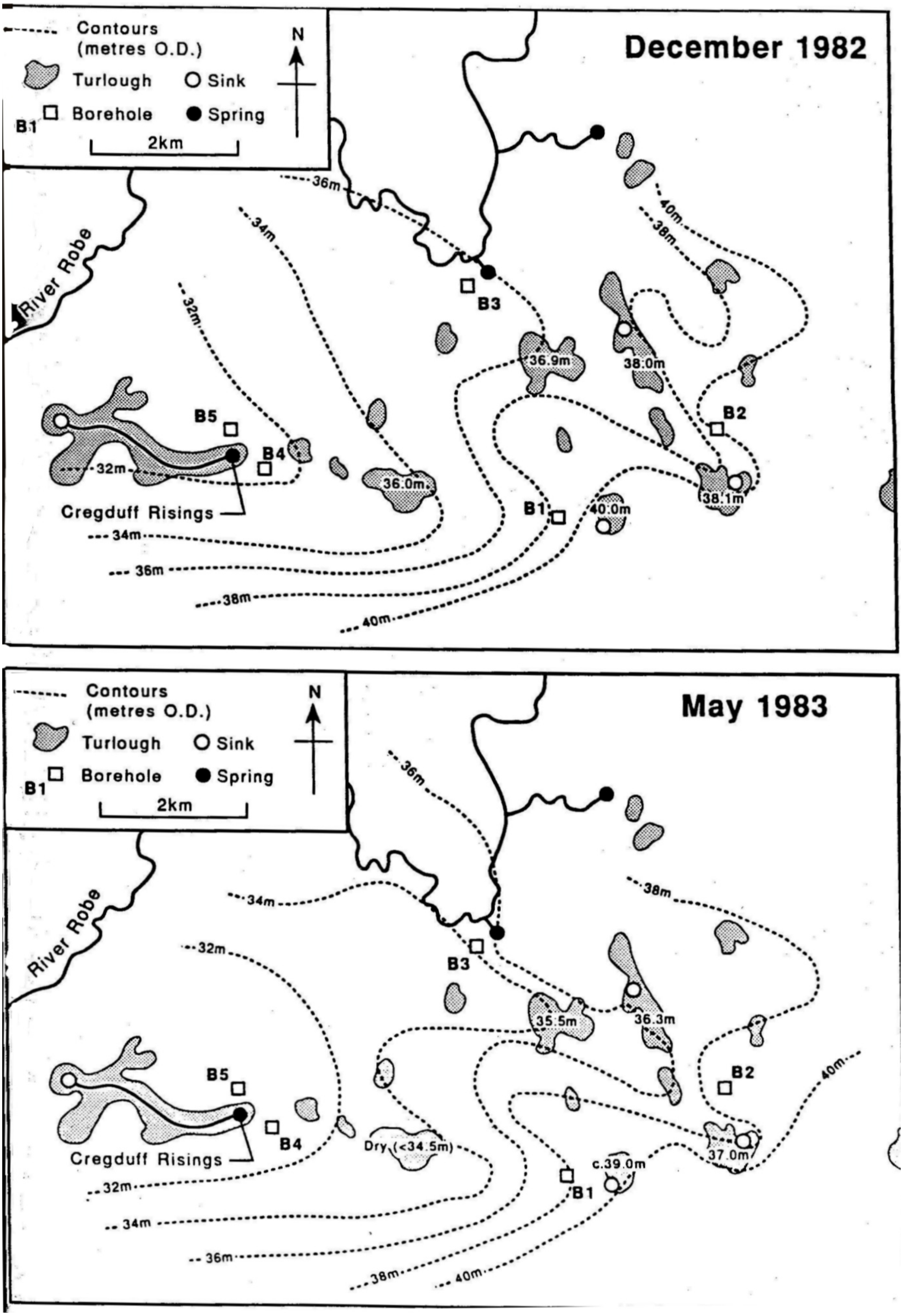

Figure 2: Water table maps of the Ballinrobe area, from Drew and Daly, 1993 (and after Coxon, 1986).

The Agricultural Catchments Programme

Teagasc, the Irish Agriculture and Food Development Authority, is conducting an Agricultural Catchments Programme (ACP) to evaluate the Nitrates Directive National Action Programme. The ACP is a partnership based programme supporting agriculture and maintaining water quality, and monitors the effects of the Good Agricultural Practice (GAP) regulations and changes in nutrient (N and P) use allied to soil status and transfers *via* hydrological pathways to receiving water courses from 6 agricultural catchments (5 of which are small, 6-12km^2 catchment areas ... and Cregduff) representing varying levels of transfer risk. The ACP is therefore a multidisciplinary and holistic approach evaluating the implementation of the GAP regulations. An understanding of the physical pathways through the soil, subsoil and bedrock is required to help assess the transfer of Nitrogen and Phosphorous from field application to receiving groundwater and surface water.

Water courses studied in the programme range from ephemeral headwaters up to 3rd order at the outlets, with varying gradients and substrates. Socio-economic, including attitudinal, responses to the GAP regulations are also being monitored.

A further requirement of the ACP is to provide a similar assessment for the large karst contributing area of Cregduff Springs.

The Cregduff Catchment and Groundwater Vulnerability

The Cregduff Catchment is the largest by far of a number of catchments selected for the ACP. Before the karst mapping programme commenced in Autumn 2010, the Cregduff catchment site was understood to represented generally free draining conditions over karstified limestones, and was thought to represent the area shown in Figure 3. Monitoring of the water quality is achieved in this catchment through monitoring of Cregduff Spring, and the spring is considered to represent the bulk of the outflow from the catchment. Rainfall over the catchment was considered to rapidly reach groundwater in the bedrock through diffuse and point recharge mechanisms where it is then focussed through, in general, a hierarchical organisation of karstified channels within the bedrock to Cregduff Springs. There are four individual spring features at the spring output.

In order to fully understand the vulnerability of the catchment feeding the spring, detailed field-scale karst mapping was required. In this, dye tracing would also be required should suitable point sources of contamination be found.

Much work had previously been conducted in the catchment. David Drew has been continuously interested in the area for the past forty years, and tracing had been undertaken before, by Catherine Coxon, as part of her thesis work in the early to mid-eighties. Paul Johnston has also been working on various aspects of turlough flow in the catchment over the last ten years. Donal Daly and David Drew wrote an outline hydrogeological account of the area as part of their 1993 publication.

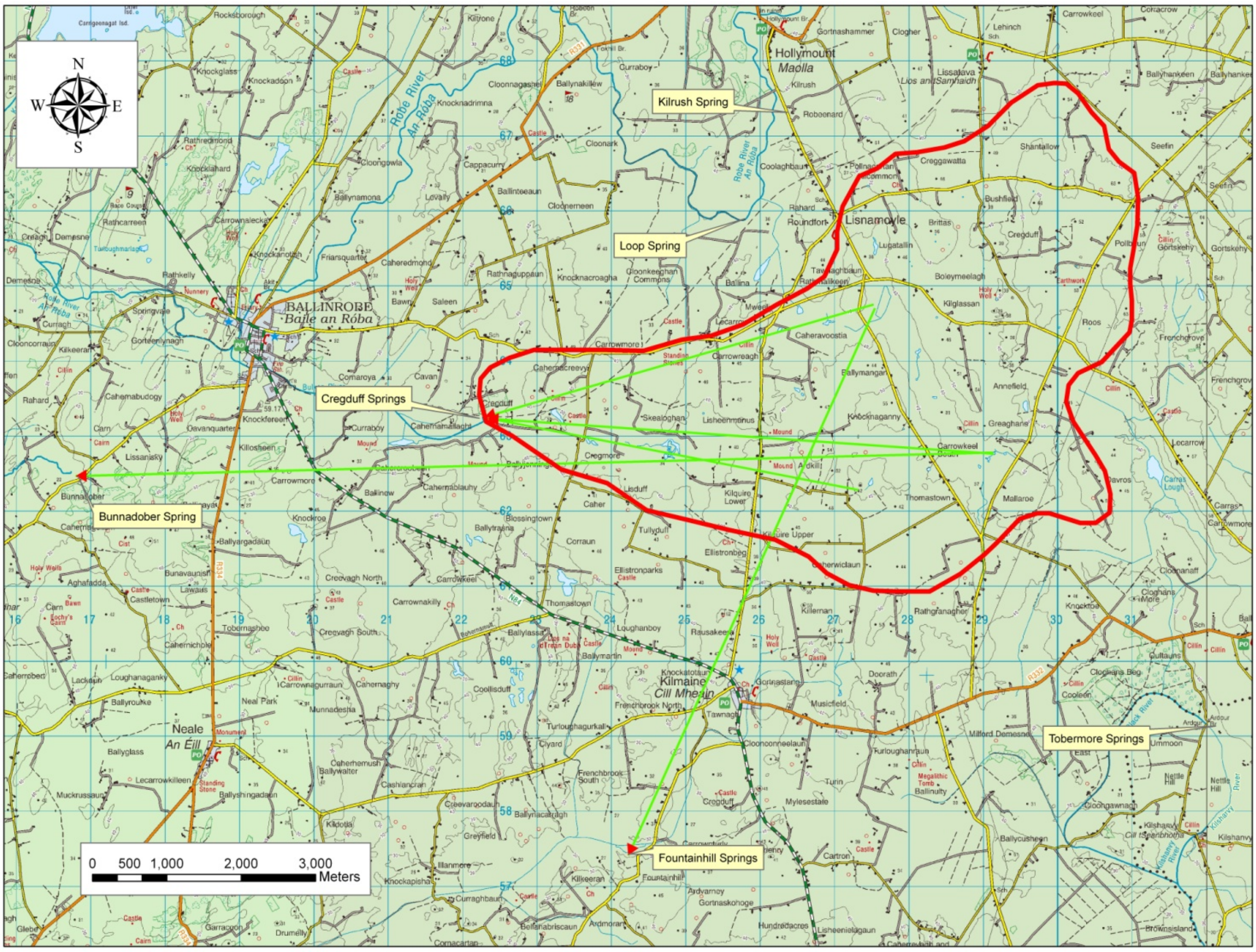

Figure 3: Cregduff Springs Catchment as understood before the ACP Mapping Programme, as well as previously conducted traces in the region undertaken by Coxon (1986).

As part of the ACP mapping programme, a detailed characterisation of Groundwater Vulnerability was required to allow for appropriate assessment of the groundwater pathways within the catchment and the potential implications of this for water quality at the springs.

Groundwater Vulnerability is a component of risk and risk assessment, and is defined as the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater can be contaminated by human activities. Four main vulnerability categories are recognised: extreme (X and E), high, moderate and low, and these are determined by mapping the various types and depths of subsoils overlying the groundwater and assigning vulnerability ratings to each, based on pragmatic judgements, experience and available scientific information. As indicated above, the extreme vulnerability category is subdivided into two further categories: ‘X’ represents rock outcrops, rock close to surface and on and adjacent to karst features; and ‘E’ essentially represents 1 m to 3 m depth to bedrock. This refinement of the Extreme vulnerability category is particularly important for this specific study as the ‘X’ category represents the areas on the land surface which allows for the most rapid transmission of recharge into the bedrock and therefore to the receiving groundwater, including the output of groundwater from the catchment focussed principally in this case to Cregduff Spring.

As well as this, the type of recharge (whether point or diffuse) is taken into consideration in vulnerability mapping, expressing the degree to which the protection provided by subsoils is bypassed. Groundwater is everywhere under our feet, and therefore every portion of the entire land surface of the country should have a vulnerability rating assigned to it.

The completion of the National Groundwater Protection Scheme Programme was being undertaken in County Mayo in 2010. This programme is work which primarily seeks to assist local authorities in reaching informed decisions of land zoning and allow for sustainable development; a regional scale study bringing together point data and large scale spatial data which provides a robust conceptual model of the groundwater vulnerability, subsoil permeability and broad depth to bedrock patterns. The methodologies employed are robust and rigourous, however, the level of detail was insufficient for the ACP study because a field-scale study was required, at a much greater resolution than the 1:40,000 (county) scale vulnerability mapping. A field by field study would integrate detailed information on depth to bedrock and subsoils permeability; in particular it would map out to a high level of accuracy and completeness the rock outcrops, rock close to surface and karst features (for example, enclosed depressions (dolines), swallow holes, losing and sinking streams).

The principal tasks which were undertaken in the performance of the ACP field-by-field vulnerability mapping work included:

- Collate all relevant literature, desk study data and existing information;
- Conduct field mapping of nature and extent of subsoil materials;
- Organise and supervise drilling;
- Organise laboratory testing of material samples;
- Compile subsoil permeability maps, based on field investigations;
- Compile depth to bedrock maps, based on field investigations;
- Prepare groundwater vulnerability maps

.

All data were digitised in ArcGIS with appropriate metadata.

ACP Groundwater Vulnerability Field Mapping Programme

A 40 day mapping and site investigation programme was undertaken in Cregduff Catchment. The previously-considered catchment boundary was used as a basis for mapping, and some fields outside of this were also walked if relevant to the overall understanding of the three dimensional conceptual model of the region. In this, an area of 47 square kilometres was traversed, at a rate of approximately 1.25 km^2 per day.

The field work comprised:

- 38 days mapping in the field (subsoil permeability mapping / karst features / sinking streams / depth to bedrock).
- 2 days drilling and clearing
- 10 days preparing maps and reporting.

Teagasc liased with all landowners to allow free access to fields, and the catchment was then walked field by field in October and November 2010 and February 2011. The vulnerability mapping was conducted according to the GSI Groundwater Vulnerability Guidelines (Fitzsimons, *et al,* 2003). The three critical components were the subsoil permeability map, the depth to bedrock map and the karst features map.

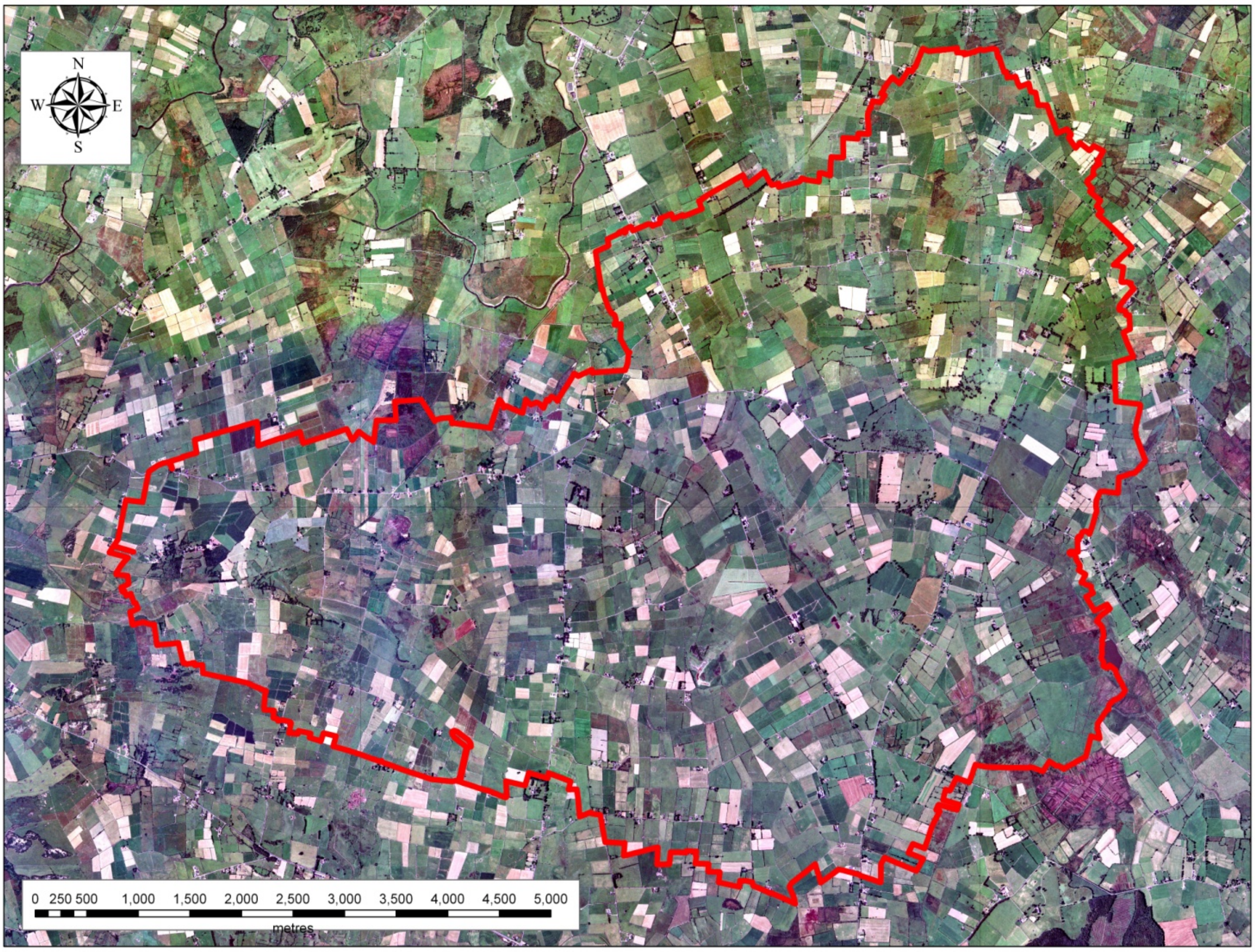

Figure 4: Aerial photograph showing area walked field-by-field during ACP Cregduff Springs Catchment Mapping Programme.

The mapping was conducted according the GSI Groundwater Vulnerability Guidelines (Fitzsimons, *et al,* 2003).

- ⇨ Logging of exposures (soil, subsoil, rock) using the GSI exposure sheets and the flow chart for describing subsoils which is based on British Standards BS 5930.
- ⇨ Outcrops were walked over to assess the degree of karstification, fracturing, weathering, extent if any of epikarst and soil cover.
- ⇨ Hand augering was employed in the subsoil permeability mapping in areas with few or no subsoil exposures. Particular focus was given to areas with rock close to surface to pick out and map in detail the rock close-subsoil ‘boundary’.
- ⇨ Drilling was carried out to assess the depth to bedrock and the subsoil permeability. This included drilling in the various subsoil types – till, marl and cutover peat areas.
- ⇨ Karst features were recorded, assessed, georeferenced and photographed.
- ⇨ Streams were walked over to establish sinking zones,.

Turloughs were assessed for epikarst and hand augering focussed on 3 prime areas; off the main outcrops, in the vicinity of turloughs and in the thicker till areas to examine the soils for texture and possible permeability indications such as mottling.

<u>Approach to subsoil permeability mapping</u>

The subsoil permeability map is a critical component of the vulnerability map. Compiling information on permeability of subsoils involves assessing the infiltration capacity of these by direct and indirect means, which is based on the broad question ‘*can water and contaminants reach groundwater easily?*’, and results in classifications of ‘high’, ‘moderate’ or ‘low’ subsoil permeability.

High permeability subsoil materials are generally sands and gravels. Moderate permeability subsoils are silty to sandy glacial tills that are generally quite free draining. Low permeability subsoil materials are clayey tills, peats and lake clays.

The GSI and Trinity College Dublin have completed a body of research in recent years on permeability assessment, developing proxies for assessing permeabilities at specific locations and to identify secondary indicators that provide an indication of recharge acceptance and vulnerability as a whole, across a particular area (Swartz *et al,* 2003; Swartz, 1999; Lee, 1999).

The GSI Vulnerability Mapping Guidelines (Fitzsimons *et al*., 2003) outlines the approach taken in subsoil permeability mapping. This is a holistic method involving:

- field description/classification/analysis of texture using British Standards 5930;
- sampling and detailed grain size analysis at ‘type’ localities;
- examination of soil type, particularly presence or absence of mottling;

- presence of ‘wet’/’dry’ vegetation indicators in the areas examined;
- data on artificial and natural drainage density;
- parent bedrock characteristics and;
- topographic data.

Subsoil permeability mapping was not undertaken within areas where the depth to bedrock is interpreted as less than three metres. In these areas, subsoil matrix and permeability are assumed to be variable and unpredictable due to the influence of bedrock fractures, the influence of *in situ* weathered bedrock, glaciotectonied rock units, and associated preferential flow paths. In these areas depth to bedrock is the primary factor governing vulnerability, with permeability becoming secondary, less relevant, and unmapped.

Depth to bedrock contouring

For vulnerability mapping, total subsoil thickness is assessed using contours at 3m, 5m and 10m. The contours provide general approximation of broad trends across an area at a regional scale. The contouring process is not an automated process; the contours are drawn based on a combination of data, expertise and experience, and the data include:

- Outcrop and shallow rock locations from the GSI databases and the Teagasc Subsoil Mapping Project.
- Depth to bedrock from borehole databases[1].
- Karst data from GSI databases.
- Interpreted subsoil stratigraphy.
- Geophysical surveys.
- Elevation and slope of ground surface.
- Landscape morphology.

An important component of the depth to bedrock mapping in the field included hand augering, and over 400 auger samples were taken throughout the catchment.

Karst feature mapping

Karst feature mapping included the mapping of:

- Limestone outcrop at surface, or within 1m of the surface while hand augering;
- Epikarst, where seen in exposure;
- Turlough extents at time of mapping;
- Interpreted maximum turlough extents, from discussions with landowners and vegetation /geomorphological mapping;

[1] Includes well data from GSI Groundwater Section; borehole data from GSI Minerals and Geotechnical Sections; borehole records from road schemes, site investigations, academic studies, well surveys and other site data from consultants; Bord na Móna peat depth maps; Local Authority well grant records; and mineral exploration drilling.

- Springs, with an estimation of flow rate;
- Swallow holes, with lateral extent, depth, descriptions;
- Sluggeras, with lateral extent, depth, descriptions;
- Enclosed depressions (dolines), with lateral extent, depth, descriptions;
- Ephemeral streams, with size and approximate flow rate;
- Limestone pavement (superficial solution features), extent and degree of karstifiaction;
- Epikarst windows, with lateral extent, depth, descriptions.

As well as this, drainage ditches (depth and lateral extent were mapped). Most features were photographed with a resulting photographic database of over seven hundred photographs.

Mapping Results.

