Irish Groundwater Newsletter

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Groundwater Newsletter No. 53 contains the customary mix of articles and news items relevant to hydrogeology in Ireland. The first article gives examples of some of the work been undertaken as part of the GSI's four year programme of groundwater investigations outlined in Newsletter No. 52. The remaining articles address aspects of two topics that are of particular importance in Irish hydrogeology: surface water- groundwater interactions and groundwater quality with particular reference to micro-organisms.

At the time this editorial was being written (mid-March 2016) roads were still blocked by flood water and large areas of farmland remained inundated in the lowland karstified limestone areas of western Ireland. The flooding had lasted for almost four months, continuing for many weeks after the flooded rivers such as the Shannon had subsided. Ted McCormack and Owen Naughton present the results of recent research into this groundwater driven flooding in the Gort area of Co Galway. Ray Flynn and Daniel Hogan question our conceptual assumptions concerning groundwater-surface-water interactions whilst Jean Wilson presents the results of her research into the use of natural environmental tracers to assess groundwater discharge into Loughs Ennell and Owel.

On the theme of groundwater quality Ray Flynn provides an overview of the behaviour of pathogenic micro-organisms in aquifers. Paul Hynds contributes the second installment of three articles concerned with pathogens in groundwater which reviews viruses in groundwater. Paul also provides an article summarising recent research into contamination by micro-organisms of private wells in Ireland.

Monica Lee, Groundwater Section, GSI
Katie Tedd and David Drew, Editors

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Cover photo: Flooding in the Gort Lowlands, 2009. [OPW] **See page 7**

GSI's Priority Groundwater Mapping Areas

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This paper highlights recent progress of the GSI's programme in investigating key areas of work.

Introduction

In the previous newsletter (Issue 52, July 2015), the Geological Survey of Ireland (GSI) outlined a new four year programme comprising higher resolution mapping, data collection, modelling and investigations to address various stakeholder needs and information gaps. The intention of this article is to highlight some of the work done in the first year. Three broad themes were identified to pursue in priority areas: karst; sand and gravel resources and pathways; and groundwater flow and chemistry. Comprehensive articles will be published in future newsletters for each of the themes/ investigations as the work progresses.

Karst Investigations

Two areas were identified for investigations using different and focused techniques: north Co Cork and the Rathcroghan uplands in Co Roscommon. In north Co Cork an extensive well survey, bedrock drilling, logging key bedrock exposures, river surveys, and water sampling were carried out. In the Rathcroghan Uplands, where tracing has proved successful in the past, it was proposed to use dye tracing to investigate groundwater characteristics to define contributing areas of water supply springs.

Karst investigations in North Cork

The study area is in the upper Blackwater river catchment, specifically, the fluvio-karst terrain drained by the Awbeg and Funshion river systems (Figure 1, Figure 2). It is an area where groundwater is the main source of drinking water, supplying some 30,000 m^3/d across the