The mapping of the Cregduff Catchment yielded vast amounts of new data on features on the ground, and meant that further work was thereafter completed to refine the karst flowpaths in the catchment, as well as map outputs. The results can be summarised as follows:

- Much limestone at surface was mapped, and the extent of limestone subcrop was also mapped in detail. Just over a fifth of the mapped area comprised limestone within 1 metre of the surface (9.95 km^2);
- Much of this limestone was considered to be epikarst, as all rock exposures displayed this;
- At the time of mapping, which was a dry winter, turlough extents were very low; this allowed a high quality map of outcrop and subcrop, as well as associated swallow holes and springs, in or around the turloughs to be produced;
- The total area of water area within the catchment covered just under two kilometres when turloughs were flooded;
- Thirty six springs were mapped; again, only ten of these were previously known;
- Seventeen swallow holes were mapped; eleven of these were previously unknown;
- One sluggera was mapped, previously unrecorded;
- Eighteen hundred and fifty five enclosed depressions) were mapped, with none recorded previously in the GSI Karst Database;
- Eighteen lengths of ephemeral stream were mapped, with these all sinking into swallow holes for all or part of the year;
- Forty one areas of karst pavement were mapped in their entirety, with none of these previously in the GSI Karst Database;
- Two epikarst windows were mapped, which are depressions which have a spring at one side and a swallow holes at the other.

Plate 1: Doline field in Thomastown in the southeast of the area mapped.

Plate 2: Epikarst window in Shantallow in the northeast of the area mapped.

Plate 3: Epikarst over competent limestone bed in exposure at Caher, in the southwest of the area mapped. Auger is 1.2m long.

Plate 4: Newly-found swallow hole at the base of Greaghans turlough.

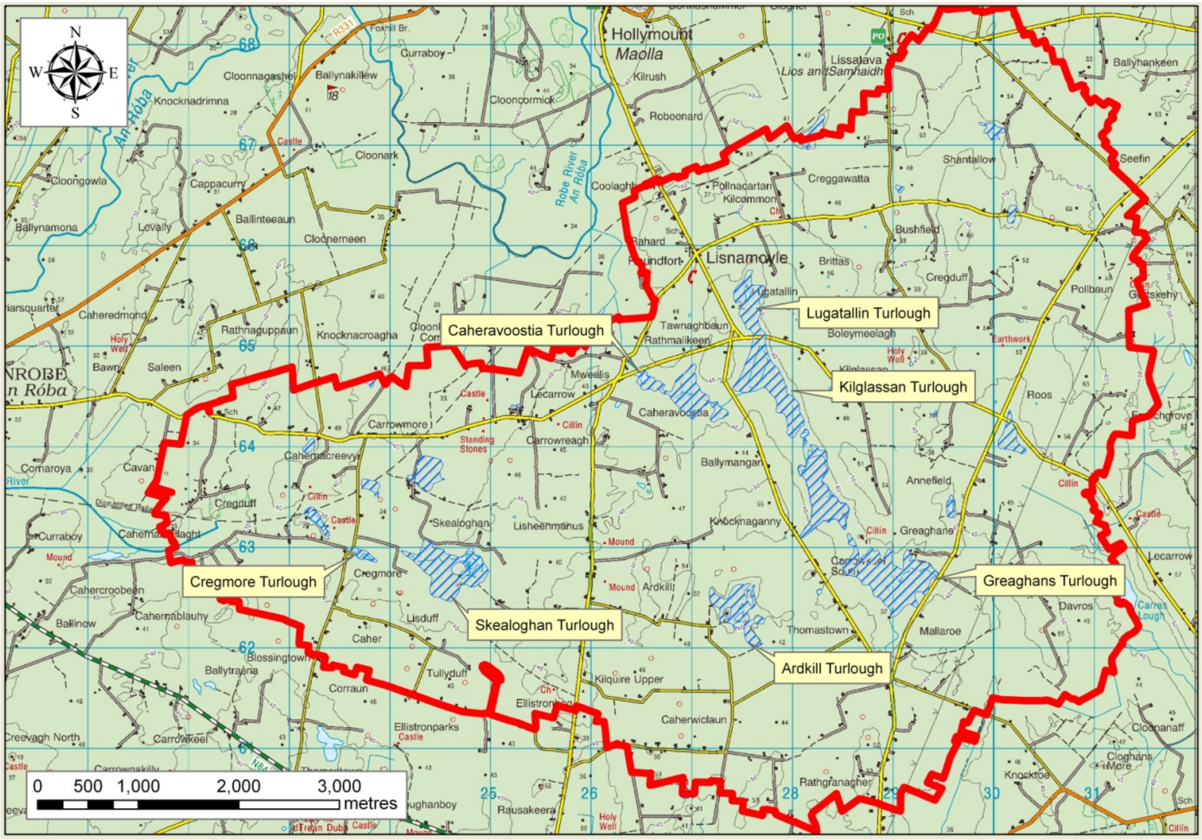

Figure 5: Turlough areas in the potential Cregduff Catchment.

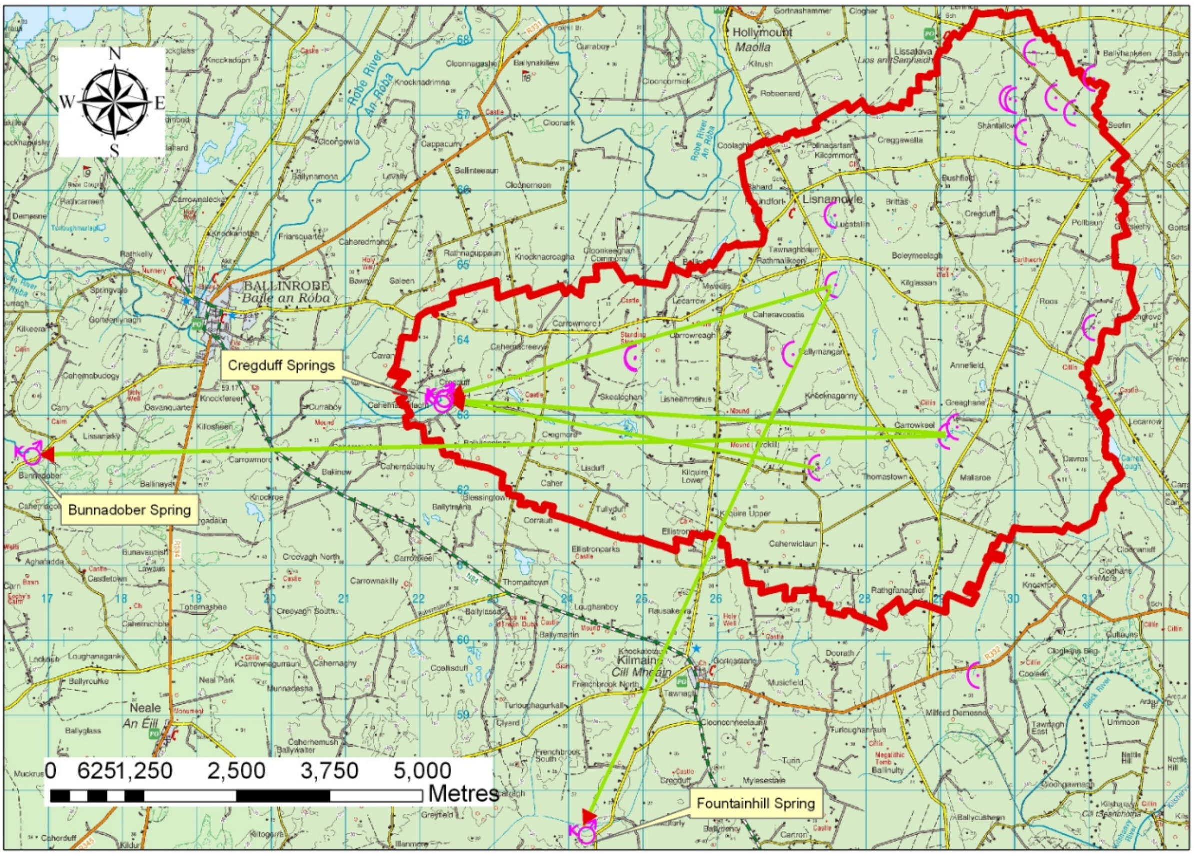

Figure 6: Swallow holes and previously-confirmed tracer lines mapped in the potential Cregduff Catchment.

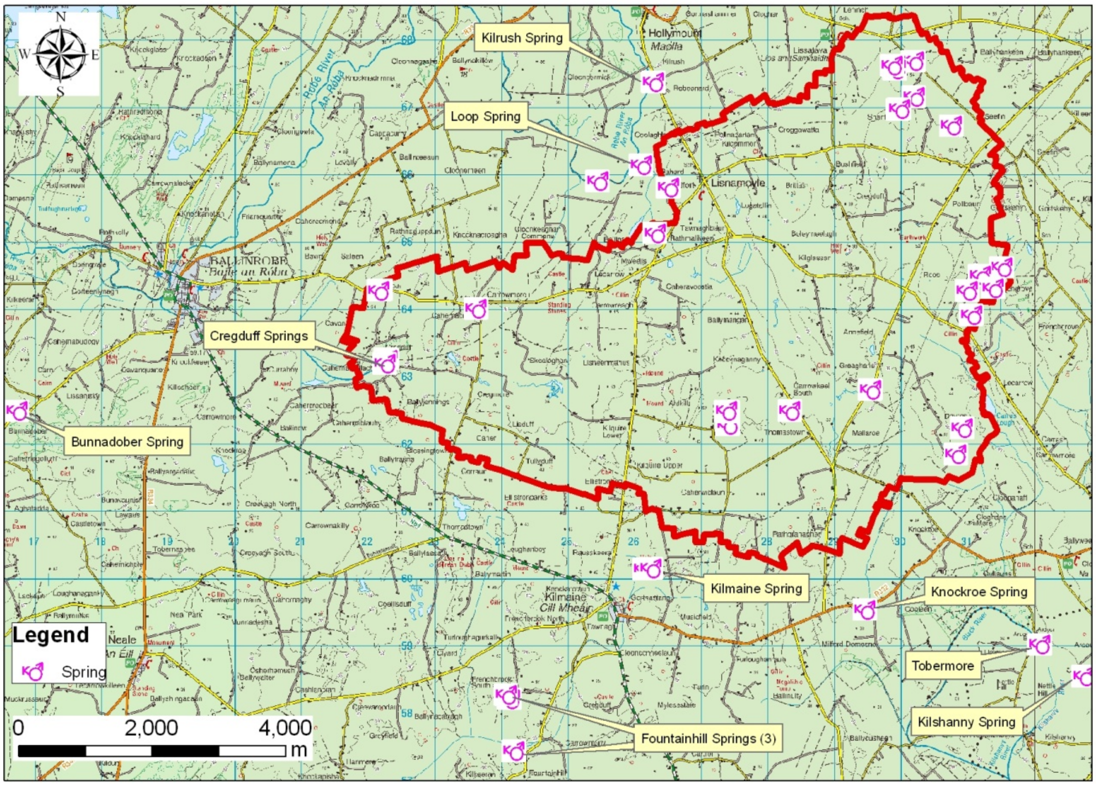

Figure 7: Springs mapped in the potential Cregduff Catchment.

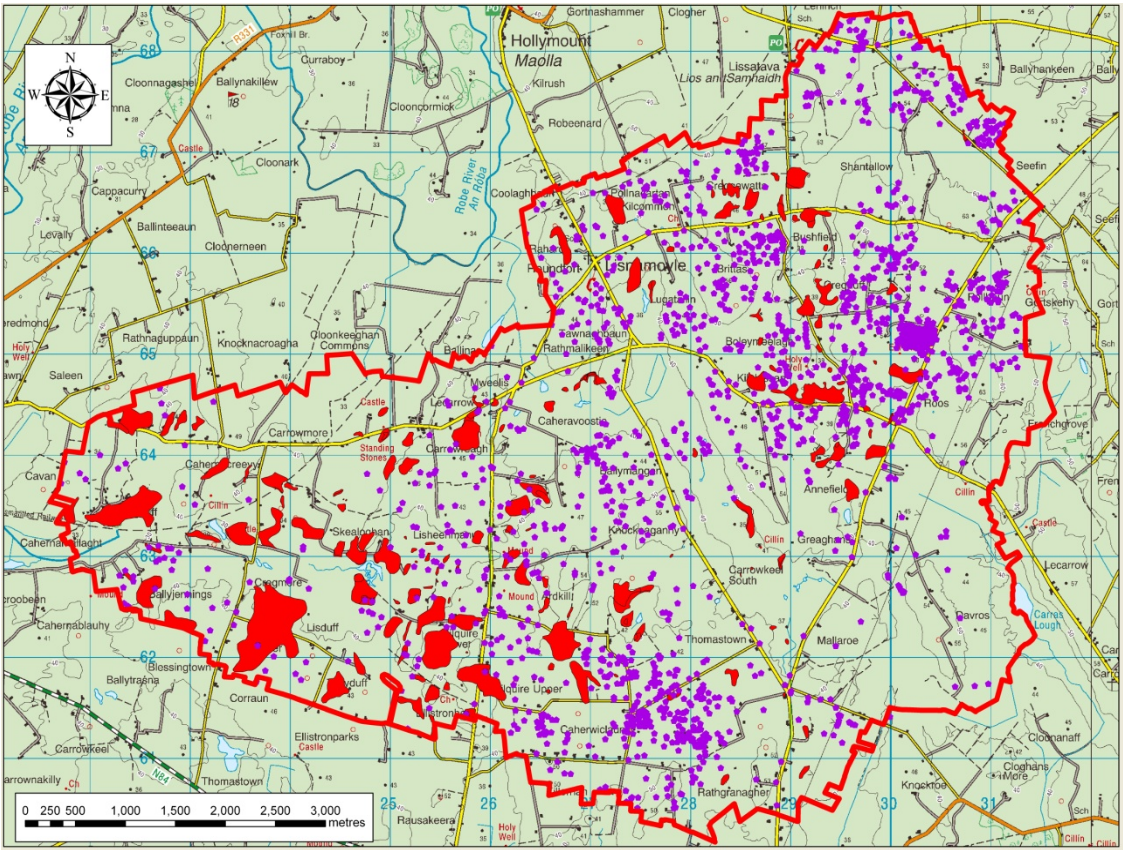

Figure 8: Dolines mapped in the potential Cregduff Catchment. Areas of bedrock within 0.5m of the surface are also shown as red; dolines seem to occur almost exclusively outside of these areas, but this may be owing to land management practice and infilling of features.

Plate 5: The 'Loop' Spring, adjacent to the Robe River.

Plate 6: Fountainhill Spring, southernmost of three.

Drilling

Drilling was carried out over a two day period in April 2011. Drilling was conducted using Teagasc's Giddings Drilling Rig in areas where uncertainty existed with respect to the depth to bedrock, in particular in areas where the three metre contour was difficult to determine as part of the vulnerability map draw-up. A number of boreholes were also drilled at the edge of deep dolines.

Sixteen boreholes were drilled to depths between 0.6m and 4.1m, with an average depth of 2.4m.

Plates 7 and 8: Top ... Drilling to 3.5m in Caheravoostia and below ... drilling at the edge of a deep doline in Pollbaun.

Groundwater Vulnerability map

The Groundwater Vulnerability Map for the mapped area is shown in Figure 9. In the western portion of the catchment, where bedrock outcrop and subcrop is common, 'Extreme – X' and 'Extreme – E' vulnerability dominates. Moving eastwards, sediment thickness increases, but most of the depth to bedrock is still less than 10m; as moderate permeability subsoil material is dominant, 'high' vulnerability therefore dominates. A number of marked ridges having depths of over 10m of sediment do occur however, meaning there are a small number is 'islands' of moderate groundwater vulnerability.

Though small pockets of low vulnerability subsoil occur in the southeast and east of the mapped area, depths of this material are generally no more than 5m, so the consequent groundwater vulnerability ranking is also 'high' in these zones.

One of the most striking aspects of the vulnerability map is the preponderance of small circular areas of 'Extreme – X' vulnerability around doline features. With the huge number of such features, the entire groundwater vulnerability map is peppered with such localities.

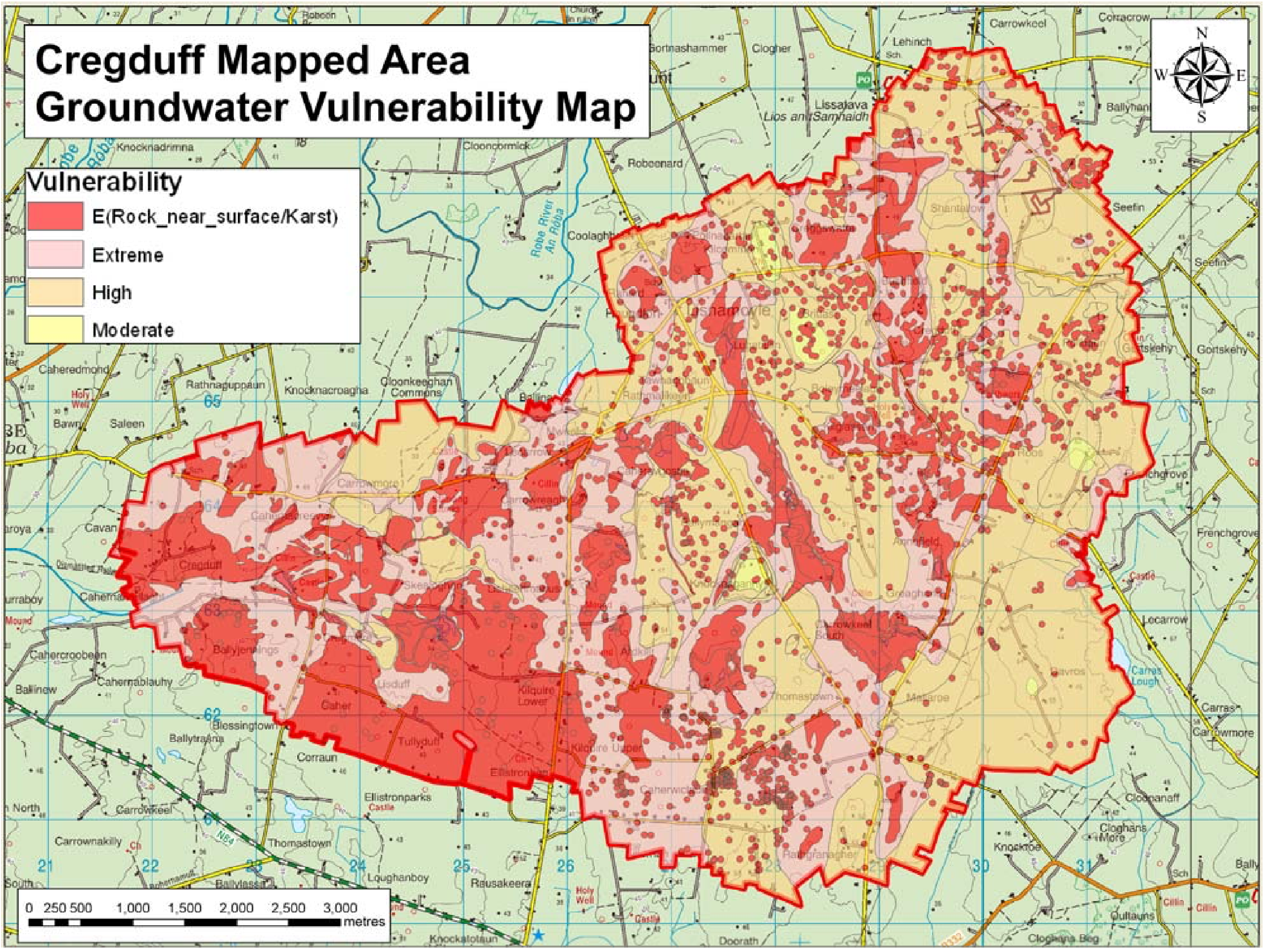

Figure 9: Groundwater vulnerability map of the area field mapped within and around the Cregduff Catchment.

Further work on karst features and phosphate susceptibility map

In order to fully understand the vulnerability of the catchment feeding the spring, intensive work on field-scale karst features was required following the recognition of the spatial distribution of these features. Within this detailed field-scale tracer testing of swallow holes and epikarst windows, as well as a ranking of swallow holes, epikarst windows and dolines with respect to susceptibility of phosphorous infiltration directly into the subterranean groundwater conduit network, was required. In this dye tracing was employed simultaneously at various features and a ranking system was developed for 'phosphate susceptibility'.

The principal tasks undertaken in the performance of the work were as follows:

- Organising dye tracer testing at swallow holes and epikarst windows and field sampling of springs;
- Organisation of laboratory testing of material samples;
- Preparation of tracer vectors in ArcGIS for the groundwater vulnerability maps of the catchment;
- Employment of focussed, intrusive field methods such as augering and drilling within doline features;
- Development of a hierarchy of point recharge features (swallow holes, epikarst windows and dolines) in the catchment with respect to their geomorphology, dimensions and depth-to-bedrock;
- Supplementation of this with a phosphate susceptibility ranking for this hierarchy;
- Preparation of illustrations of this hierarchy using cross-sectional diagrams and;
- Preparation of a brief report on works completed.

Karst tracing

Seventeen swallow holes occur in the area in question, in or just outside (by a matter of metres) the previously interpreted potential zone of contribution to Cregduff Springs. As well as this, two epikarst windows occur, as well as many deep dolines and patches of surficial karst pavement.

It should also be noted that five other swallow holes occur adjacent to the northeastern portion of the mapped potential catchment area, but as these are further away from Cregduff than many of the other swallow holes, they were not be included in the analysis.

Following the mapping programme It was considered with a high degree of confidence that the pavement areas, which lie in the west of the area and which lie between proven trace localities and the spring, form part of the catchment. This, and the fact that no dolines have epikarst cavities at their bases, means that neither the pavement nor the dolines will be traced. From this, there were nineteen potential input points; the seventeen swallow holes and the two epikarst windows. In theory, to ensure a robust model catching all contributing ground to the springs, all should be traced.

This was however impractical owing to time and cost constraints, and a strategy for tracing the catchment in a less onerous but not by a greater extent less meaningful method had to be devised.

When examining the initially proposed catchment area in its' totality, the swallow holes are shown on Figures 6 and 10 and can be subdivided into two categories:

- Those associated with the draining of turloughs (seven);
- Those associated with the sinking of ephemeral streams (ten).

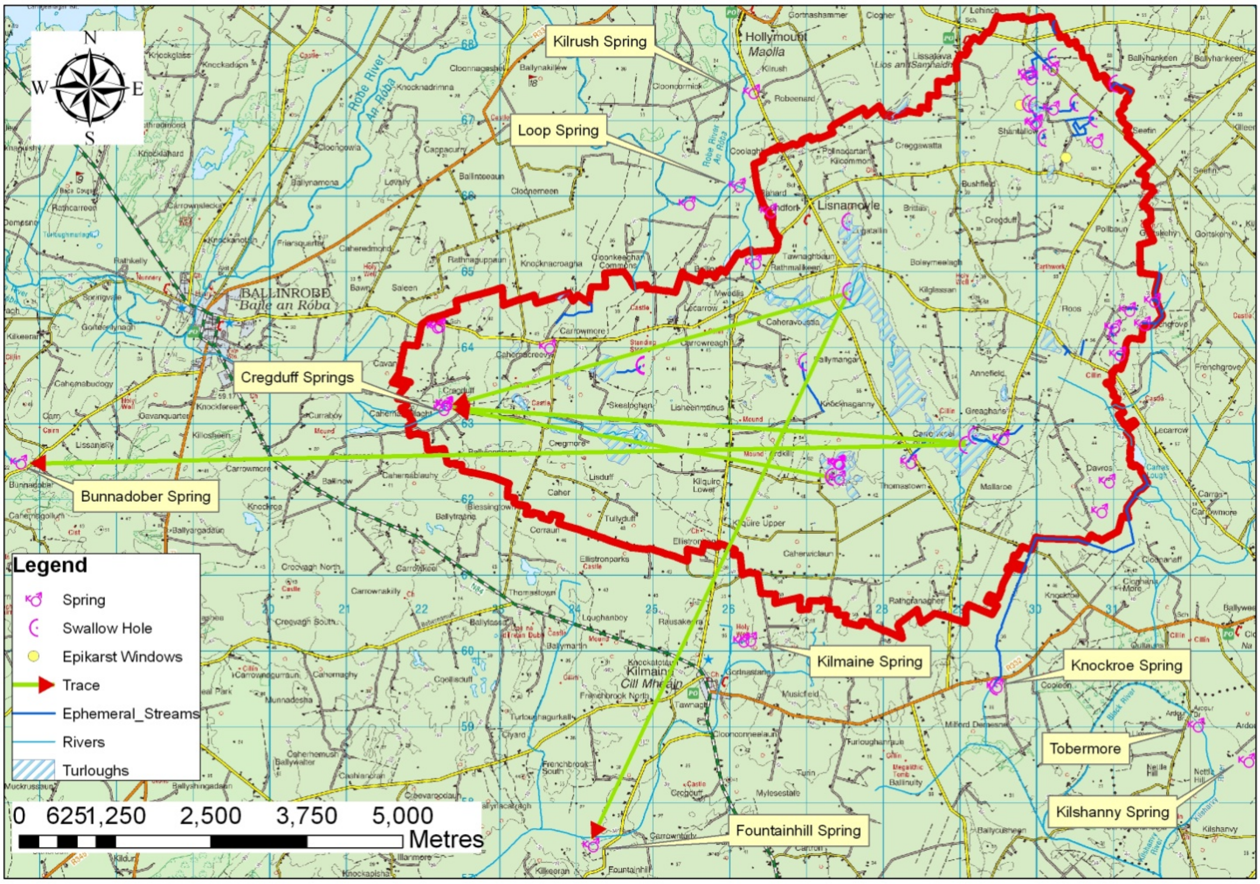

Figure 10: Swallow holes, epikarst windows and confirmed tracer lines before this mapping programme, in the potential Cregduff Zone of Contribution. Swallow holes which are flooded by turloughs in winter can be seen with the respective turlough outline overlaid.

The swallow holes associated with the draining of turloughs include:

- one draining Skealoghan Turlough (including three separate entry points) to its east;
- one draining Ardkill Turlough at its southwestern portion;
- one draining a small turlough on the boundary of Caheravoostia and Ballymangan townlands;
- one draining Kilglassan Turlough
- one draining Lugatallin Turlough (Lugatallin Turlough is at the northern end of Kilglassan Turlough and merges with it during high flooding)

- two draining Greaghans Turlough.

Traces have already been completed at Ardkill, which is proven to emerge at Cregduff, at Greaghans, which is again positive at Cregduff but also positive at Bunnatober Springs 3 km southwest of Ballinrobe, and at the Kilglassan swallow hole, which is also positive at Cregduff but also positive at Fountainhill Springs 2.5 km south-southwest of Kilmaine (Coxon, 1986).

If a tracing programme for the turlough-associated swallow holes was to be employed, the optimal strategy would be to monitor the lowering water levels in the turloughs in late spring and assess where and when tracing can take place in these.

The swallow holes associated with ephemeral streams include:

- one at the southern extreme of the potential catchment, draining Carros Lough, in Knockroe Townland;
- one at the eastern extreme of the potential catchment, in Roos;
- seven at the northeastern extreme of the potential catchment, clustered within a square kilometre in Shantallow, Lissatava and Corracrow Townlands
- one outside the southern edge of the potential catchment, at Knockroe.

The area at the northeast includes seven swallow holes and also includes two epikarst windows, which are deep doline-depressions with springs at one side and a swallow hole at the other. These could also potentially be traced.

<u>Tracing programme undertaken</u>

The tracing programme began in May 2011. At that time all of the swallow holes draining ephemeral streams, as well as the epikarst windows, all could potentially be traced as the spring and early summer had been dry.

The optimal strategy for tracing the potential catchment area, following discussions with David Drew of Trinity College Dublin, was as follows:

- All existing flow data from the two monitored Cregduff Springs, as well as the spot flow measurements taken by the EPA Hydrometric Section Staff at the other two springs in the spring set, were assessed to arrive at a best estimate for the springs' discharge;
- 'Mean' flow measurements of the main surrounding spring sets, at the River Robe, Fountainhill, Bunnadober, Tobermore and at the springs at Davros in the southeast of the catchment, were also assessed;
- The above data were analysed and used to arrive at a best estimate of the size of the ZOC of each spring-set;

- When this had been achieved and ZOC's delineated for each spring set, a trace on the lowest swallow hole at the northeast of the potential Cregduff Catchment in Lissatava, as well as at the swallow holes at the extremities of this area to the south in Knockroe and to the east in Roos, while monitoring at the eleven main spring sets as shown on Figure 10, would allow a good estimate of the potential ZOC for Cregduff.
- Simultaneously, dye was to be injected into the swallow hole at the northern end of Lugatallin Turlough to see if this would follow a similar pathway to the swallow hole at the south.

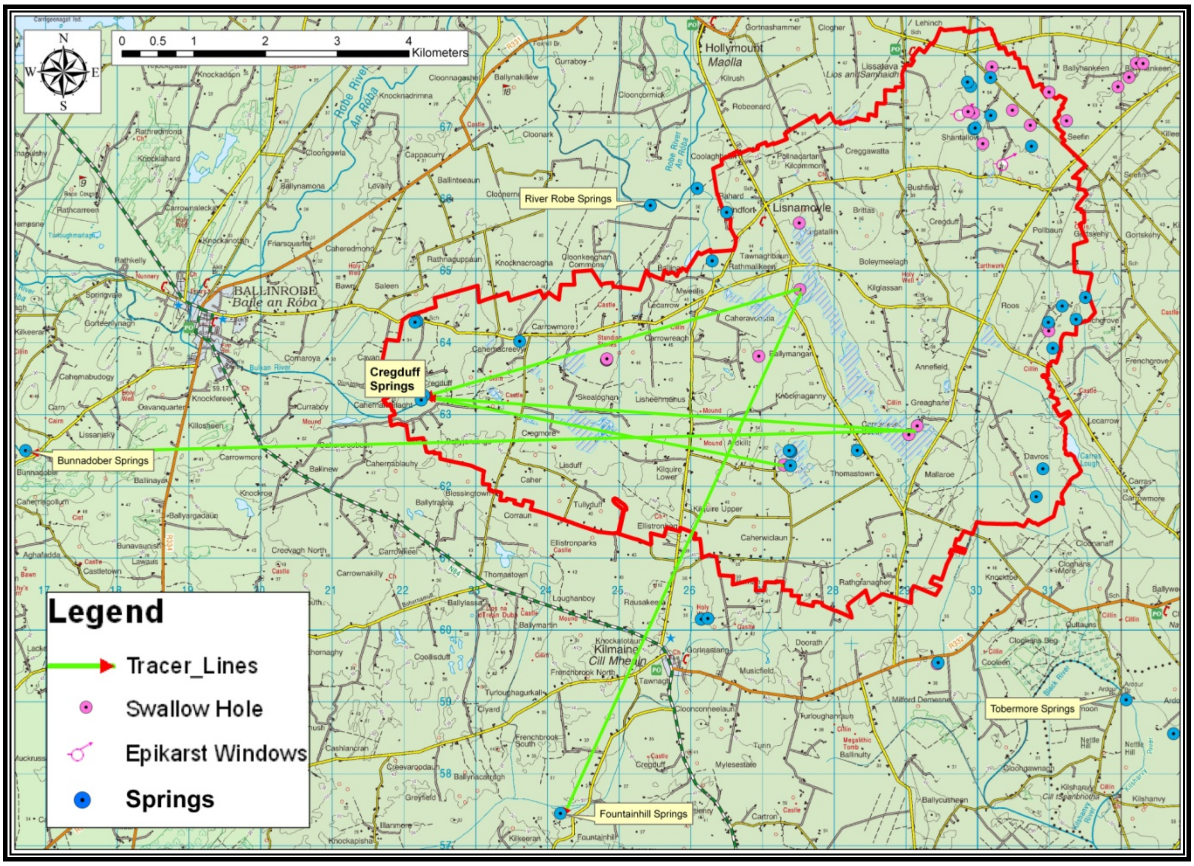

Figure 11: Map showing all thirty six springs situated in or around the potential Cregduff Zone of Contribution. Swallow holes, epikarst windows, current-mapped turlough extents and confirmed tracer lines from before this mapping programme are also shown.

The tracing of the other swallow holes in the northeast and east of the potential catchment, as well as those at the base of the turloughs, should be done as a 'Phase II' tracing programme at some stage later, and when the turloughs are dry yet water is entering their swallow holes. This Phase II would basically be a refinement of the potential ZOC delineated in Phase I.

It should be noted that, in this, the springs feeding Greaghans, Ardkill and Skealoghan Turloughs, were inaccessible at the time of the trace and could receive some or all of the dye from these traces. It was felt, however, that the traces should nonetheless give a positive/negative signal as to whether the major part of the area they drain to is within the Cregduff Catchment, or another spring catchment, or both.

The tracing programme therefore involved four injection points (Lissatava, Roos, Knockroe and Lugatallin) and fourteen monitoring points (four springs at Cregduff, three at Fountainhill, Kilrush Spring, the Loop Spring, Kilmaine Spring, Tobermore Spring, Kilshanny Spring, Knockroe Spring and Bunnadober Spring).

The lowest of the swallow holes in the northeast of the 'catchment' at 44 m AOD was traced with Flourescein. The swallow hole at the east of the 'catchment' in Roos was traced with Rhodamine (54 maOD). The large swallow hole at the northern end of Lugatallin Turlough was traced with Optical Brightener (33 maOD). The swallow hole at the southern side of the 'catchment', at Knockroe was traced with Eosin (approx. 38 maOD)

Projected times of travel to each of the springs from the four swallow holes to be traced were calculated from each of the input points. The maximum groundwater velocity Catherine Coxon recorded in her thesis (1986) from the tracing she completed in the catchment was 123 m/hour, and the minimum was around 10m/hour.

This means the minimum estimated time to get to **Cregduff** from the nearest swallow hole at Lugatallin (5.7 km away) is 46.7 hours. The travel times from the other swallow holes were projected to be longer to Cregduff ... 2 days plus. From this, monitoring of Cregduff was continued for three weeks, with some spot sampling after this time also undertaken.

It was expected that the dye from Lugatallin could potentially get to the **Loop or Kilrush Springs** in 7 hours or so. So sampling began at these springs 3 hours after injection at Lugatallin. For the other swallow holes the travel times to the Robe Springs was expected to be 1 day plus. For **Fountainhill**, the minimum time calculated from any of the springs was around 2 days-4 days. For **Tobermore, Knockroe, Kilmaine** and **Kilshanny**, a day or so plus travel time was projected . For **Bunnadober**, the expected time was Cregduff travel time plus.

<u>Tracing programme results</u>

Forty litres of optical brightener were injected into Lugatallin swallow hole at 10.00 on 2nd June 2011, with the help of two ‘flushing’ tankers of water. Following this ten litres of flourescein were injected into the northeast swallow hole at 11.30 (8 kg @ 0.8%); here water was flowing into the hole so no tanker was required. Twenty litres of rhodamine were injected into the Roos swallow hole at 12.30 (4 kg @ 0.2%), again with the help of two tankers of water, and 4 kg of Eosin was then injected into Knockroe at 14.00, where water was flowing into the swallow hole.

Sampling then began immediately at all fourteen springs, and was conducted by Dr. Avril Rothwell of Teagasc. Each spring was sampled twice daily. The collected sample bottles were analysed by GSI.

Plate 9: Injecting optical brightener (40 litres) into swallow hole at Lugatallin, with tanker flushing water into system.

Plate 10: Injecting rhodamine (20 litres) into swallow hole at Roos

Plate 11: Flourescein emerging at Kilrush Spring after 7 days.

Two of the springs showed positive results; after one week, Kilrush was turned green with flourescein dye, showing that the dye took seven days to travel 3.5 kilometres westwards from Lissatava. The flourescein did not appear at any of the other springs in the region.

A positive was also recorded for optical brightener, which was injected in the swallow hole of Lugatallin turlough, at the Robe 'Loop' Spring, 1.5 km to it's northwest. Again, the optical brightener did not appear at any of the other springs in the region.

Given these results, it can be clearly seen that the northeastern portion of the area previously-thought to be part of the feeder catchment to Cregduff Springs is not the case, as that are drains westwards and not to Cregduff. This means that the water in Kilglassan turlough, when at a high flood level merges with Lugatallin turlough, drains to two different spring outlets.

The overall area of the revised Cregduff Catchment now covers 32.5 km^2.

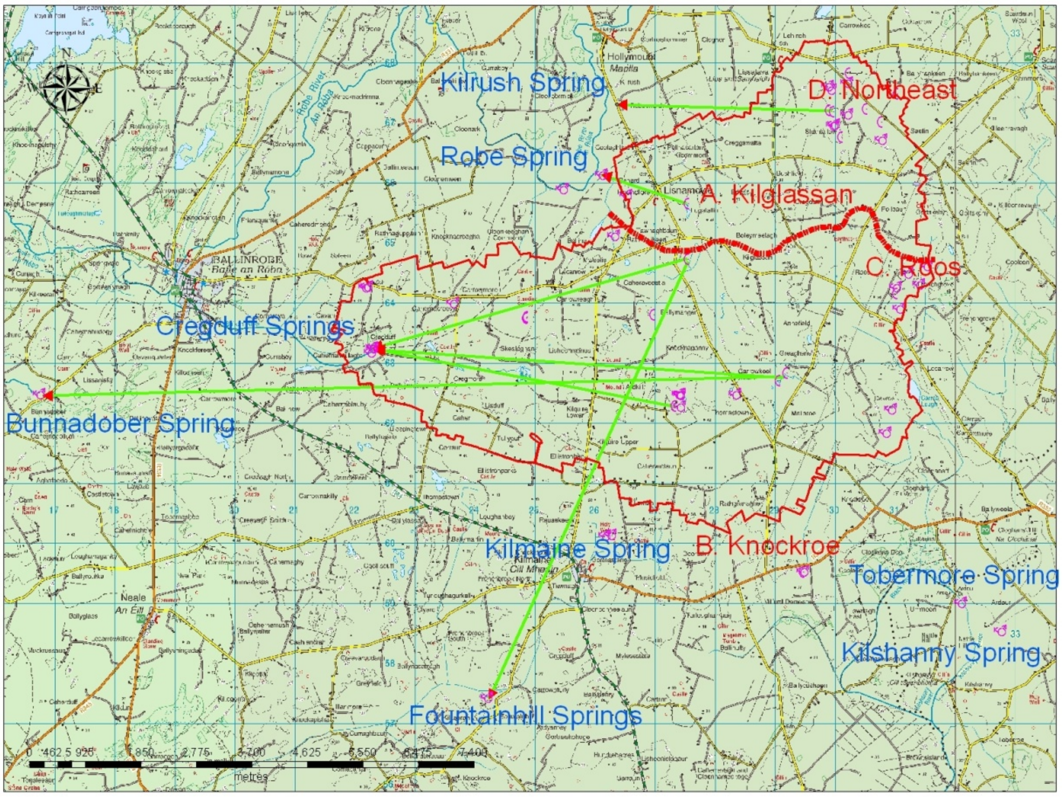

Figure 12: Map showing previous and new tracing results. The new traces prove that the northeastern portion of the previously-thought catchment of Cregduff Springs do not flow to Cregduff, but drain due westwards. This means the thick red line can now be assumed to be the northeastern catchment boundary of Cregduff Springs.

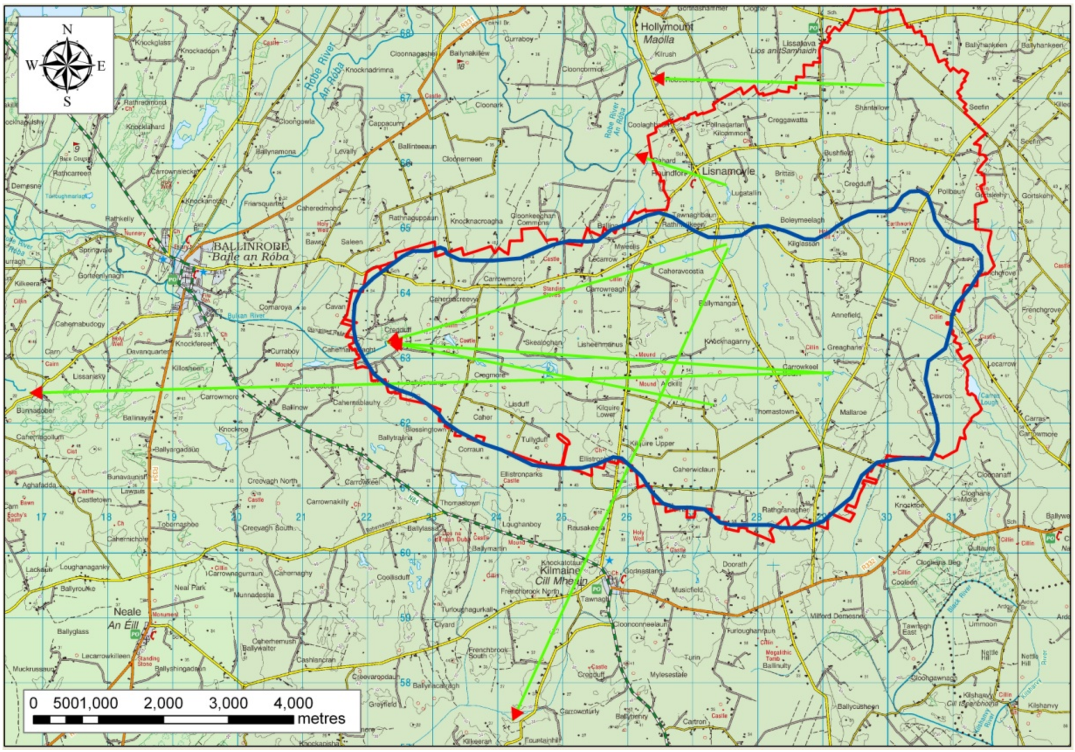

Figure 13: Revised Cregduff Springs Catchment (dark blue) compared to the area field mapped for karst features (red), as well as all traces undertaken in the region.

If the total area of the potential catchment feeding the springs is 32.4 square kilometres, with rainfall data for the rainfall stations installed by Teagasc, and the calculated evapotranspiration, we get 513mm effective rainfall in the west of the catchment and 630mm in the east. Assuming 90% recharge coefficient in the western portion (dominated by bedrock outcrop and subcrop) and 80% in the east (half outcrop and subcrop, rest dominated by moderate permeability till) we get a total recharge for the catchment of 15,705,575 cubic metres per year.

That equates to 43,028 cubic metres per day potential recharge to the four springs. Using EPAs gauging of discharge at Cregduff, the main Cregduff Spring discharges an **average** of 10,829 cubic metres per day. That is, with respect to water balance the output from Cregduff seems about a quarter of the total discharge, which seems relatively accurate when examining the discharges of the other springs in the locality.

Groundwater Phosphate Susceptibility Map

In order to deliver a ‘Groundwater Phosphate Susceptibility Map’, further refinement of a ranking system for the mapped features of point recharge (epikarst areas within 1m of the surface, surficial pavement areas, dolines, swallow holes, turloughs, epikarst windows) across the catchment was required. Several tasks aided in devising such a classification:

- The delineation of a 0.5m depth-to-bedrock contour;
- Mapping of turlough extents using field-gathered high water mark data and aerial photographs in GIS;
- Ranking of doline sizes;
- Drilling a small number of boreholes through subsoil to bedrock in doline fields;
- Thorough augering through the bases of a sample of dolines of different depths and dimensions;
- Mapping areally extensive dolines and calculating dimensions from field notes and aerial photographs in GIS;
- Ranking doline-type and form into a hierarchical classification;
- Drafting of cross-sections of each doline type in the hierarchy;
- Ranking surficial pavement, 0-0.5m epikarst, 0.5m-1m epikarst, turloughs, the various classes of dolines, epikarst windows and swallow holes with respect to potential groundwater contamination risk;
- Liaison and discussion with Teagasc on the final groundwater phosphate susceptibility risk.