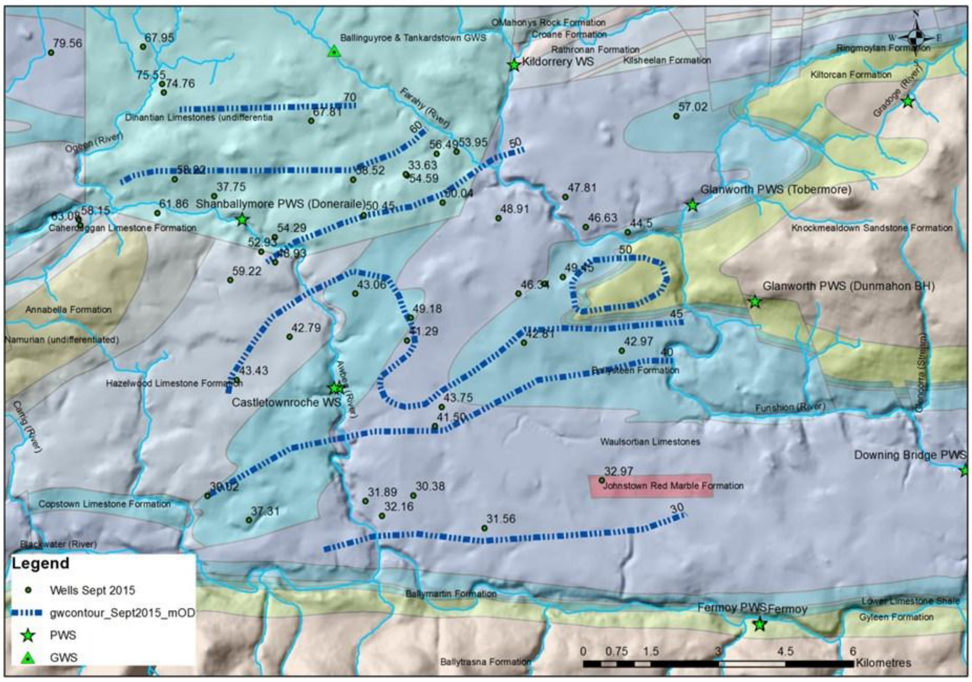


Figure 1
Interpreted groundwater contours in the north Co Cork study area

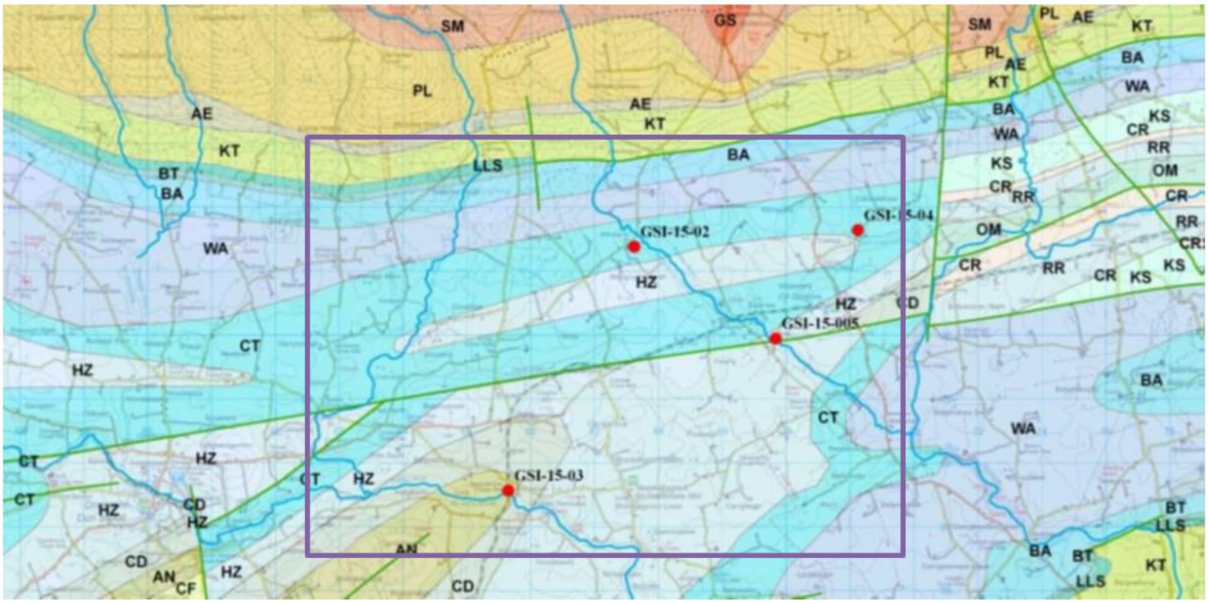


Figure 2 Geology of North Cork (Pracht, 2016). The area within dark blue line is the previously undifferentiated limestone block in the northern portion of Figure 1

greater North Cork region (Kelly and Drew, 2014). The work comprised two extensive well surveys across an area of approximately 100 km^2. The GSI drill rig was used to drill four bedrock boreholes to investigate the geology and stratigraphy in an area of undifferentiated limestones (Sleeman et al., 1995).

Outputs include interpreted groundwater contours (Figure 1) and a new geology map for the area (Figure 2). Geologically, there appears to be significant deformation and a major fault running east west through the area (Figure 2) (Pracht, 2016). There is a regional north-south groundwater flow component as was anticipated, however, there are local deviations highlighting more complex flow patterns that need to be taken into account when determining potential drinking water or habitat risk issues (Figure 1).

Rathcroghan Uplands, County Roscommon

The Rathcroghan Uplands is a relatively high plateau located in central Co Roscommon, ranging between 60–150 m above sea level. The bedrock comprises karstified limestone with a large number of mapped karst features, including swallow holes, distributed across the plateau. Springs are generally located around the plateau perimeter. Several of these springs supply group or public water supply schemes (Figure 3).