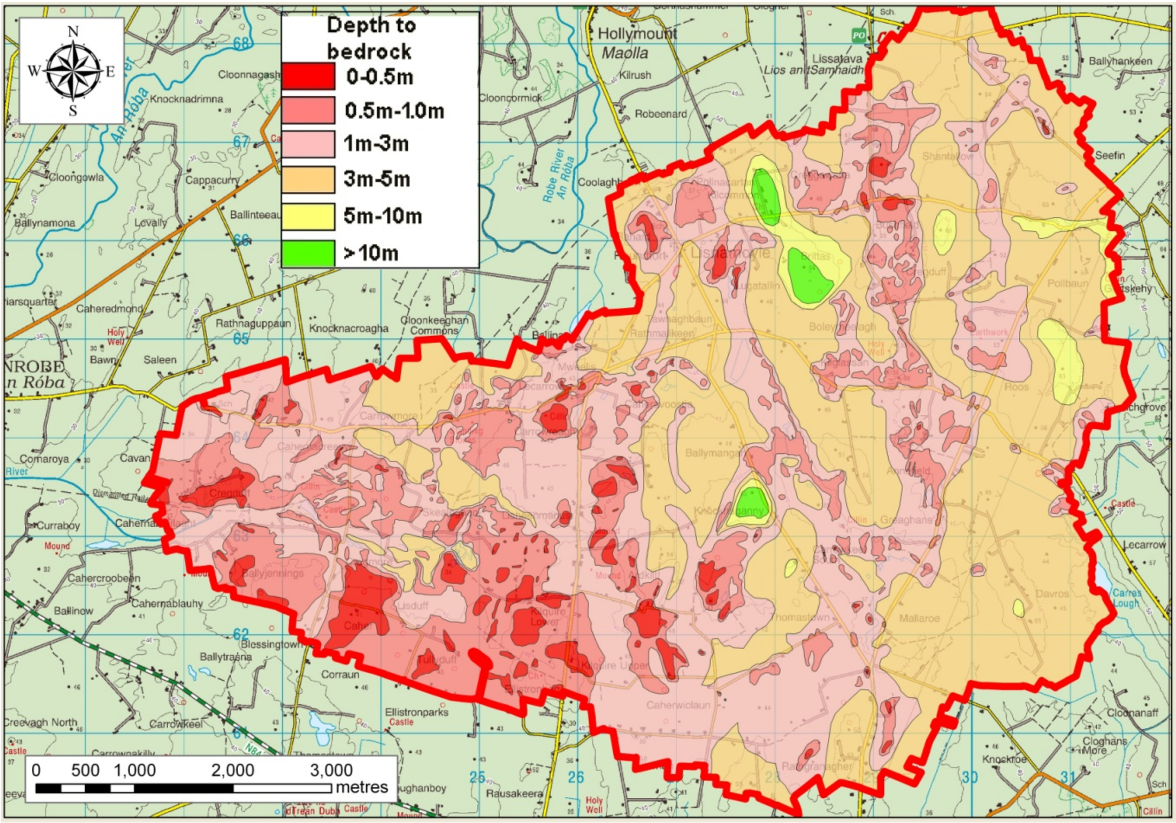

Figure 14: Depth to bedrock across the area mapped, with 0.5m contour line included.

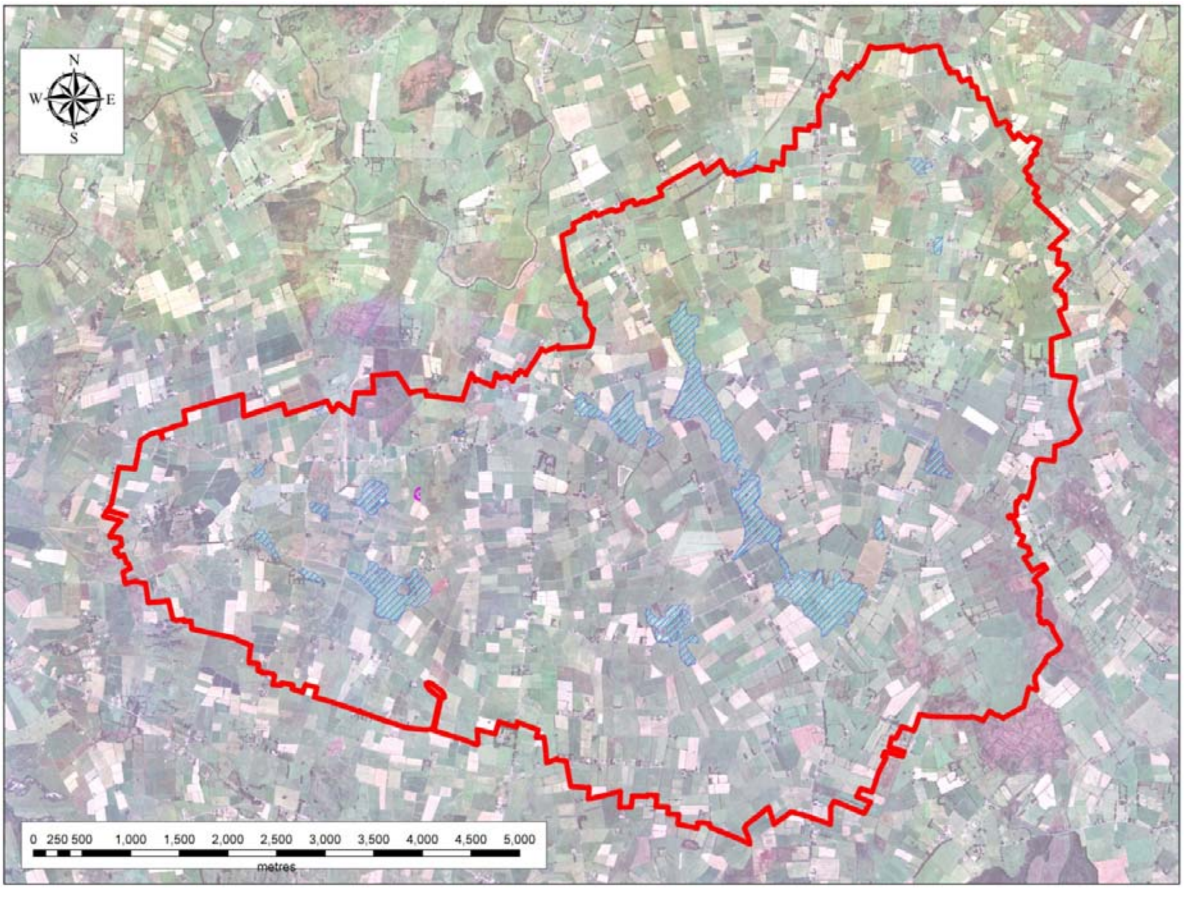

Figure 15: Maximum extent of turloughs in the catchment.

Sites being visited on the trip to Cregduff Catchment, Saturday 1st October 2011

1. Cregduff Springs

Overview of Agricultural Catchments Programme ... outline of the four springs .. public supply abstraction ... EPA Monitoring ... Teagasc Monitoring ... overview of ACP Groundwater Vulnerability Mapping Programme ... hydrogeology of the area around the springs and wider catchment

2. Caher Quarry

Epikarst ... presence and absence of fractures in deeper bedrock ... soil type ... phosphorous infiltration ... rock dolines

3. Ardkill or Kilglassan Turlough

Turlough geomorphology ... hydrogeology, swallow holes and springs ... pressures ... hydrogeological modelling and monitoring

4. Lissatava swallow hole and epikarst window

Overview of recent tracing programme ... morphology of swallow hole ... sluggeras ... epikarst window geomorphology and hydrogeology

5. Pollbaun doline field

Doline density in locality and within catchment ... doline classification within the catchment ... cross sections and modelling ... phosphorous susceptibility mapping

6. Knockroe swallow hole / spring couplet

Defining catchment boundaries ... tracing with Eosin ... issues with tracing and sampling

<u>**References:**</u>

Coxon, C., 1986. A study of the hydrology and geomorphology of turloughs. Unpublished PhD Thesis, Trinity College Dublin, 428 pp.

Coxon, C. and Drew, D.., 1986. Groundwater flow in the lowland limestone aquifer of eastern Co. Galway and eastern Co. Mayo, western Ireland. In: Paterson, K and Sweeting, M. (Eds.) New Directions in Karst, Norwich, 259-280.

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.

Fitzsimons, V, Daly, D. And Deakin, J., 2003. GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination. Draft Report by Groundwater Section of Geological Survey of Ireland, 75pp.

Lee, M., 1999. Surface indicators and land use as secondary indicators of groundwater recharge and vulnerability. Unpublished (Research) MSc thesis. Department of Civil, Structural and Environmental Engineering, Trinity College Dublin.

Swartz, M., 1999. Assessing the Permeability of Irish Subsoils. Unpublished (Research) MSc thesis. Department of Civil, Structural, and Environmental Engineering, Trinity College Dublin.

Swartz, M., Misstear, B.D.R., Daly, D. And Farrell, E.R., 2003. Assessing subsoil permeability for groundwater vulnerability. Quarterly Journal of Engineering Geology and Hydrogeology, Vol. 36, 1-4, pp. 173-184.

Delineating Zones of Contributions for Four Karst Sources in County Galway – June 2010 - April 2011

Principal Authors:

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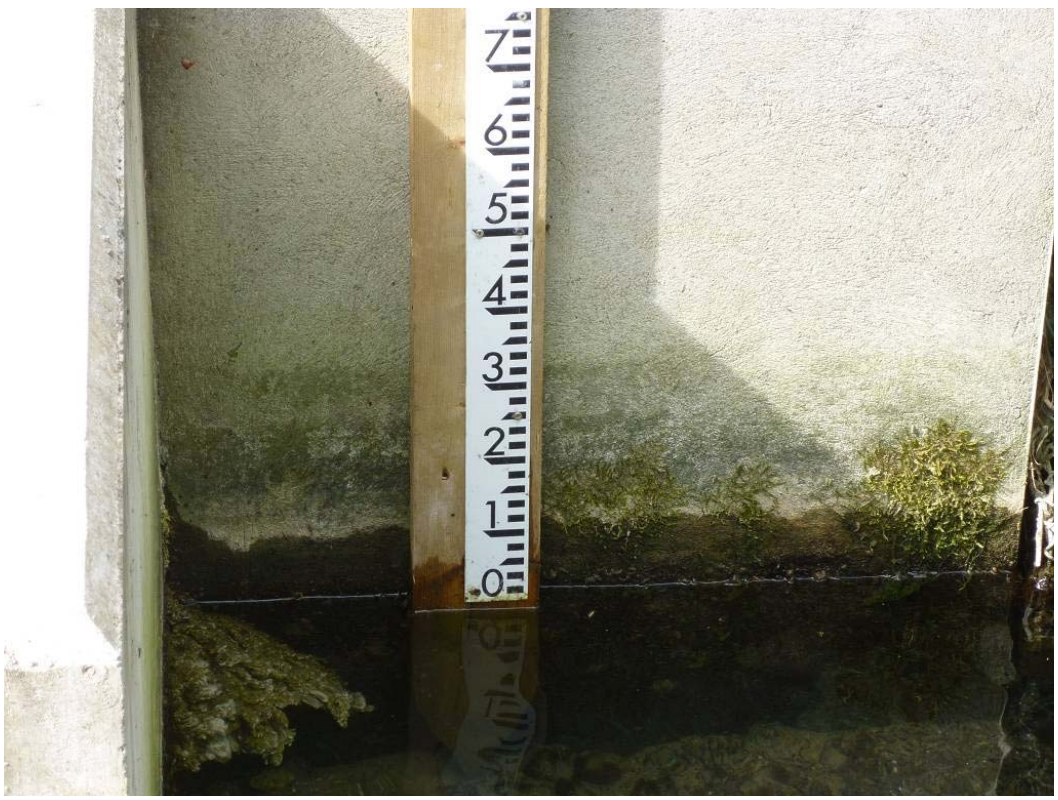
With Contributions From:

Dr. David Drew, TCD; Dr. Caoimhe Hickey, GSI;
Dr. Robert Meehan, Consultant Geologist and Jenny Deakin, TCD



Prepared for the IAH Irish Group Field Trip, October 1st and 2nd , 2011

Background

The work described on this field trip is part of the "Establishment of Groundwater Source Protection Zones" project led by the Environmental Protection Agency, which represents a continuation of the GSI's SPZ work in the past. A CDM/TOBIN/OCM project team, assisted by the GSI, was retained by the EPA to establish Groundwater SPZs at approximately 35 sources across the country since 2009, focusing on monitoring points in EPA's National Groundwater Quality Network. The SPZ work is being carried out 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.

NOTE - Technical peer review of the information presented in this booklet has not yet been completed. Results are therefore to be considered as: a) DRAFT; and b) the technical opinions of the principal authors only.

Methods

Initial Site Visit

- Background research (e.g. 6-inch maps);
- Site walks and project scoping.

Investigative Field Work

- Well audits;
- Karst and (hydro)geological mapping
- Testing suitability of potential injection points;
- Tracer testing;
- Water sampling for laboratory analysis;
- 2-D resistivity surveying at selected locations;
- Hand augering and window sampling at selected locations.

Monitoring

- Flow measurements in streams and at springs;
- Field EC.

SPZ Reporting

ZOC Delineation

- Tracer test results;
- Water balances;
- Hydrogeological principles and conceptual models.

SPZ Delineation

- ZOC/vulnerability intersects

Summary of Sources: June 2010 – May 2011

Source	Elevation (mOD)	Average Abstraction (m^3/d)	Minimum Estimated Overflow (m^3/d)	Maximum Estimated Overflow (m^3/d)	Mean Estimated Overflow (m^3/d)	Volume Discharged June 2010 - May 2011
Kilkerrin PWS	68	11,550	0	5,789	2,673	914,350 [1]
Mid-Galway PWS	55	5,000*	4,320	187,488	20,146	7,280,000 [2]
Mountbellew PWS	67	2,000	86	39,917	7,536	2,868,000 [3]
Caltra GWS (PWS)	62	500	346	12,010	3,388	1,100,000 [4]

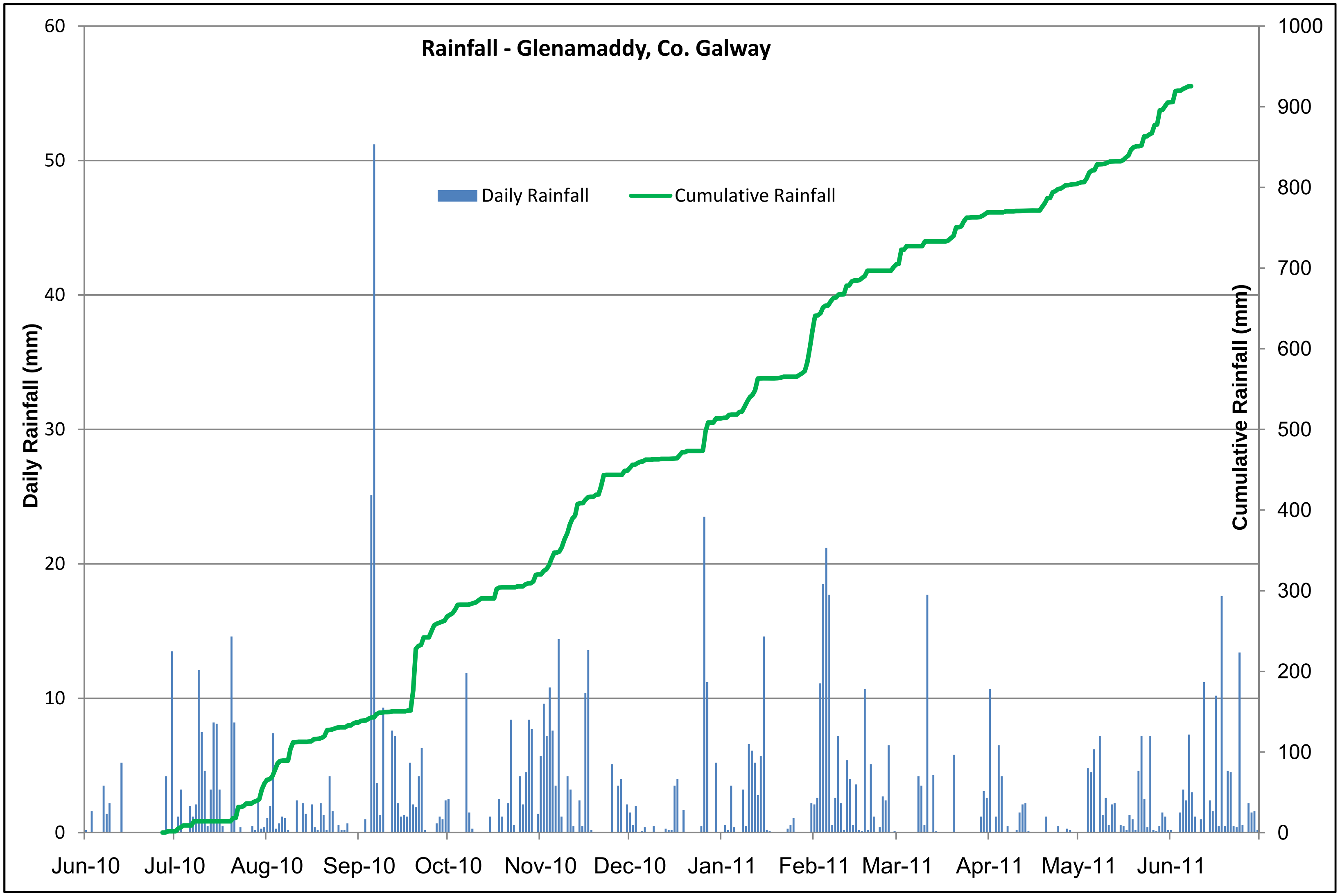
[1] - complete record

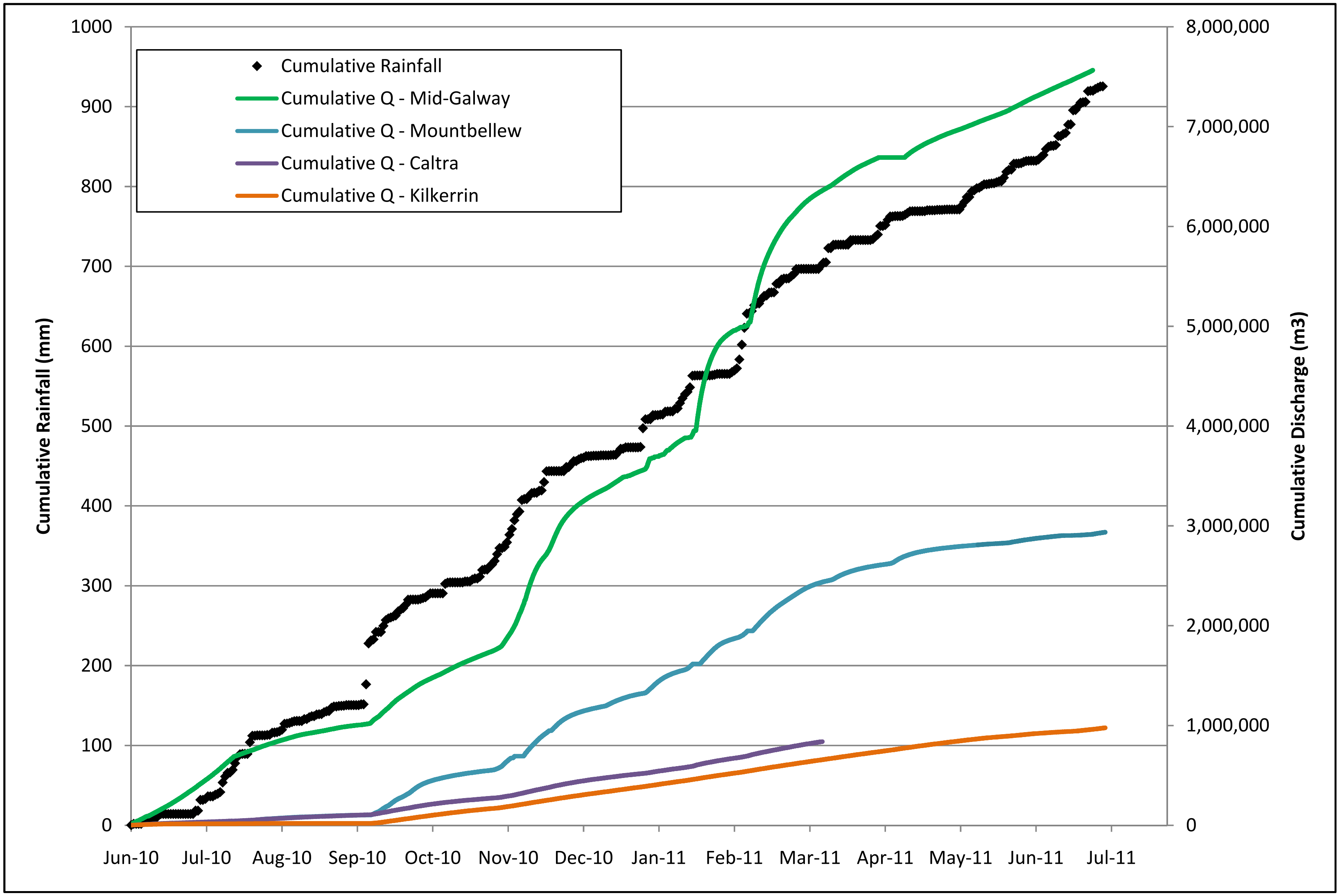
[2] - minimum, some gaps and inconsistencies in flow records

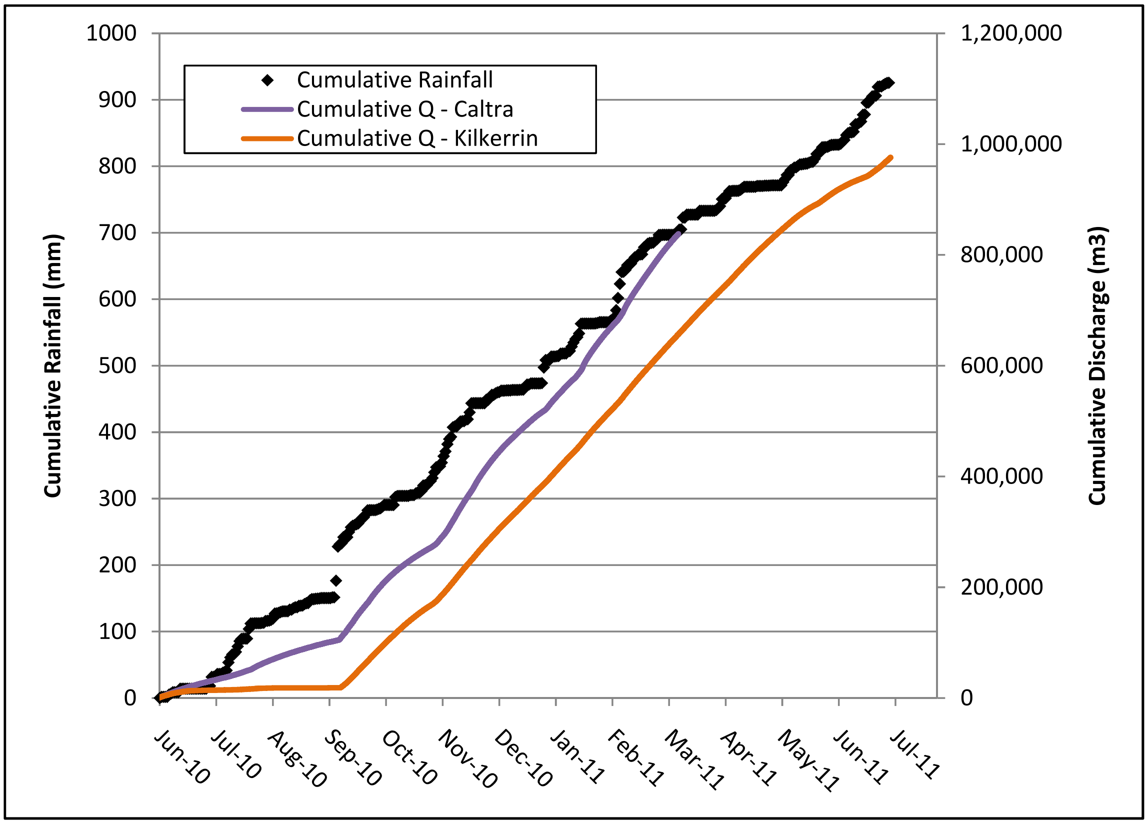
[3] - minimum, minor gaps in flow records

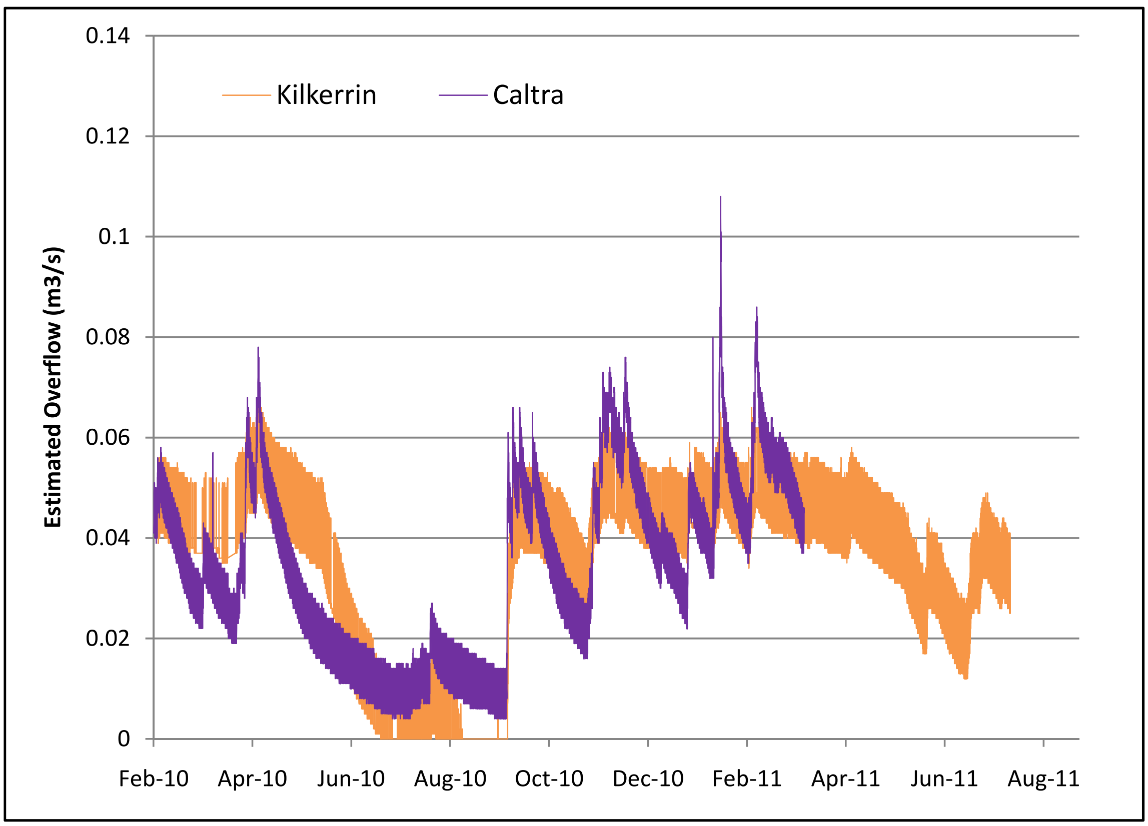
[4] - projected through May 2011; 838,000 m^3 measured through March 8th, 2010

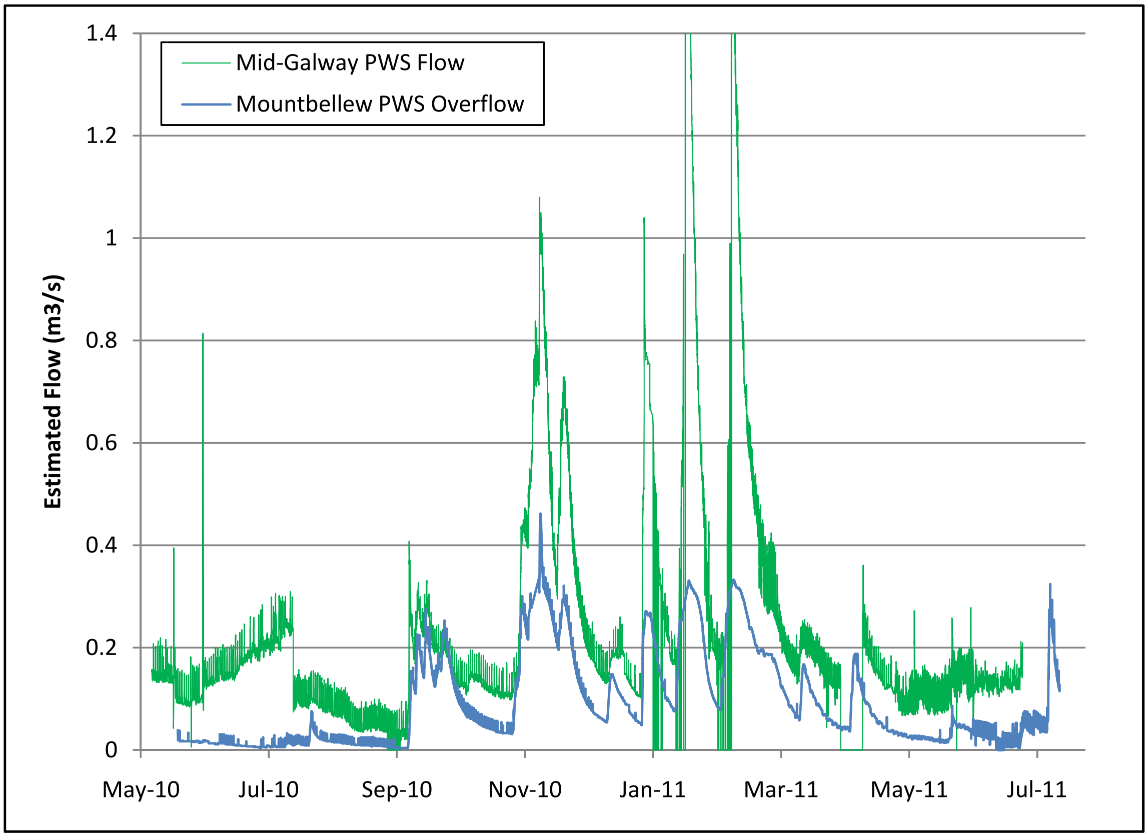
* - combined discharges from springs, seeps, and surface water contributions

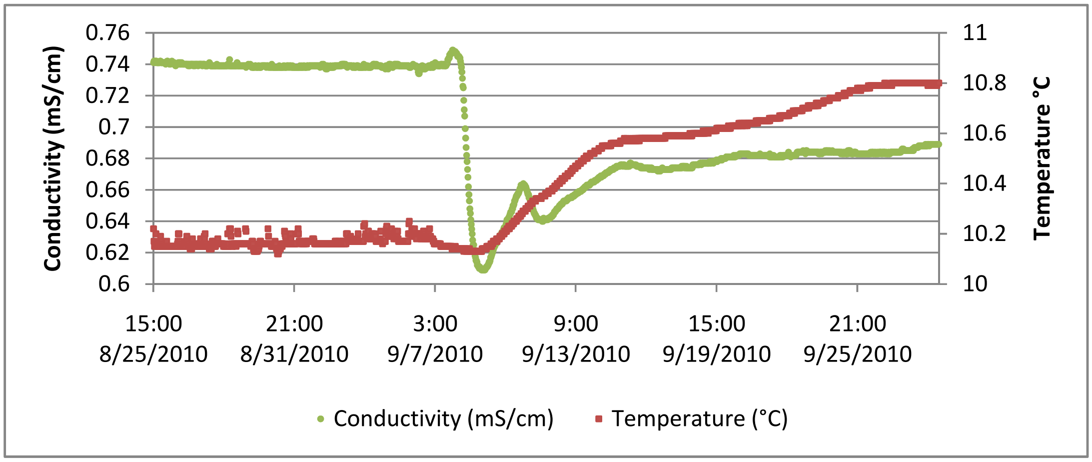

Rainfall - Glenamaddy, Co. Galway
Daily Rainfall
Cumulative Rainfall
Daily Rainfall (mm)
Cumulative Rainfall (mm)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700
800
900
1000
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11

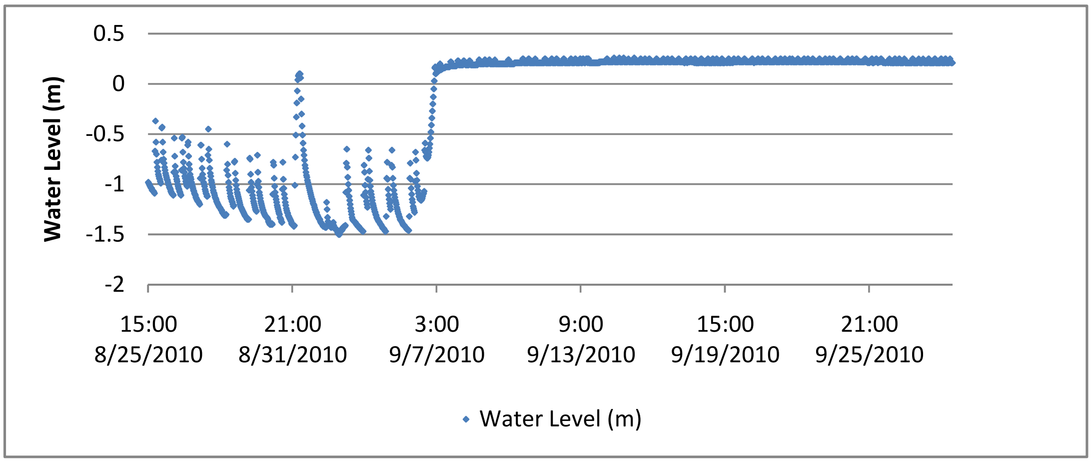

Cumulative Rainfall
Cumulative Q - Mid-Galway
Cumulative Q - Mountbellew
Cumulative Q - Caltra
Cumulative Q - Kilkerrin
Cumulative Rainfall (mm)
Cumulative Discharge (m3)
1000
900
800
700
600
500
400
300
200
100
0
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11


Cumulative Rainfall
Cumulative Q - Caltra
Cumulative Q - Kilkerrin
Cumulative Rainfall (mm)
Cumulative Discharge (m3)
1000
900
800
700
600
500
400
300
200
100
0
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11

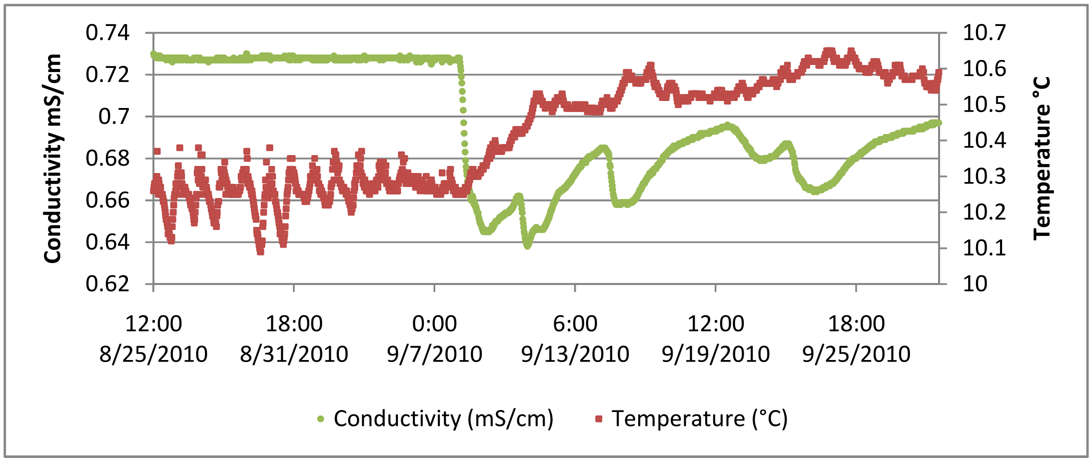

Kilkerrin
Caltra
Estimated Overflow (m3/s)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Feb-10
Apr-10
Jun-10
Aug-10
Oct-10
Dec-10
Feb-11
Apr-11
Jun-11
Aug-11

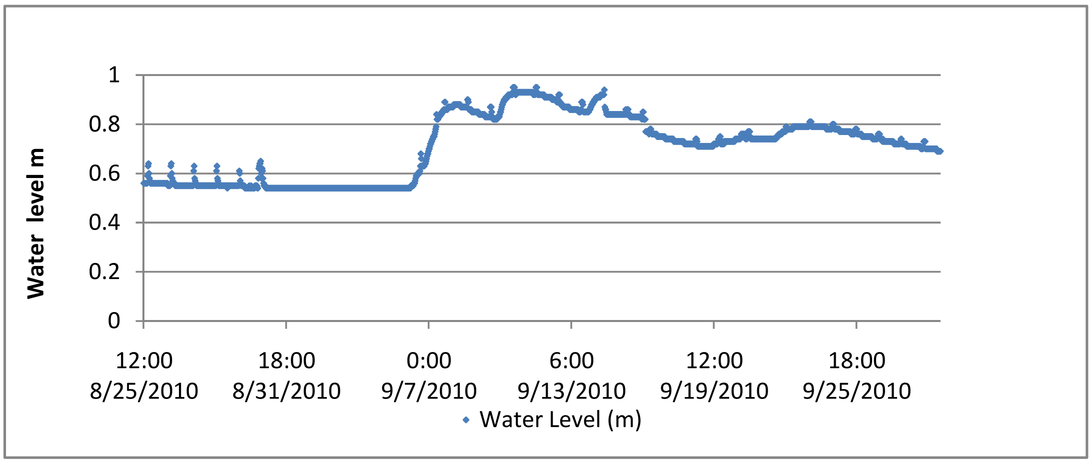

Mid-Galway PWS Flow
Mountbellew PWS Overflow
Estimated Flow (m3/s)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
May-10
Jul-10
Sep-10
Nov-10
Jan-11
Mar-11
May-11
Jul-11





Kilkerrin – Water Level vs. T and EC





Mountbellew – Water Level vs. T and EC

Tracer Testing

- 18 dye injection locations were selected, and dye trace tests at 17 locations were carried out;
- A total of 20 dye tests were implemented (3 tests at 3 locations were repeated once for confirmation of initial results);
- Dyes used = Rhodamine, Fluorescein, Optical Brightener (OB);
- All dye materials were purchased from the GSI, and all dye was prepared by Caoimhe Hickey (GSI) and injected by Caoimhe and/or CDM; All sample analysis was conducted by Caoimhe;
- Quantities of dyes used for 20 tests:
    - Rhodamine – approx.15.5 kg/79.0 litres (range used = 6-10 litres per test)
    - Fluorescein – approx. 37 kg/46 litres (range used = 3-10 litres per test)
    - Optical Brightener – approx. 70 litres (range used 10-15 litres per test)
- Total cost of dye materials for 20 tests ~ €7,000;
- Of 16 locations where dye was injected, 11 positive traces were achieved (i.e. 5 locations did not yield any positive detections).

<u>Results – Kilkerrin:</u>

- Only 1 trace of 6 possible was detected at the main PWS spring (Marganure);
- 2 traces went to Gortgarrow PWS;
- 2 traces went to nearby local springs;
- 2 traces were inconclusive (not detected anywhere).

<u>Results - Mid-Galway:</u>

- 4 traces of 7 possible were detected at the mid-Galway PWS;
- 2 traces were inconclusive (no detection anywhere, sampled with Kilkerrin, Mid-Galway, Mountbellew). 1 trace was incomplete – could not find cotton samplers.

<u>Results – Mountbellow:</u>

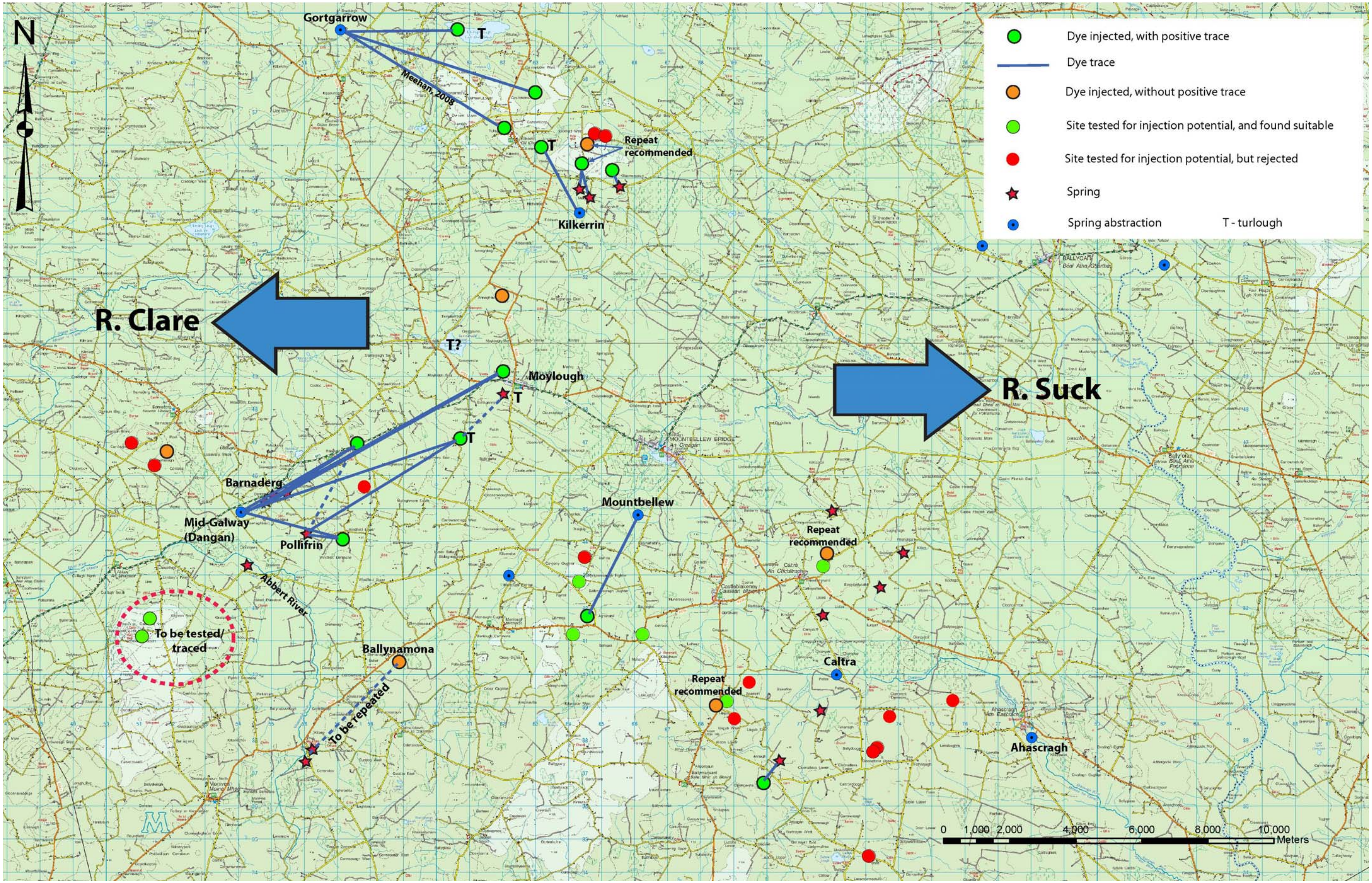
- Only 1 trace of 5 possible was detected at the main PWS spring;
- 2 traces were detected at Mid-Galway and 2 were inconclusive (no detection anywhere, sampled with Kilkerrin, Mid-Galway and Caltra).