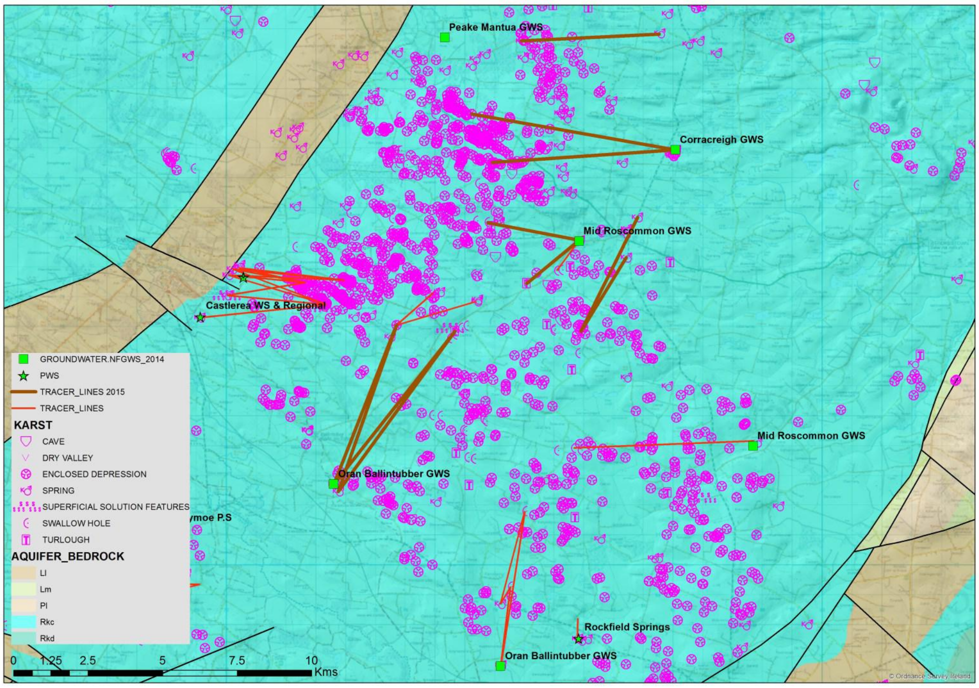
A dye tracing programme was conducted with dyes put into nine swallow holes across the uplands. Approximately 40 sites were monitored: water grab samples, with activated charcoal and unbleached cotton wool as back-up detectors.

Seven of the nine traces were positive (Figure 3). The traces indicate that groundwater flows: 1) west to east and east to west; and 2) northeast to southwest and southwest to northeast. These patterns are coincident with the main structurally related veining (jointing) orientations. The flow rates range from approximately 100 m/hour to 200 m/hour and the slower rates coincide with somewhat drier conditions. An eighth positive trace was conducted by Roughan O'Donovan to the north of the study area. Such collaborations highlight the cumulative benefits of pooling resources and results to aid regional understanding.

Sand and Gravel Investigations

The principle focus of the 2015 programme was to investigate the extent of sand and gravel

Figure 3 Rathcroghan Uplands: traces (2015 traces bold highlight), karst features and aquifer type



bodies across Donegal, Mayo, Leitrim, Sligo and Roscommon.

New information was obtained from both desk study and field mapping: hydrogeological mapping, logging of exposures and well surveys. The analysis and interpretation was carried out in the GSI using the in-house GIS environment and utilising the existing data, as well as the new data obtained from the field work. The main outcomes are:

- Updated areal extents to known sand and gravel bodies;
- 'New' sand and gravel bodies;
- Updated sand and gravel aquifers; and
- Definition of 'extreme' groundwater vulnerability in the updated sand and gravel aquifers.

As interpretation will be on-going, the online national maps will be updated at a later stage.

Groundwater Flow Throughput in Poorly Productive Aquifers

The work carried out within this theme builds on the concept of maximum recharge capacities for Irish Poorly Productive Aquifers and the "recharge caps" which are applied in the estimation of groundwater recharge for the National Recharge Map (GWWG, 2005; GSI, 2013).

Based on the collective evidence from a suite of different methods, it is suggested that 200 and 300 mm/a may be representative of national annual average deep and shallow groundwater throughput capacities in Irish poorly productive bedrock aquifers. As this is a national annual average value, the deep and shallow groundwater throughput capacity of any single Irish poorly productive bedrock aquifer may vary significantly. Given the uncertainties further work is required to:

- Improve the estimates of aquifer and groundwater flow system properties;
- Improve the characterisation of other pathways; and
- Use the improved information to better model groundwater and surface water flow.

Groundwater Hydrochemistry Maps

A series of national groundwater chemistry maps is being prepared. The first map in this series is a preliminary groundwater total hardness map (Figure 4). It is hoped these maps will be a useful reference for professionals with an interest in groundwater and surface water, as well as the general