<u>Results – Caltra:</u>

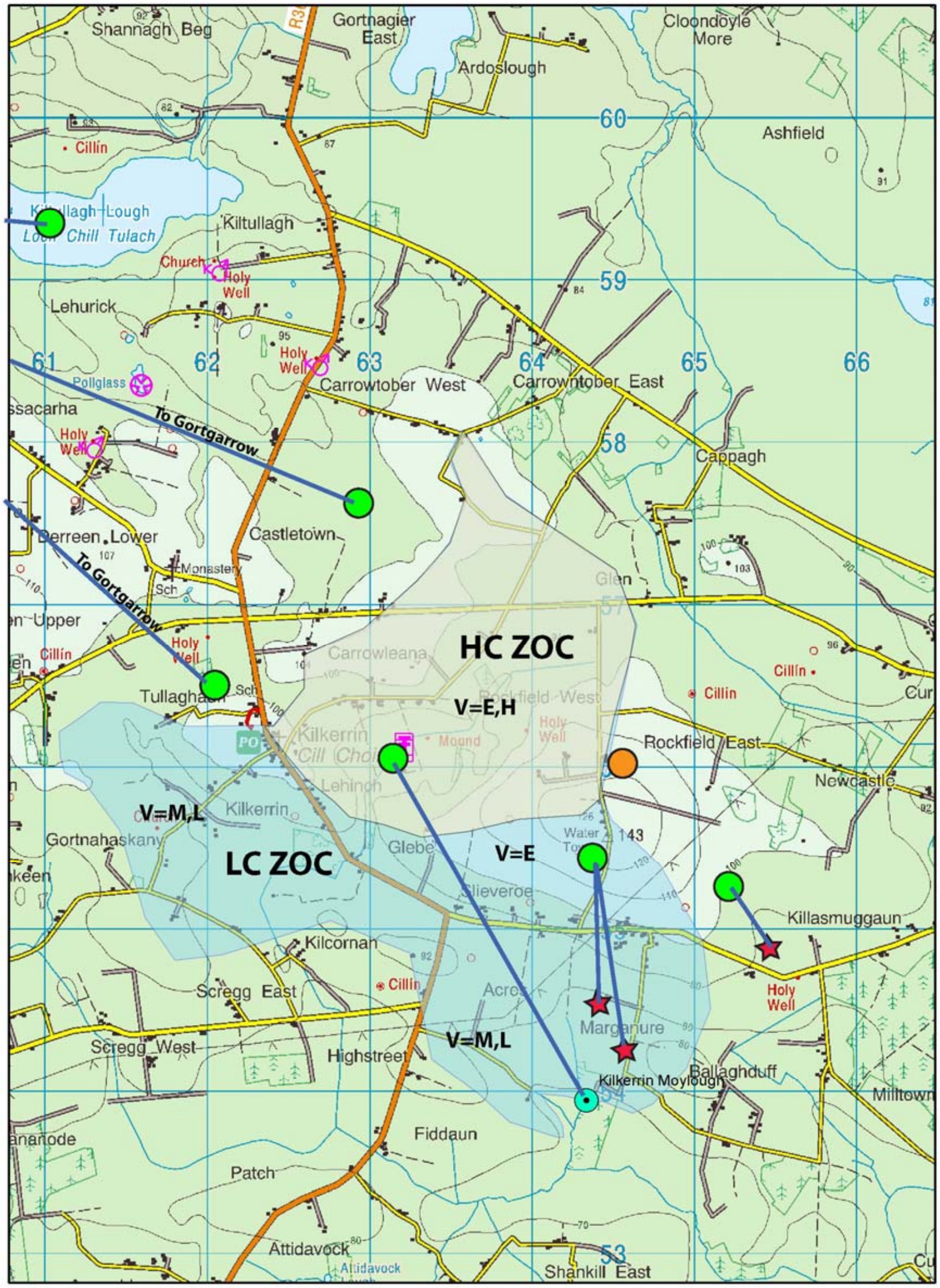
- No traces from 3 possible were detected at the main PWS (or a nearby GWS).
- 1 trace was positively detected at a local, small spring.

- Shortest trace: 0.2 km; Longest trace: 9 km
- Estimated range of flow velocities: 11-150 m/hr

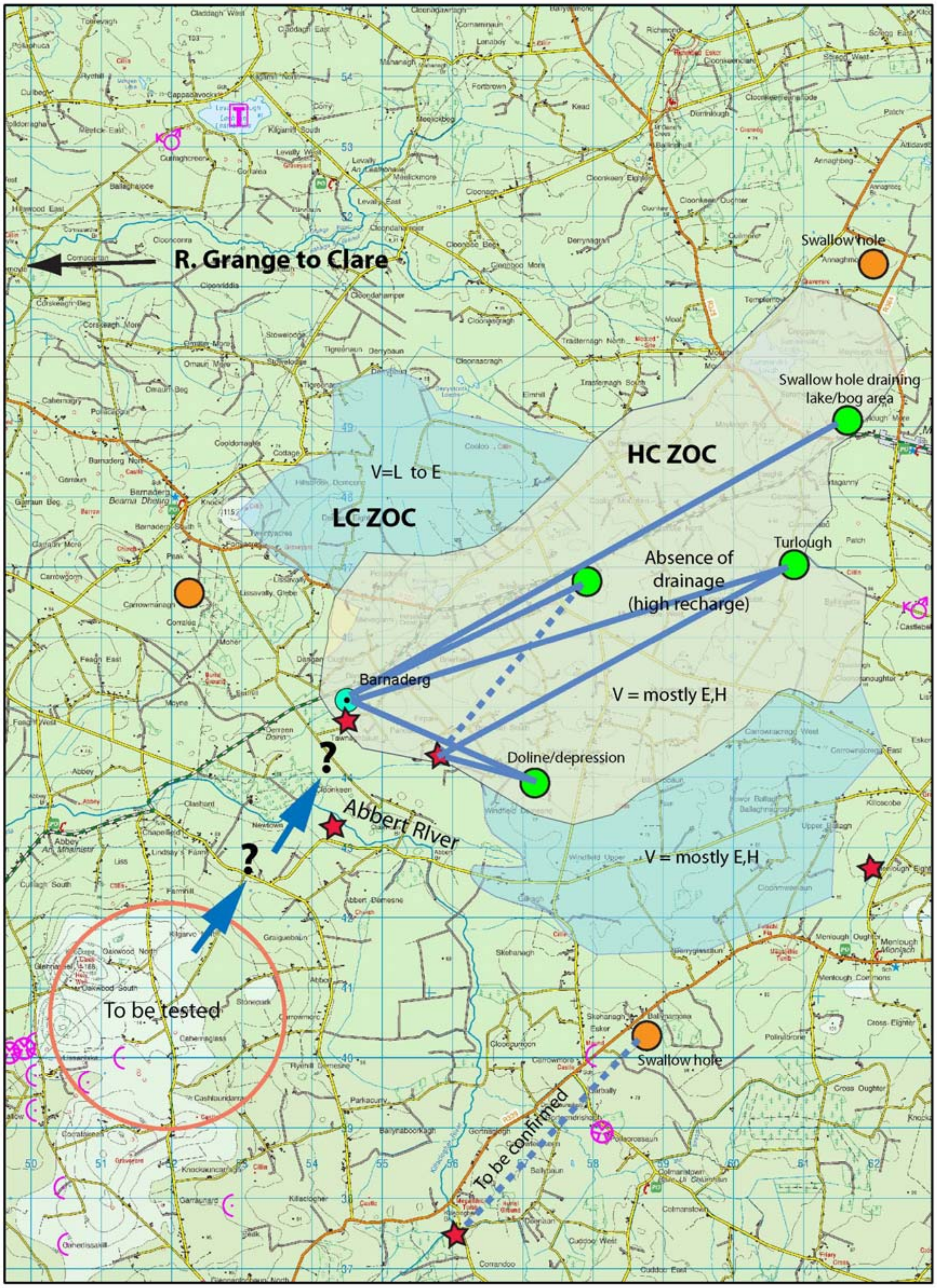
- <u>Recommendations - 5 tests should ideally be repeated on the basis of initial results:</u>
    - 2 tests @ Caltra - insufficient quantities of dye may have been used or sampling duration should be extended; also expanded monitoring of smaller springs;
    - 2 tests @ Kilkerrin - low-flow conditions are needed;
    - 1 test for mid-Galway (injection @ Ballynamona) – during previous test, OB was used and the cotton samplers could not be recovered (not found);
- One test to the S of the River Abbert has yet to be conducted (not possible during the study period – persistently wet ground conditions did not allow for movement of heavy equipment across farmer's land to the injection point(s)).


N
Gortgarrow
T
Meehan, 2008
Repeat recommended
Kilkerrin
R. Clare
T?
Moylough
T
R. Suck
Barnaderg
Mid-Galway (Dangan)
Pollifrin
Mountbellew
Repeat recommended
Abbert River
To be tested/ traced
Ballynamona
To be repeated
Caltra
Repeat recommended
Ahascragh
Dye injected, with positive trace
Dye trace
Dye injected, without positive trace
Site tested for injection potential, and found suitable
Site tested for injection potential, but rejected
Spring
Spring abstraction
T - turlough
0 1,000 2,000 4,000 6,000 8,000 10,000 Meters

Kilkerrin PWS – Draft ZOC

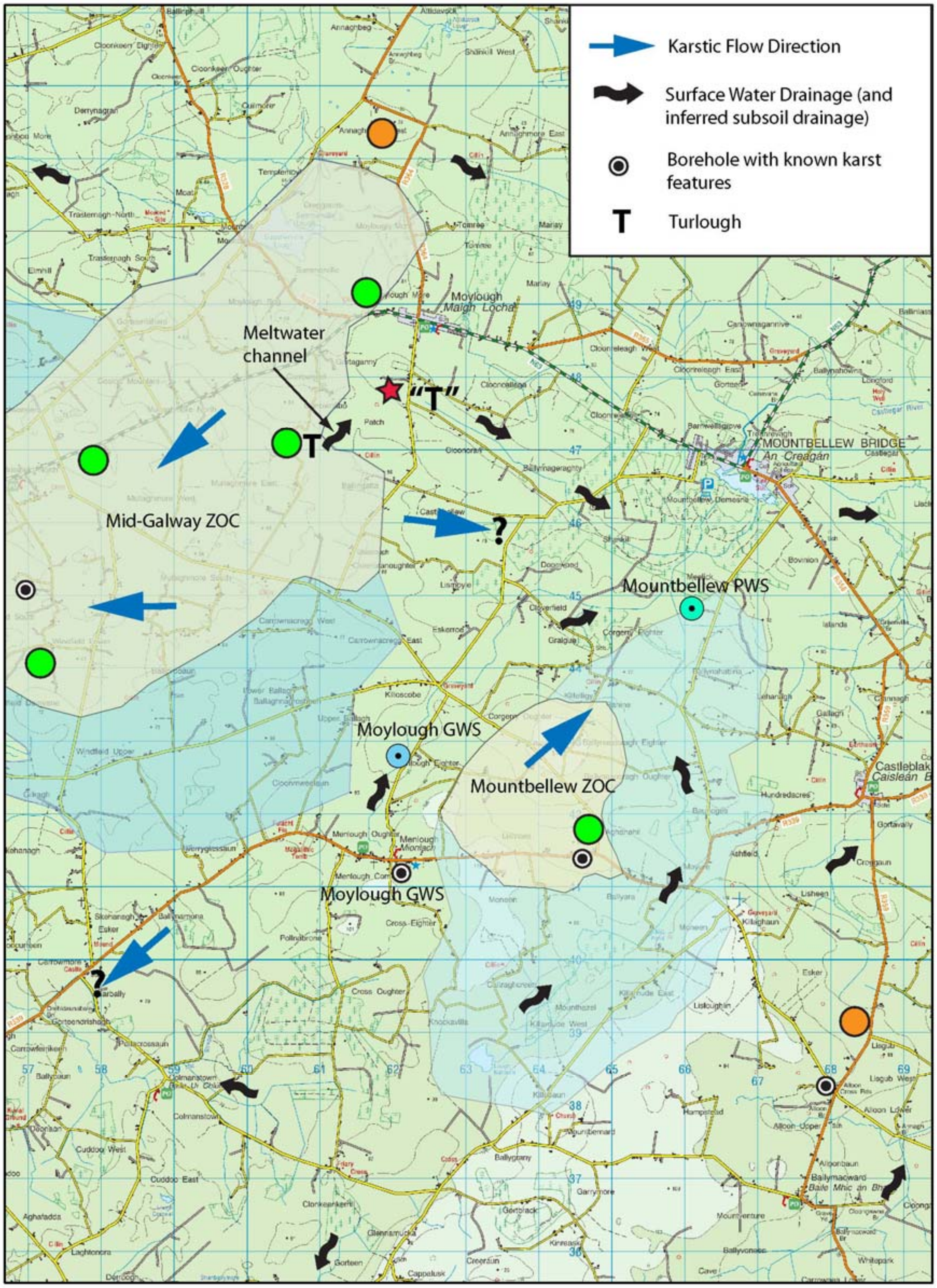


Mid-Galway PWS (and Barnaderg GWS) – Draft ZOC

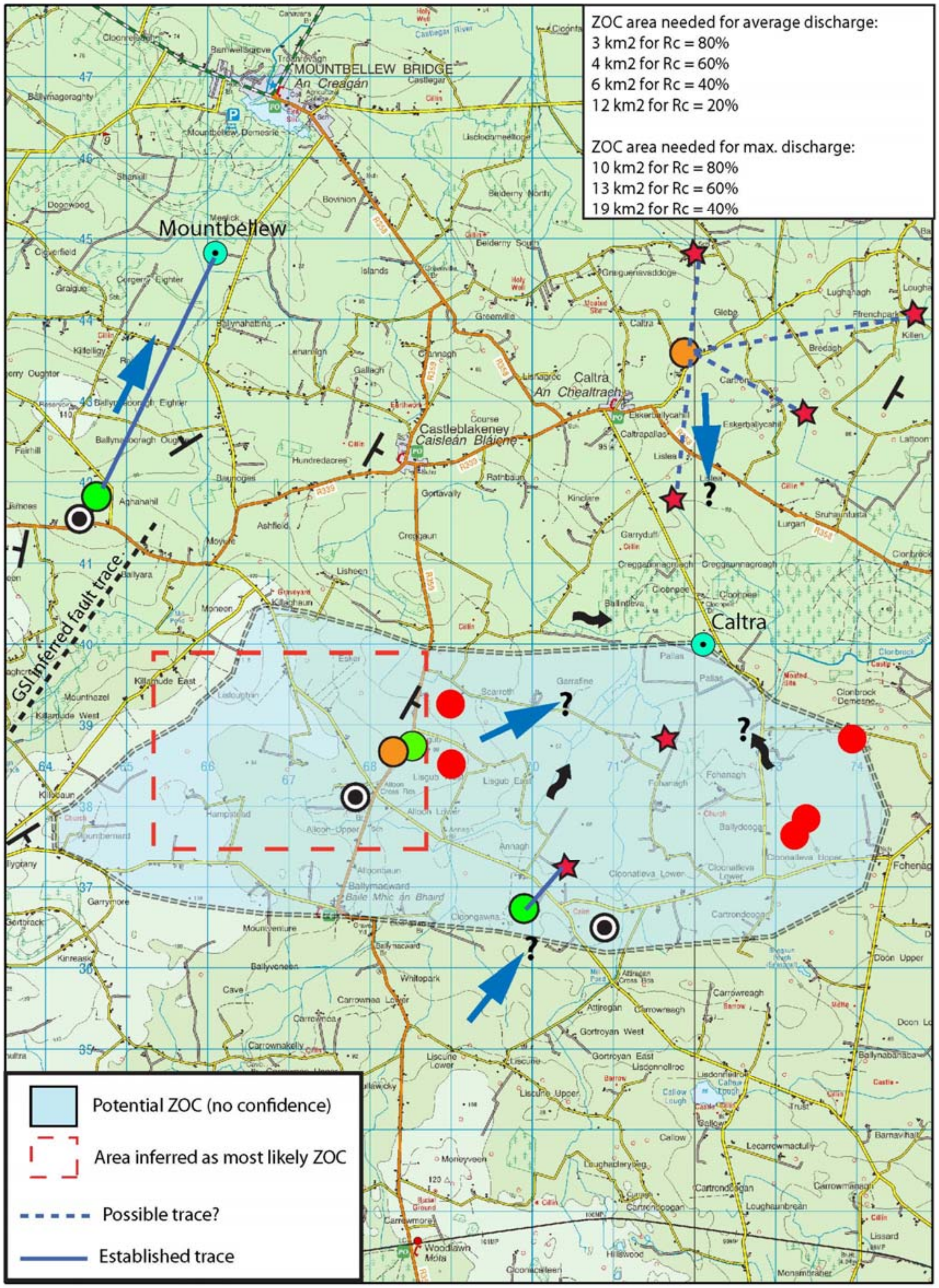


Mountbellew PWS – Draft ZOC

Mid-Galway/Mountbellew PWS – Opposing Karst Flow Directions

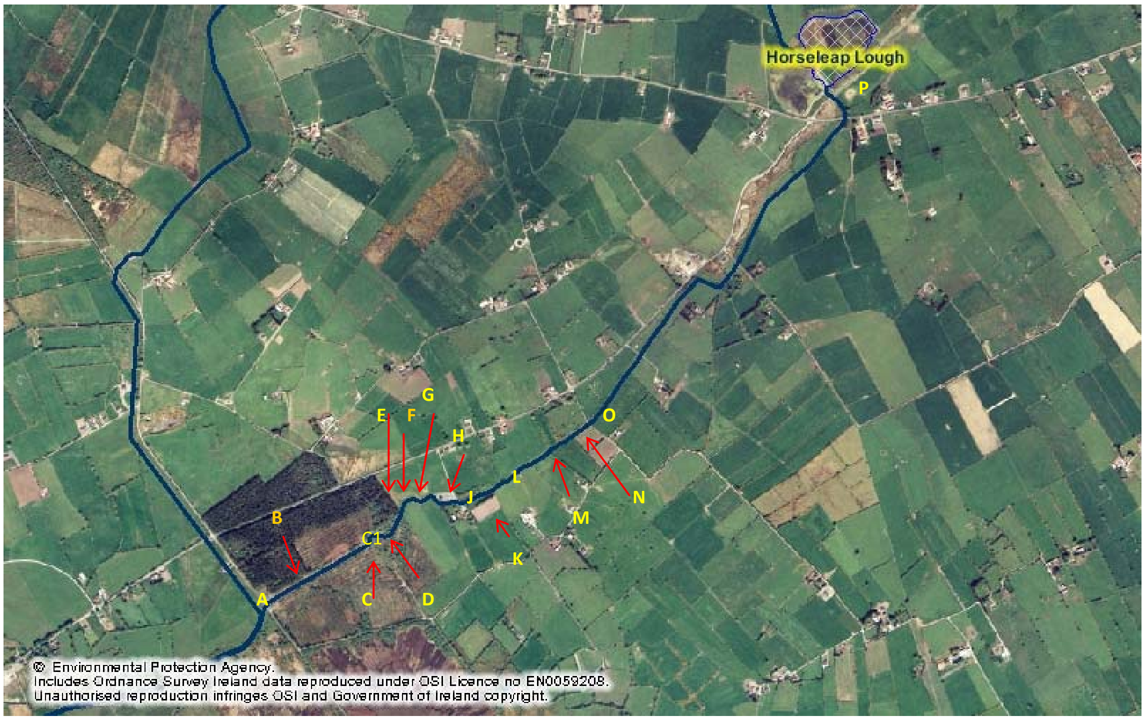


Caltra


ZOC area needed for average discharge:
3 km2 for Rc = 80%
4 km2 for Rc = 60%
6 km2 for Rc = 40%
12 km2 for Rc = 20%
ZOC area needed for max. discharge:
10 km2 for Rc = 80%
13 km2 for Rc = 60%
19 km2 for Rc = 40%
Mountbellew
Caltra
GSI inferred fault trace
Potential ZOC (no confidence)
Area inferred as most likely ZOC
Possible trace?
Established trace

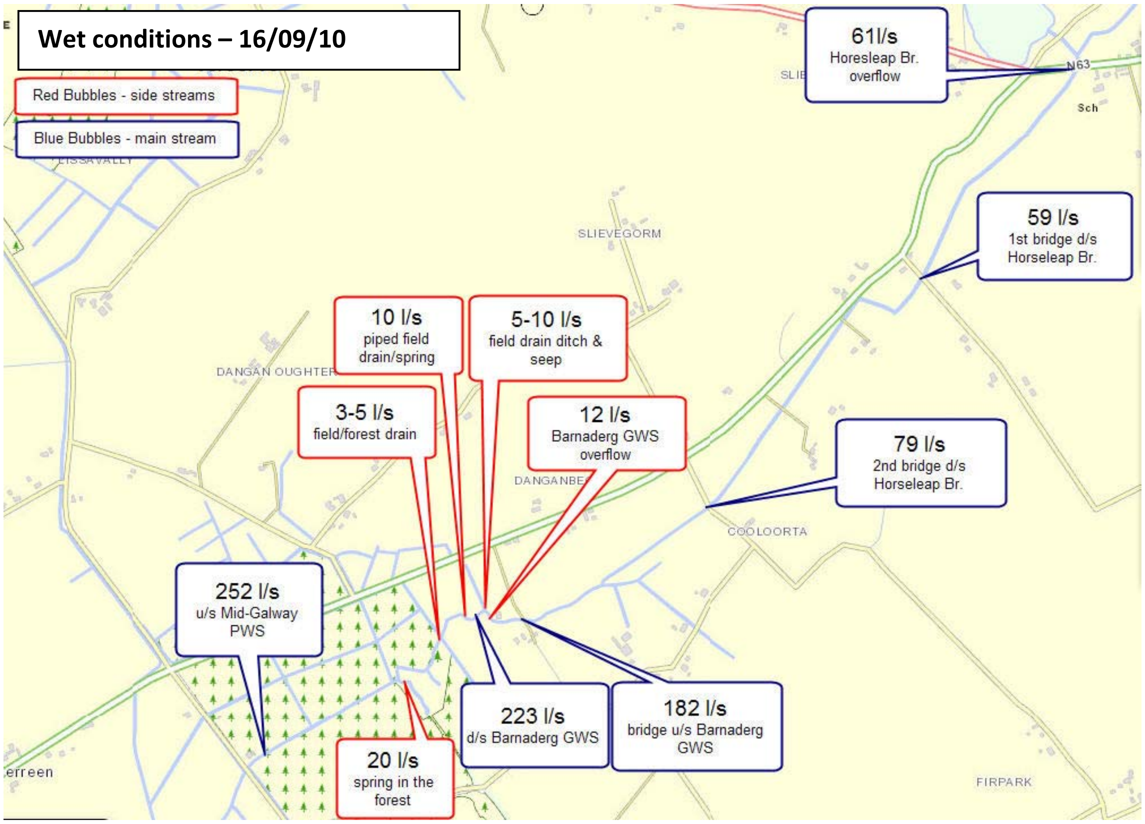
Stop No. 1 – Barnaderg GWS

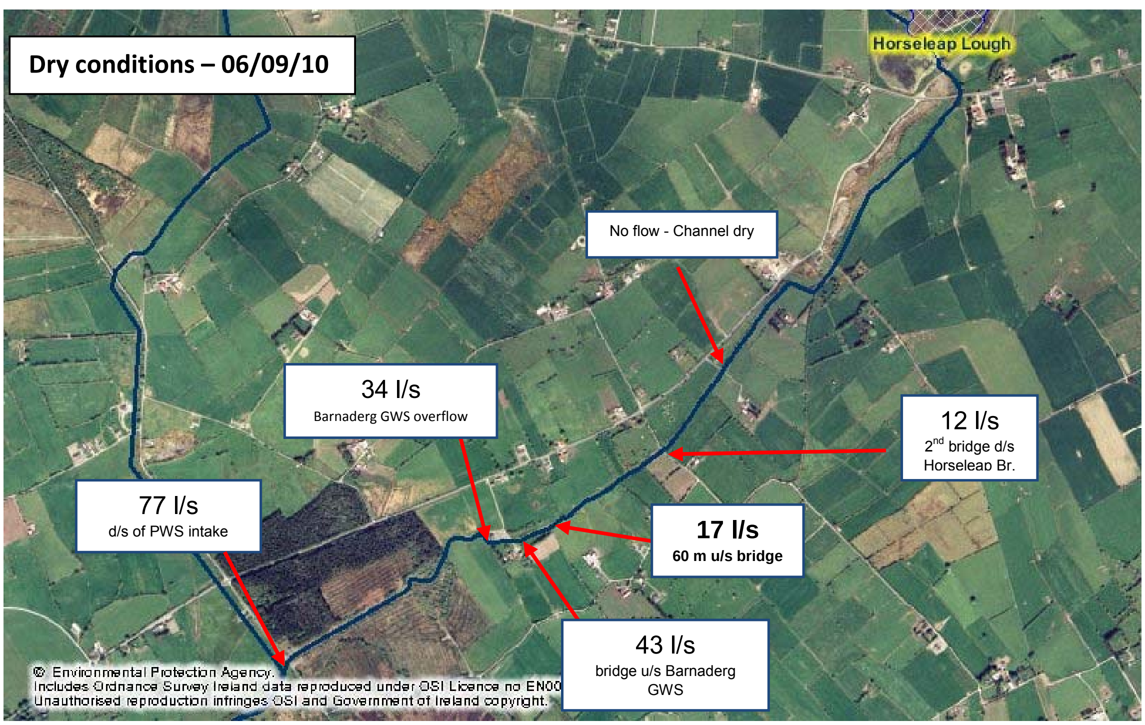
- Significant groundwater discharge area – supplies the Barnaderg GWS, Mid-Galway PWS (0.7 km to the SW), Brierfield GWS, and provides flow to the Abbert River;
- Two dominant springs = Barnaderg GWS and Polliffrin (1.7km to the SE, see Stop No. 2);
- Barnaderg (Dangan) spring was recently the subject of drilling for expansion and upgrade of the GWS.



Measurements, March 6th, 2011

Location	Flow m³/s	EC	Ph	Temp	Description
A	0.3316	703	7	10.5	Main channel, just u/s of Mid-Galway PWS
B	0.0363	693	7.12	10.2	Inflow (ditch)
C	0.0858	709	6.76	10.2	Spring contribution
D	0.0158	708	6.94	10.2	Spring contribution
E	0.0055	790	7.46	9.7	Inflow (ditch)
F	0.007	728	7.09	10.2	Inflow from covered spring via pipe
G	0.0023	712	7.06	9.2	Spring
H	0.006	708	6.81	10.2	Overflow from spring at Barnaderg GWS
J	0.188	715	6.82	9.9	Main channel
K	0.0866	708	6.76	10.1	Diffuse discharges from the stream bank
L	0.1014	700	7.26	9.6	Main channel
N	0.035	680	7.03	9.4	Seep via ditch
O	0.057	661	7.51	9.1	Main channel
P	0.0368	604	8.15	8.6	Outflow from Horseleap Lough


Wet conditions – 16/09/10
Red Bubbles - side streams
Blue Bubbles - main stream
61l/s
Horesleap Br. overflow
59 l/s
1st bridge d/s Horseleap Br.
10 l/s
piped field drain/spring
5-10 l/s
field drain ditch & seep
3-5 l/s
field/forest drain
12 l/s
Barnaderg GWS overflow
79 l/s
2nd bridge d/s Horseleap Br.
252 l/s
u/s Mid-Galway PWS
223 l/s
d/s Barnaderg GWS
182 l/s
bridge u/s Barnaderg GWS
20 l/s
spring in the forest
SLIEVEGORM
DANGAN OUGHTER
DANGANBE
COOLOORTA
FIRPARK
N63


Dry conditions – 06/09/10
Horseleap Lough
No flow - Channel dry
34 l/s
Barnaderg GWS overflow
12 l/s
2nd bridge d/s Horseleap Br.
77 l/s
d/s of PWS intake
17 l/s
60 m u/s bridge
43 l/s
bridge u/s Barnaderg GWS
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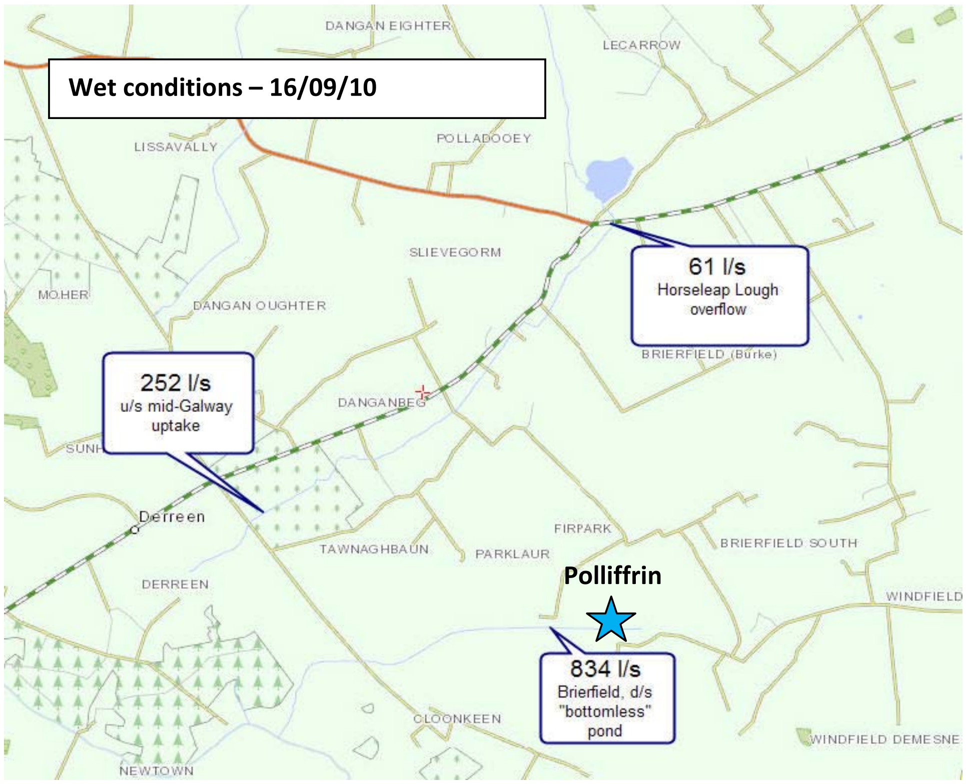
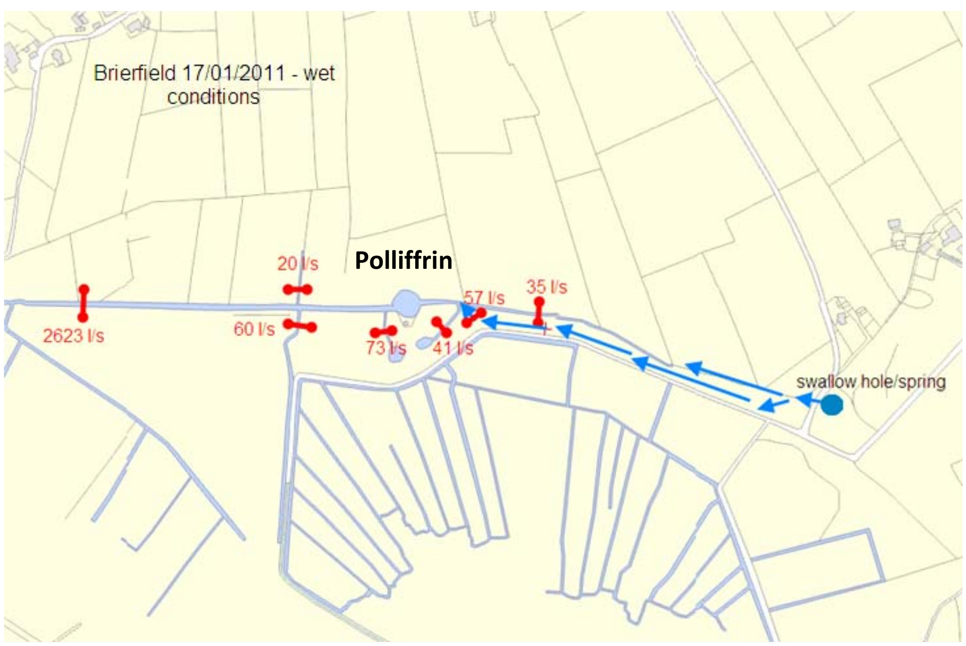
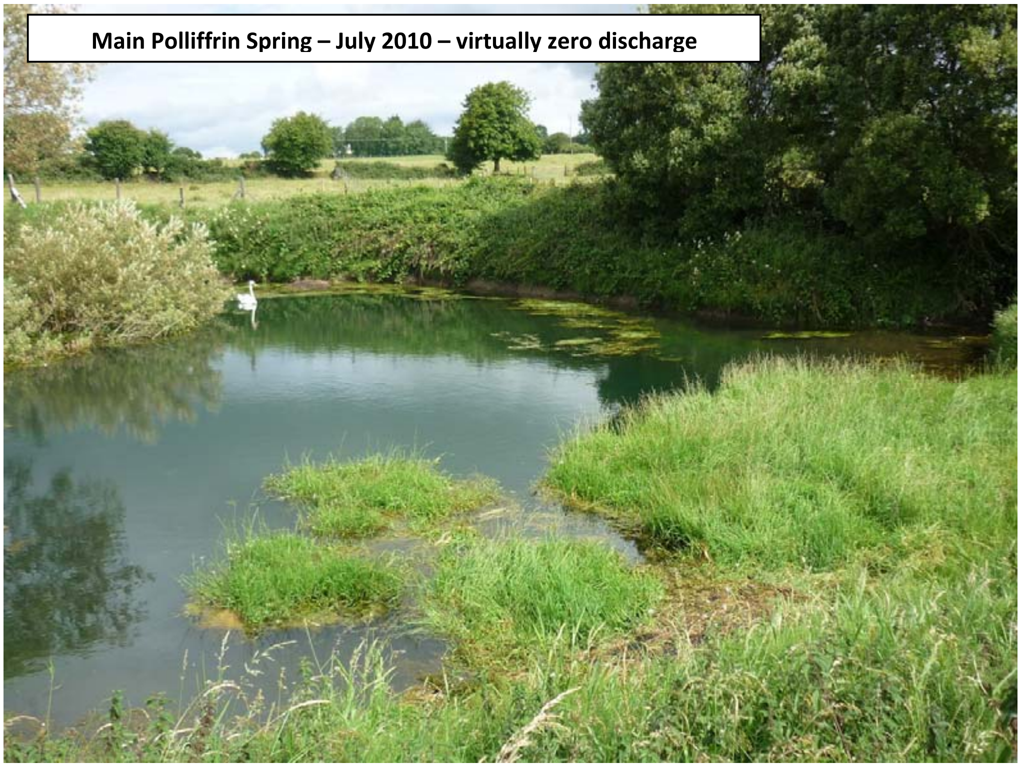
Stop No. 2 – Polliffrin

- Minimum measured flow = trickle June 2010; 0.042 m^3/s on July 20th, 2010;
- Maximum measured flow = 2.6 m^3/s on January 17th, 2011.





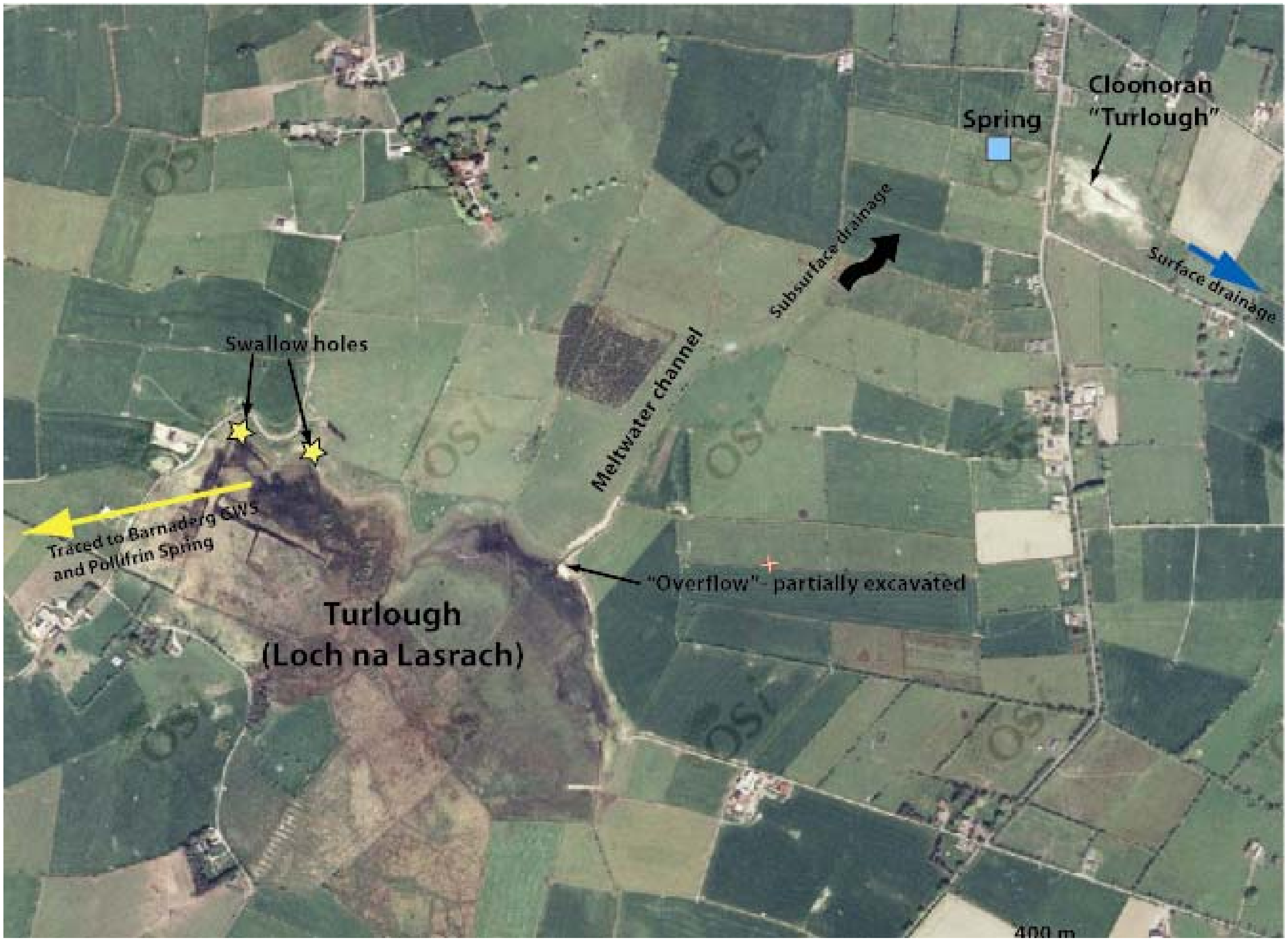


Main Polliffrin Spring – July 2010 – virtually zero discharge

Adjacent, smaller spring – September 2010

Stop No. 3 – Turlough (Loch na Lasrach)

- Elevation approx. 80 mOD;
- Prone to significant flooding;
- Two swallow holes at the NW margin of the turlough (additional swallow holes exist);
- Turlough traced to both the Barnaderg and Polliffrin springs, hence, the turlough is at the headwater of the River Abbert and the River Clare catchment.
- Area shows many glacial features – e.g. eskers and ice marginal moraines deposited as 5-10m high linear ridges on top of thin till.
- An apparent meltwater channel at the NE end of the turlough drains "overflow" to the NE. Given the high elevation of the turlough, and during flooding, the drainage is believed to feed a spring near the village of Moylough, where surface water is ultimately drained to the east. As such, Loch na Lasrach also potentially represents a headwater of the River Suck catchment.


Cloonoran
"Turlough"
Spring
Subsurface drainage
Surface drainage
Swallow holes
Meltwater channel
Traced to Barnaderg GWS
and Pollifrin Spring
"Overflow"- partially excavated
Turlough
(Loch na Lasrach)
400 m

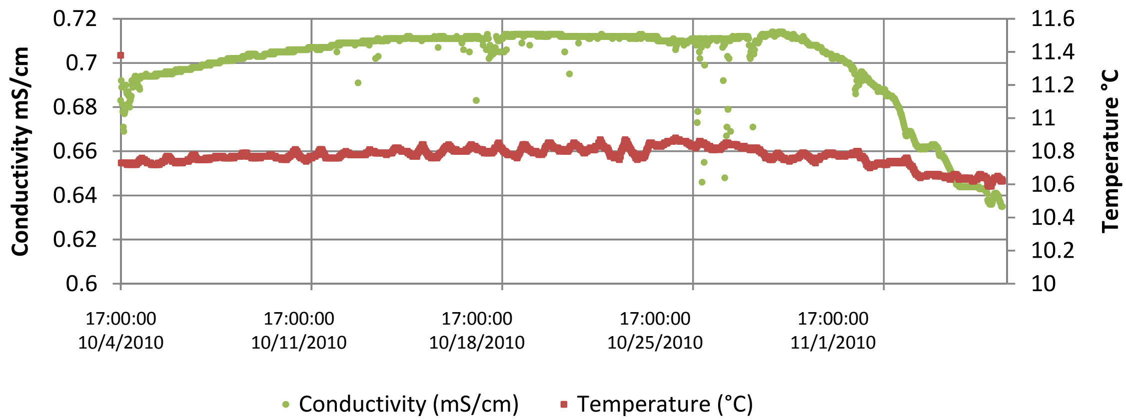
Stop No. 4 – Caltra

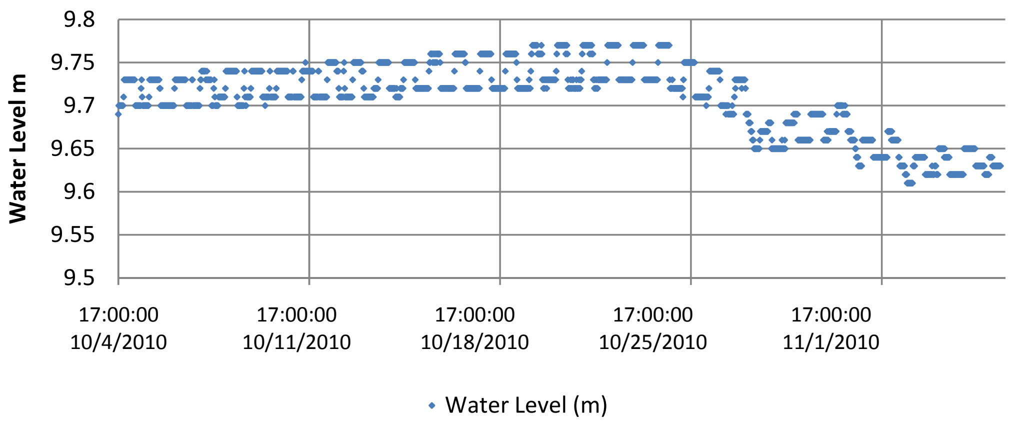
- Apparent karst spring in low-lying bog area;
- Zero of three traces from three locations were detected at the spring, yet tracer materials were injected into active swallow holes to the S, W and N of the spring, between 3.5 and 4.5 km away. Daily samples were collected for a three week period in each case.
- Land below 80 mOD - distinctly flat with high drainage density. Subsoil (till) thick (> 5 m);
- Land above 80 mOD – includes some karts features; Subsoil mostly thin (<3 m) and absent;
- Bedrock in the area is "Calp-like" and very different from the limestone at the other sources explored;
- Role of stratigraphy and structural geology on karst development?
- Deep weathering (possible karst weathering) inferred from 2-D resistivity surveying near spring.
- Results from drilling about 4 km to the SW of the spring (at Attyregan) confirm dark grey/black "Calp-like" limestone. Borehole encountered very little water to 70 m below ground level, then a very different type of limestone and sand-filled conduit from 72 to 77 m.
- Why were tracers not detected at the Caltra spring?
    - Conduit flow not dominant?
    - Travel times simply very slow (note apparent sand-filled conduit at Attyregan)?
    - Insufficient quantities of dye used?
- ZOC delineation to date has yielded more questions than answers.