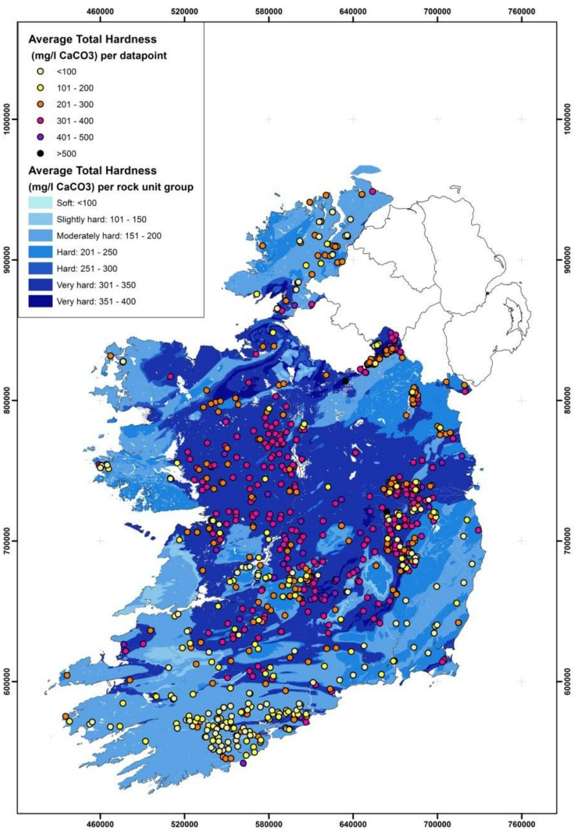


Figure 4 Preliminary groundwater total hardness map

public.

To underpin the series of groundwater chemistry maps, a national groundwater chemistry database is being collated. The database parameters include physico-chemical parameters, major ions, minor ions, nutrients and trace elements. Data have been sourced from a wide range of disparate sources; approximately 300,000 data have been collated from more than 2000 locations.

The next step will be to continue to populate the groundwater chemistry database, particularly to: address spatial data gaps; quality check the data; and develop national maps for other parameters.

Transition zone story map

The transition zone is the broken, weathered zone between subsoil and bedrock. It may be formed by chemical weathering, physical processes or both. It can have a different permeability to the subsoil and bedrock, and can act as a significant pathway for, or barrier to, groundwater and contaminant flow.

An on-line story map has been published to illustrate the transition zone in different geological settings. If you have photographs or data which may be useful for characterising the Transition Zone, or if you have any comments, please contact groundwaterinfo@gsi.ie. The story map can be accessed here:

http://j.mp/groundwaterstorymap

GSI Groundwater viewers and social media

A web application was prepared to make the GSI groundwater viewer readily available to mobile phones. It can be accessed here:

http://j.mp/groundwatergsi

The primary desktop viewer has been improved and comes with additional functionality:

- ITM coordinate search
- Printing maps
- Uploading shapefiles
- Data extraction
- Draw and measure.

Finally, you can now tweet to @GsiGroundwater to communicate groundwater titbits.

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Groundwater flooding in the Gort lowlands

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A comparison between the 2009 and 2015 flooding in the Gort Lowlands.

Introduction

Following a lull during much of the second half of the 20th century, the issue of flooding and flood mitigation has recently re-entered the public consciousness. This has been driven by a series of unprecedented events in the last two decades, of which the floods of November 2009 and December 2015 were the worst in living memory in many parts of the country. While national attention may be focussed on the fluvial (river) flooding which inundated large swathes of Athlone, Longford and Limerick, the phenomenon of groundwater flooding (GSI Newsletter Issue 51) is of particular interest to the groundwater community.

Unlike fluvial or coastal flooding, where the flood location is concentrated along the river network or coastline, groundwater flooding is controlled by locally variable geological and hydraulic factors and can occur in a discontinuous manner across a wide geographical area (Naughton et al., 2015). Also unlike river flooding, where flood magnitude is typically linked to peak flow, groundwater flooding is typically driven by cumulative flow or recharge. It is the accumulation of recharge, due to the lack of adequate drainage, over a period of weeks or months that determines flood severity and duration.

**Figure 1: Flooding in the Gort Lowlands, 2009.
Image provided by OPW.**

In Ireland this form of flooding is primarily associated with the karstified limestone landscape prevalent in the west of the country. Here, the most susceptible region to groundwater flooding is the Gort Lowlands in South Galway.

The Gort Lowlands

The Gort Lowland catchment covers an area of approximately 500km^2 in south Co. Galway. It is bounded to the north by the Dunkellin catchment, to the east by the Slieve Aughty Mountains and to the south-west by the Burren plateau. Bedrock geology is divided between the relatively impermeable sandstones of the Slieve Aughty Mountains in the east and the Carboniferous limestone of the lowlands in the west. Allogenic recharge (originating outside the limestone catchment) draining from the relatively impermeable sandstone uplands onto the lowlands below has promoted karst development in the limestone plain.

Three main rivers drain the sandstone uplands, the Owenshree, Ballycahalan and Beagh. The Owenshree River feeds Blackrock and Coy turloughs, after which the water flows underground south-west joining with the Ballycahalan River after it sinks at Ballylee. This combined flow then merges underground with the Beagh (or Gort) River which entered the conduit network from the south via Polltoophill sink. The combined discharge from these three rivers then rises at Polldeelin in Kiltartan, near the under-construction M18 and flows onwards towards the Coole-Garryland complex, Caherglassaun turlough and Kinvara where it ultimately discharges to sea.