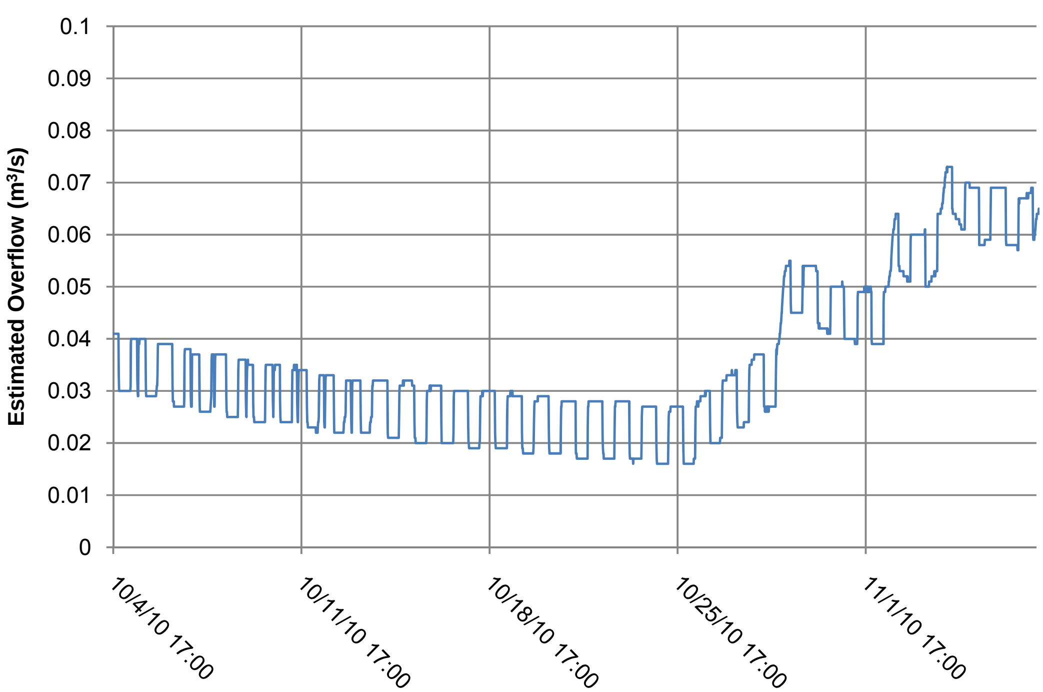
Water Quality 2007-2009; 13 samples (Data Source: EPA)

Parameter	Average Concentration	Concentration Range
(Lab) Conductivity (µS/cm)	701.0	640-754
Ammonium (mg/l N)	0.04	0.007-0.06
Chloride (mg/l)	17.0	11.3-25
Iron ug/l	10.0	<2-26
Total coliforms (No./100ml)	524.0	50-3,255
Nitrate mg/l (NO3)	8.5	1.9-14.5
Sodium (mg/l)	10.8	8-17
Potassium (mg/l)	3.3	2.1-6.0
Total hardness (mg/l CaCO3)	380.0	343-447
Manganese (ug/l)	2.0	<1-3
Sulphate (mg/l)	7.0	2.5-13
MRP (mg/l P)	0.012*	<DL - 0.095

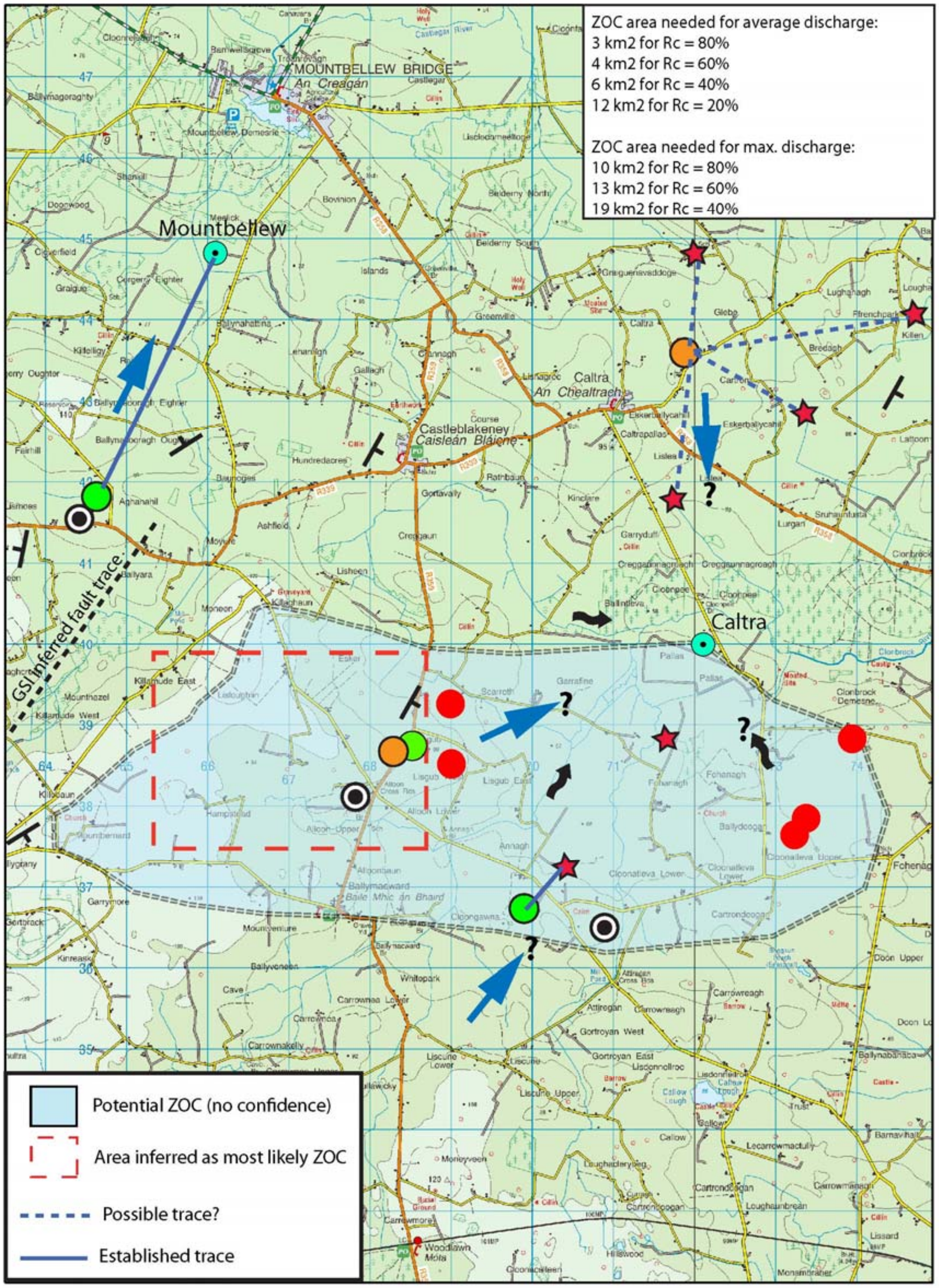
*-three detections only; DL = <0.009


Conductivity mS/cm
0.72
0.7
0.68
0.66
0.64
0.62
0.6
Temperature °C
11.6
11.4
11.2
11
10.8
10.6
10.4
10.2
10
17:00:00 10/4/2010
17:00:00 10/11/2010
17:00:00 10/18/2010
17:00:00 10/25/2010
17:00:00 11/1/2010
Conductivity (mS/cm)
Temperature (°C)

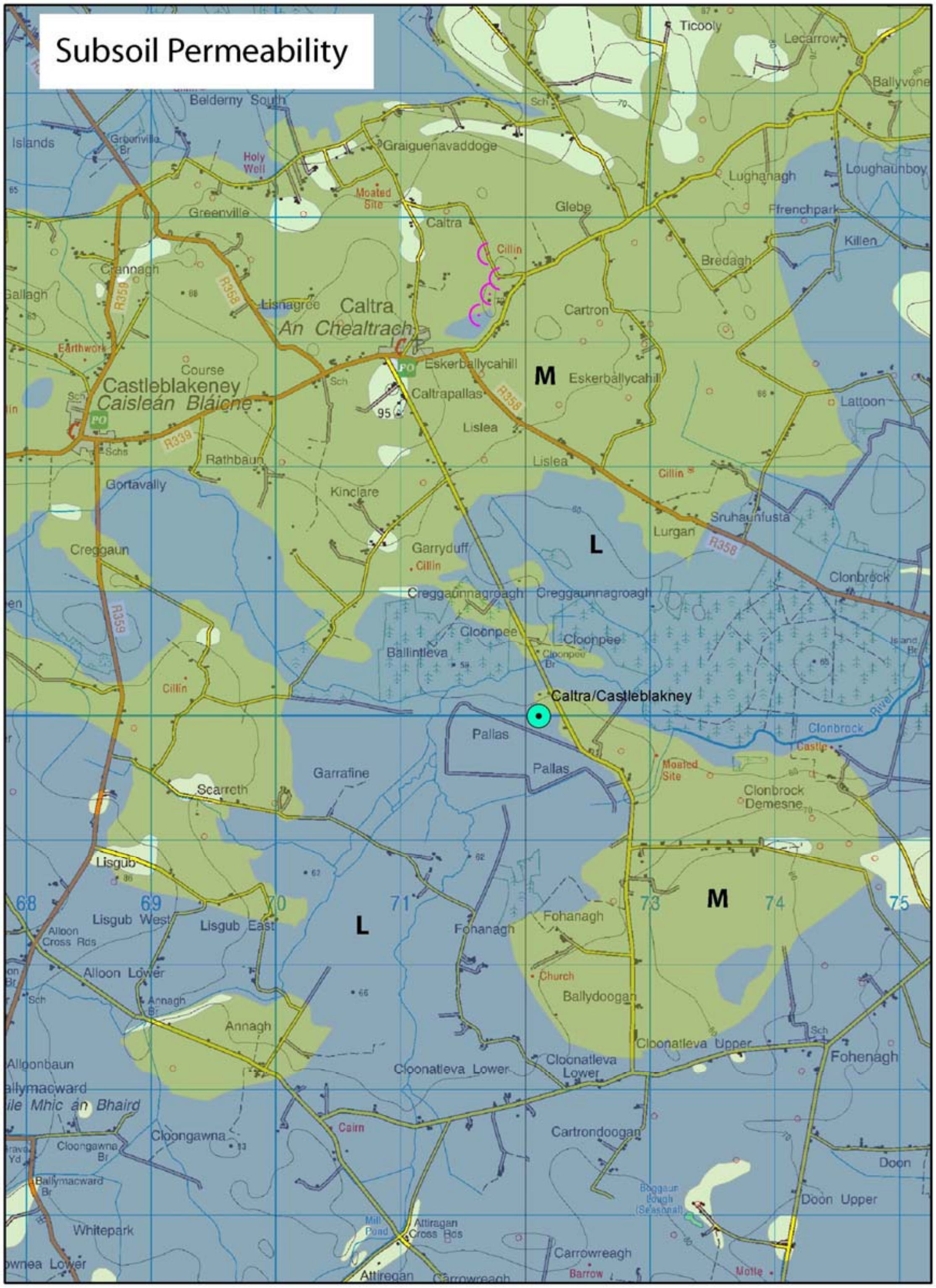

Water Level m
9.8
9.75
9.7
9.65
9.6
9.55
9.5
17:00:00 10/4/2010
17:00:00 10/11/2010
17:00:00 10/18/2010
17:00:00 10/25/2010
17:00:00 11/1/2010
Water Level (m)


Estimated Overflow (m³/s)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
10/4/10 17:00
10/11/10 17:00
10/18/10 17:00
10/25/10 17:00
11/1/10 17:00

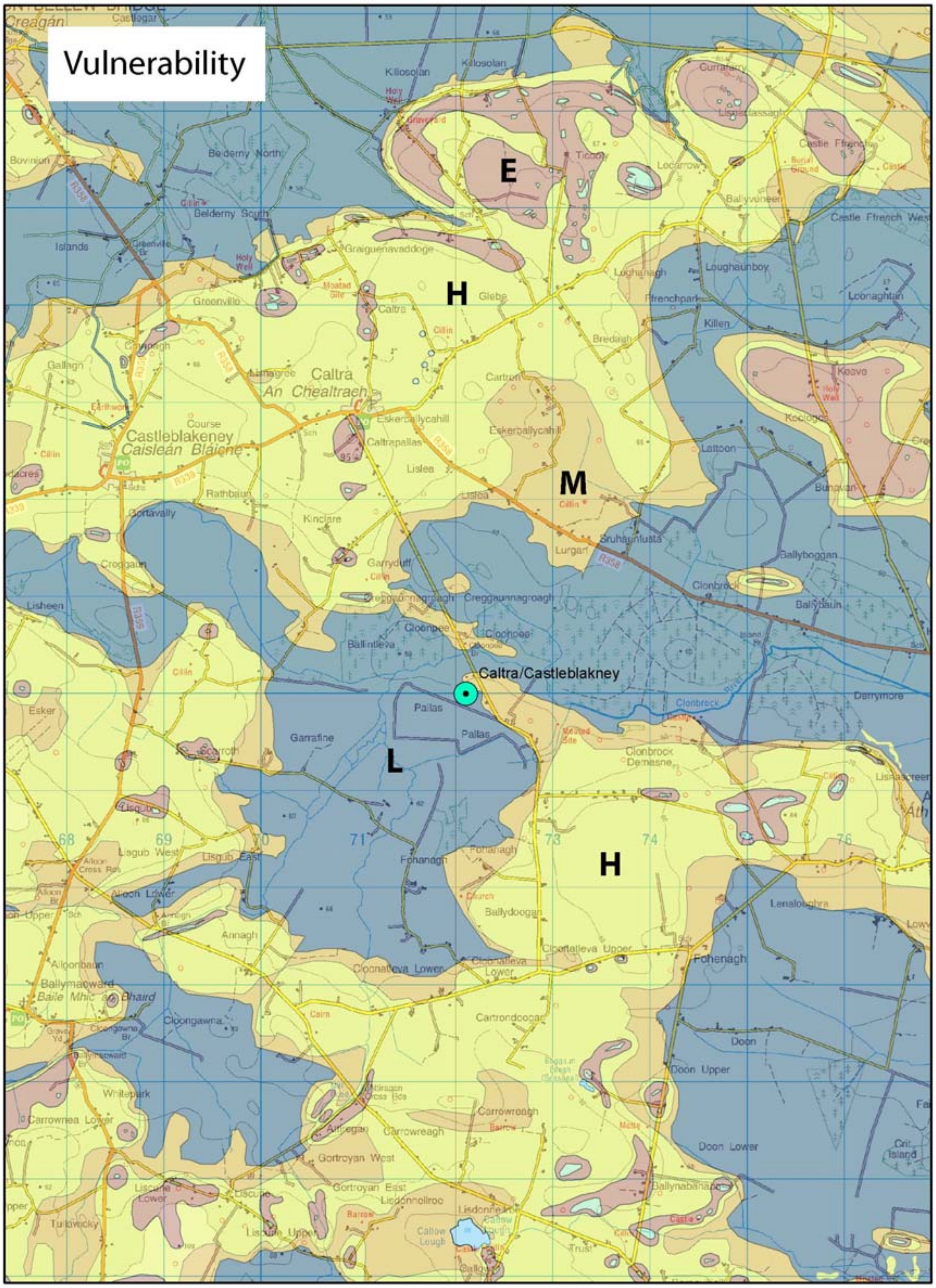
Caltra

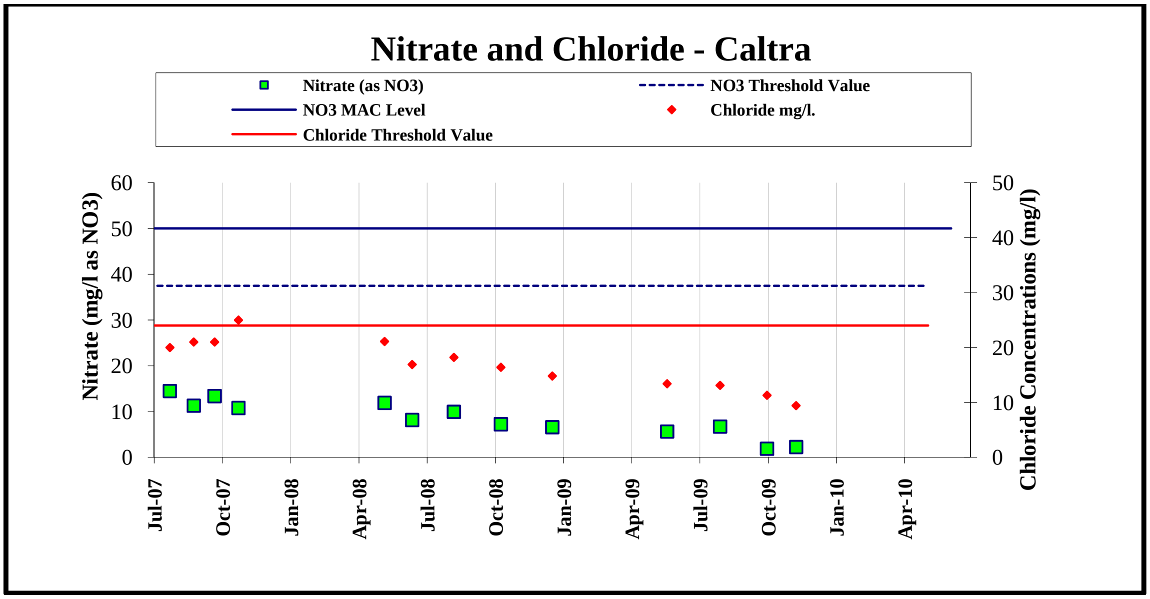

ZOC area needed for average discharge:
3 km2 for Rc = 80%
4 km2 for Rc = 60%
6 km2 for Rc = 40%
12 km2 for Rc = 20%
ZOC area needed for max. discharge:
10 km2 for Rc = 80%
13 km2 for Rc = 60%
19 km2 for Rc = 40%
Mountbellew
Caltra
GSI inferred fault trace
MOUNTBELLEW BRIDGE
Castleblakeney
Potential ZOC (no confidence)
Area inferred as most likely ZOC
Possible trace?
Established trace

Caltra


Subsoil Permeability
M
L
M
L
Caltra/Castleblakney
Caltra
An Chealtrach
Castleblakney
Caisleán Bláicne
Ticooly
Lecarrow
Ballyvone
Belderny South
Graiguenavaddoge
Islands
Greenville
Holy Well
Moated Site
Glebe
Lughanagh
Loughaunboy
Frenchpark
Killen
Bredagh
Cartron
Cillin
Crannagh
Lisnagree
Eskerballycahill
Caltrapallas
Lislea
Lattoon
Course
Gortavally
Rathbaun
Kinclare
Sruhaunfusta
Lurgan
Creggaun
Garryduff
Creggaunnagroagh
Clonbrock
Cloonpee
Ballintleva
Pallas
Garrafine
Scarreth
Clonbrock Demesne
Clonbrock River
Lisgub
Lisgub West
Lisgub East
Fohanagh
Alloon Lower
Annagh
Church
Ballydoogan
Cloonatleva Upper
Cloonatleva Lower
Alloonbaun
Cloongawna
Cartrondoogan
Whitepark
Doon
Doon Upper
Carrowreagh
Attiregan
R358
R359
R339
68
69
70
71
73
74
75

Caltra


Vulnerability
E
H
M
L
H
Caltra/Castleblakney
Caltra
An Chealtrach
Castleblakeney
Caisleán Bláicne



	Field EC (uS/cm) – EPA WQ Data			
	Min	Max	Avg	No.
Caltra	566	786	676	13
Mountbellew	507	787	703	28
Mid-Galway	559	825	725	28
Kilkerrin	530	804	717	26

	Hardness (mg/l $CaCO_3$) - EPA WQ Data			
	Min	Max	Avg	No.
Caltra	343	447	380	13
Mountbellew	160	436	367	36
Mid-Galway	154	452	373	33
Kilkerrin	177	472	371	35

	Alkalinity (mg/l $CaCO_3$) - EPA WQ Data			
	Min	Max	Avg	No.
Caltra	306	395	352	13
Mountbellew	88	430	342	36
Mid-Galway	138	424	351	34
Kilkerrin	166	430	351	35

	Iron (ug/l) - EPA WQ Data			
	Min	Max	Avg	No.
Caltra	<2	34	20	13
*Cloonatleva**	*<50*	*659*	*<100*	*17*
Mountbellew	<2	833	102	36
Mid-Galway	<2	1900	162	35
Kilkerrin	<2	232	87	35

** - near Caltra, from Galway Co. Co. records*

	Manganese (ug/l) - EPA WQ Data			
	Min	Max	Avg	No.
Caltra	<1.5	3	1.9	13
*Cloonatleva**	*<5*	*21*	*11***	*15*
Mountbellew	<1	59	<20	34
Mid-Galway	<1	614	Spikey***	35
Kilkerrin	<1	38	8**	34

** - near Caltra, from Galway Co. Co. records*

***-for values > ND*

****- mostly <1 post-2006*

	Turbidity (NTU) - EPA WQ Data			
	Min	Max	Avg	No.
Caltra	0	3.6	0.6**	13
*Cloonatleva**	*<0.2*	*1.5*	*0.5***	*15*
Mountbellew	<1	1.3	0.5**	32
Mid-Galway	0	1.7	0.5**	34
Kilkerrin	<0.2	3	0.6**	34

** - near Caltra, from Galway Co. Co. records*

***-for values > ND*

	MRP (mg/L-P) - EPA WQ Data			
	Min	Max	Avg	No.
Caltra	<0.009	0.095	0.037**	13
*Cloonatleva**	*nd*	*nd*	*nd*	*nd*
Mountbellew	<0.009	0.079	0.031**	36
Mid-Galway	<0.009	0.875	0.066**	35
Kilkerrin	<0.009	0.084	0.036**	36

** - near Caltra, from Galway Co. Co. records*

***-for values > ND*