The geological dichotomy provides the catchment with unique hydrological and ecological characteristics in the form of a well-developed cave network and associated groundwater dependent habitats. As a result, the area has historically been the subject of research by hydrologists, ecologists and speleologists (Williams, 1964, Praeger, 1932, Kozlowski and Warny, 2009). It also renders the catchment susceptible to groundwater flooding. During intense or prolonged rainfall, the subterranean flow paths are unable to drain the catchment and available subsurface storage rapidly reaches capacity. Consequently, surface flooding occurs in low-lying topographic depressions (turloughs).

Under normal conditions this inundation does not represent a flood hazard; in fact it is a supporting condition for the flood-dependent turlough habitats. However, under extreme conditions, complex and often unpredictable patterns of surface flooding and ephemeral overland flow can develop, posing a flood risk to surrounding buildings, agricultural land and infrastructure. Observed flood mechanisms include backwater flooding of sinks, overland flow caused by the overtopping of sink depressions, and surface ponding in local epikarst watersheds (Naughton et al., 2015). This area has suffered six notable floods since the early 1990's (1989-1990, 1991, 1994, 1995, 2009 and 2015-2016). The flooding in 2009 was the most severe on record, until it was surpassed in many areas by the events of 2015. This article describes and compares the main features of flooding during these two extreme events, and the future prospects for the region in terms of groundwater flooding and remediation are discussed.

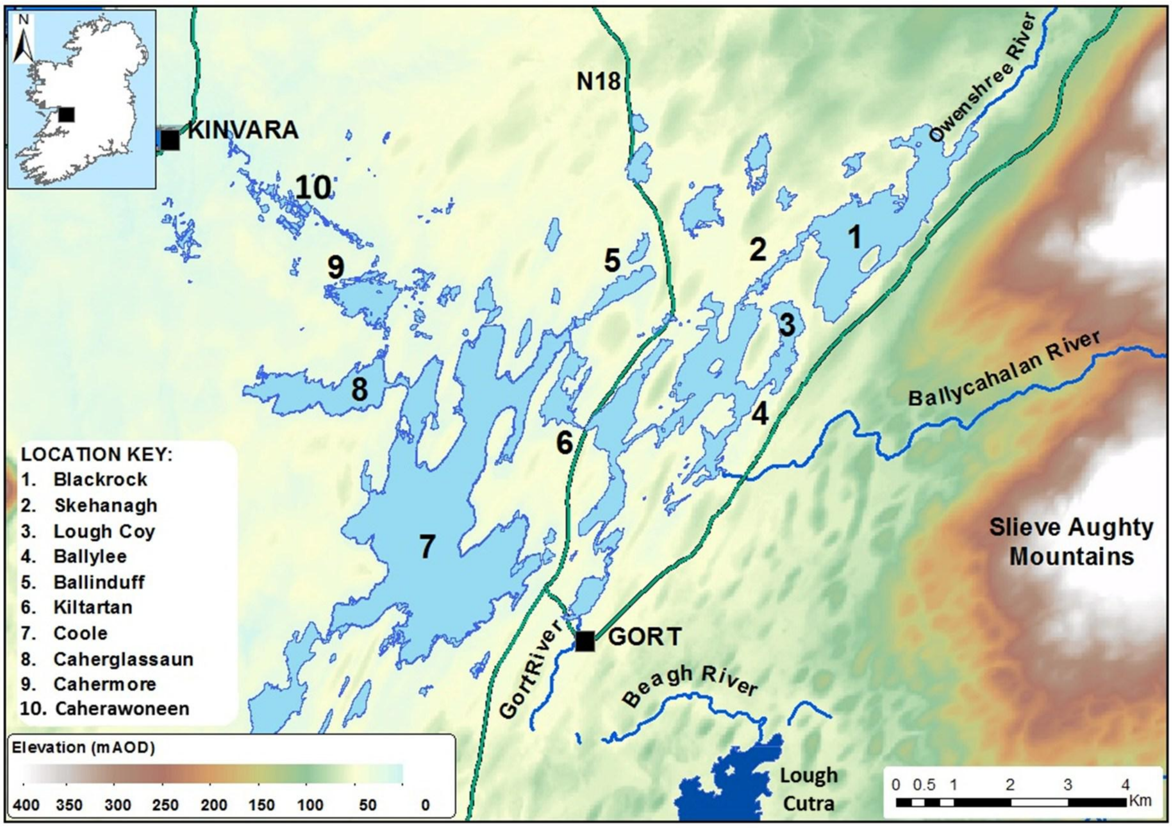

Figure 2: Maximum flooding extent in the Gort Lowlands, winter 2015-2016.

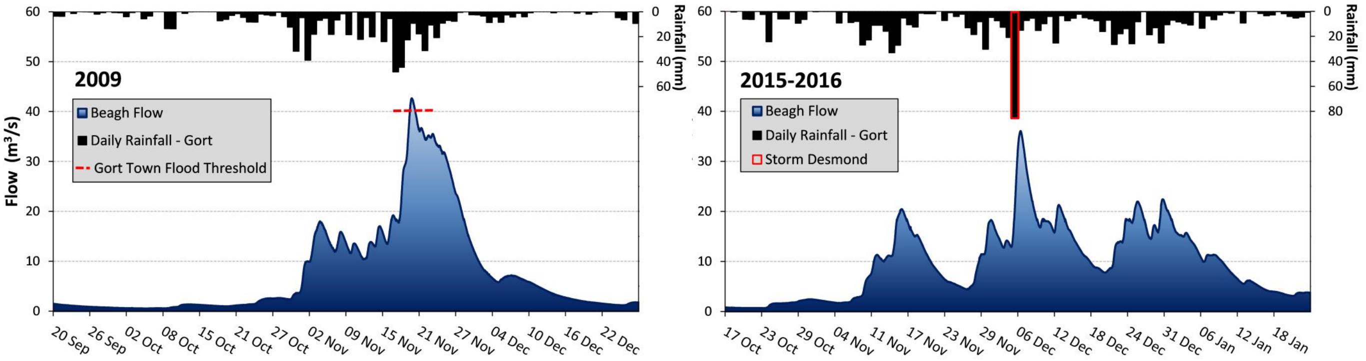

Figure 3: Beagh River discharge (based on TCD rating curve) and precipitation (2009: Met Éireann, 2015: TCD) over 100 day periods in 2009 and 2015-2016

Weather conditions

In late 2009, Ireland experienced very unsettled weather as a series of deep, fast-moving Atlantic depressions brought active frontal systems across Ireland causing heavy rainfall throughout the country (Walsh, 2010). Monthly rainfall at the Met Éireann Gort station for November was 428 mm, or 310% the long-term monthly average (1981–2010). Daily rainfall totals were not exceptional during this period. However, storm events were extreme at longer durations. For example, the return period estimate for the maximum cumulative 25-day rainfall event exceeded 500 years.

The winter of 2015-2016 was dominated by South Atlantic weather fronts bringing mild and moist air to Ireland (McGreevy, 2016). November and December saw a succession of storms crossing the country, producing high winds and daily rainfall of up to 100mm in some areas. Rain gauges operated by Trinity College Dublin around Gort recorded rainfall of 297mm in November and 437mm in December, representing an increase of 203% and 288% compared to the long-term monthly averages respectively. The cumulative 25-day rainfall return period exceeded 150 years which is seemingly less intense than 2009. Critically however, the persistence of rainfall in 2015 saw 660mm (TCD gauge) over the wettest 50 day period whereas 2009 only saw 550mm (Met Éireann gauge).

River Flooding

2009 produced the highest flows on record in the Slieve Aughty Rivers. Estimates based on OPW gauging stations and rating curves developed by Trinity College Dublin show flows in the Owenshree and Ballycahalan Rivers exceeding $20m^3/s$, while the Beagh River reached over $40m^3/s$ (Figure 3: left). The Beagh discharge hydrograph of 2009 consisted of one principal event, corresponding to the peak rainfall events around the 19th Nov, whereas 2015 saw three distinct events, each of a lesser peak discharge than 2009. The volume of water, however, was 26% greater overall in 2015 than in 2009 (based on the 100 day periods used in Figure 3). Thus in 2015, the impact or river flooding was less significant than 2009 whereas the impact of groundwater flooding was greatly increased.

Where this difference in peak flows had the greatest effect in terms of flood risk was in Gort town. Hydraulic modelling of the Gort River and its environs found that flooding in the town was principally linked to peak flows in the river, and not the flooding downstream at Kiltartan. Results indicated that the levels to the east of the N18 did not significantly affect or contribute to flood risk (JBA Consulting, 2015). Thus, while the culvert installed post-2009 flooding likely reduced the risk posed to the N18 by flooding, its impact on flooding in Gort Town is less significant.

Groundwater Flooding

Beginning in late October 2009, the drainage capacity of the groundwater flow system was overwhelmed causing flooding in the main turloughs. Flood levels continued to rise throughout November in response to the continuing rainfall. Peak levels occurred on 26th and 27th of November in Blackrock and Lough Coy respectively, coinciding with the maximum 25-day duration storm event in the region. Localised flow constrictions, coupled with surface storage in the turlough basins and river sinks, attenuated the storm pulses as they moved through the system. As a result, maximum water levels down-gradient in the Coole-Garryland Complex lagged behind by approximately a week, peaking on 2nd of December.

As the location where the three Gort Rivers first rise as a single discharge, Kiltartan acts as a hydrological fulcrum for the Gort Lowlands. It is the location at which the influence of river flooding diminishes and groundwater flooding dominates. While Kiltartan itself saw a similar level of flooding in 2009 and 2015, areas up-gradient were comparatively lower (or level) in 2015 whereas flooding down-gradient of Kiltartan was more severe. Blackrock turlough, which is (mostly) river-fed but groundwater drained, flooded to a similar level in 2015 as in 2009, as did Lough Coy turlough. This is primarily due to topography, rather than groundwater drainage, as overland flow routes via Skehanagh and Ballylee limit the upper bounds of flooding in Blackrock and Lough Coy respectively.

Figure 4: Kiltartan Church, January 2016. Image provided by Paul Johnston (TCD)

During a typical year, Coole turlough floods to a depth of approx. 7-10m, covering an area of 2.2-3km^2. In 2015, Coole reached a depth of 12.3m and covered an area of 4.2km^2. This represented an increase in depth of 1m compared to 2009 and a 20% increase in the volume of water stored. With Coole at this level, the head difference between it and the upstream floodwaters at Kiltartan is greatly reduced (to as little as 0.15m). Thus under the conditions experienced in 2015 the scope for mitigating flooding at Kiltartan, is limited, irrespective of culvert capacities in local roads and the under-construction M18, unless Coole can be drained more efficiently. Drainage from Coole however is ultimately halted at Caherglassaun. This turlough, which reached a record depth of 14.6m in 2015, is a natural drainage basin without a suitable surface outlet. Thus the vast majority of water moving downgradient of Caherglassaun is routed through a network of constricted subterranean conduits.

Down-gradient of Caherglassaun, flooding reoccurred at Cahermore and Caherawoneen depressions. Again, 2015 saw record flood levels which inundated several properties and thus prompted the excavation of an overland channel to link Cahermore and Caherawoneen with Kinvara. This channel allowed an additional surface drainage of over 5m^3/s (as measured by OPW Regional Drainage Office, Headford) to augment the pre-existing intertidal discharge from the Kinvara Springs.

Future prospects

Targeted remediation measures have the potential to reduce the local risk of flooding in the catchment. The means by which this is accomplished is to either shift floodwaters downstream more rapidly, or transfer floodwaters into another catchment. However, both effectively lower the flood risk in one area at the expense or raising it in another. In response to the 2009 floods, the region was reassessed for potential flood remediation works and a number of engineering proposals were subsequently implemented. These works included a new culvert at Kiltartan and surface drainage restoration works between Coole and Kinvara. However, as the drainage capacity of the catchment is limited by the conduits between Caherglassaun and the sea, it is not possible to fully mitigate flooding without improving the ability for water to get to the coast. The construction of a suitable engineered graded channel was considered for this purpose in 1998 (Southern Water Global, 1998) and again in 2010 (Jennings O'Donovan & Partners, 2011) but was deemed unfeasible on economic (rather than environmental) grounds.

The limited remediation works installed since 2009 has improved drainage locally and would likely reduce the impact of any future 2009-type event. The floods of 2015 however were of a different nature. The protracted rainfall lessened the impact of river flooding and exacerbated the impact of groundwater flooding. Thus while a number of factors have changed since 2009, the increase of cumulative rainfall in 2015 far outweighed any increase in the catchment's drainage capacity. As such, the scope of further works, such the clearing of swallow holes, increasing culvert capacity or altering land management practices, is limited without a significant increase in drainage capacity from Coole and Caherglassaun turloughs. Even impoundment structures, used to delay flow upstream, would shift the flood hazard to upstream areas not previously prone to serious flooding. This approach is also more appropriate for reducing floods linked to peak discharge, rather than the cumulative discharge flooding affecting the Gort catchment. In fact, the turloughs (as well as Lough Cutra) are essentially impoundment structures within the karst system already and they were not sufficient to prevent floods in 2009 or 2015 .

The influence of climate change on groundwater flooding in the region, currently being investigated by Trinity College Dublin, must also be considered. Current climate models project increased winter rainfall in the coming decades, particularly in western Ireland (Nolan, 2015). These seasonal changes may disproportionately affect areas such as the Gort Lowlands and flooding will have a higher likelihood of occurring.

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Groundwater / surface water interactions - are our assumptions right?

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Using a programme of tracer testing to better define the hydrological processes in the geologically heterogeneous catchment of the Nuenna River, Co. Kilkenny.

Looking through some hydrogeology text books one might be forgiven for thinking that the sole purpose of rivers is to receive groundwater discharging from aquifers. Although this is undoubtedly correct in many cases, the relationship can be more complex. Concepts such as bank storage remind us that hydraulic gradients acting between rivers and aquifers can reverse, resulting in groundwater being recharged by surface water. Similarly, natural gradients may be artificially reversed through induced recharge programmes to treat poorer-quality river water by passing it through adjacent aquifer materials to provide purer (ground) water that is more suited to human consumption. In this way, the purifying processes operating at the interface between groundwater and surface water can provide important geo-ecosystem services. Failure to consider these processes may have significant implications for understanding natural processes not in terms of drinking water quality, but for hydrological flow balances across entire catchments.

Despite proven benefits, the interaction of groundwater with rivers has been relatively neglected. Recognition of this knowledge gap by hydrological and hydrogeological communities in recent years has resulted in a significant improvement in our understanding of processes generating exchanges between groundwater-surface water. Nonetheless, the role of these processes in heterogeneous catchments, such as those typically encountered in many parts of Ireland, remains poorly understood. The EPA STRIVE Pathways project aimed to better define hydrological processes in geologically heterogeneous catchments, such as that of the Nuenna River, Co. Kilkenny. Physical and chemical hydrogeological investigations completed in the framework of the project pointed to complex processes operating in the groundwater flowing through the diffusely karstified Lower Carboniferous limestone bedrock that underlies much of the area. Water is discharged from the aquifer via a series of springs downstream of the river's headwaters, with river discharge increasing downstream (as the catchment size increases). By contrast contributions to flow further downstream, where the river passed onto a plain of deep alluvium, proved more ambiguous.

A programme of in-channel artificial tracer tests, employing non-reactive fluorescent tracers and mobile field fluorometers, coupled with point discharge measurements, aimed to characterise this process in greater detail (Figure 1). Three successive tests involved injecting pulses of tracer at increasing distance from the headwaters, while monitoring concentrations at three fixed downstream points. Simultaneous measurement of river discharge at monitoring points permitted comparison of flow rates determined from integration of tracer breakthrough curves, while continuous discharge monitoring confirmed no significant changes in flow rate over the duration of the studies.

Analysis of tracer test results confirmed that flow rates increased from the headwaters to a point where an extensive sequence of deeper alluvium was encountered. However, in contrast

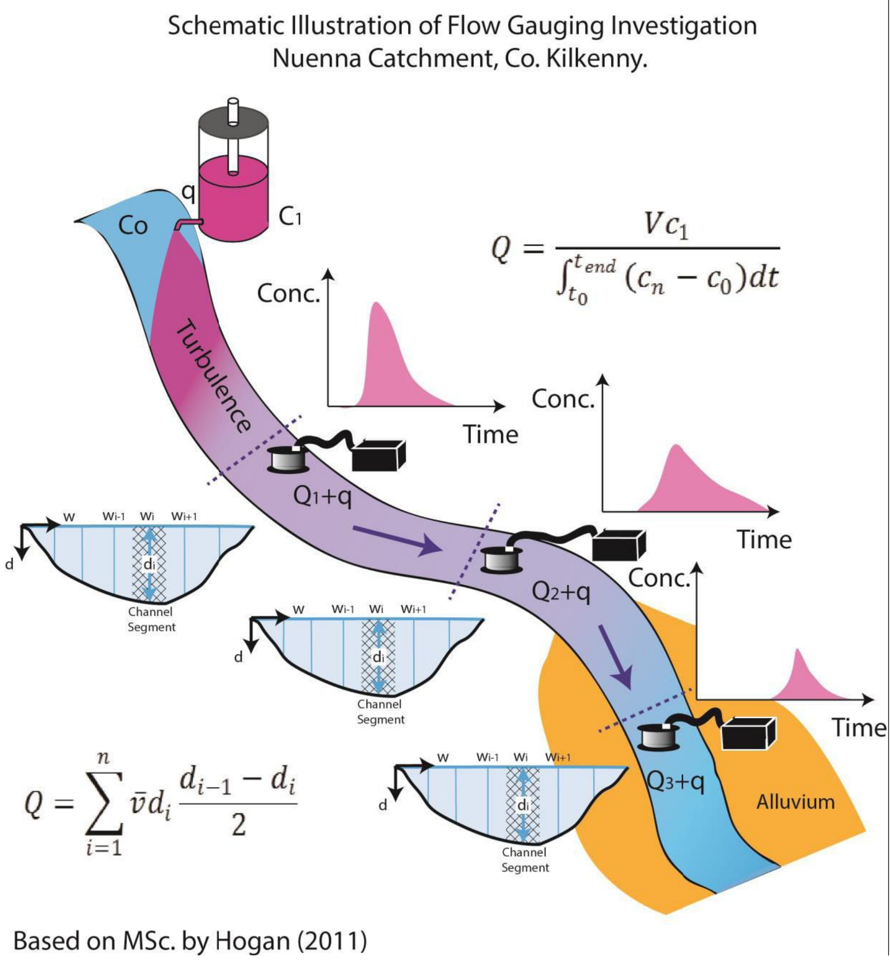

Figure 1: Schematic diagram summarising the results of the tracer tests completed in the Nuenna River, Co. Kilkenny. The addition of a known mass of artificial tracer permits flow to be calculated through mass balance methods at three downstream monitoring points. Flow gauging confirmed the method to be valid at those monitoring points upstream of a thick sequence of alluvium. However, the tracer disappeared as the river flowed further downstream.

to monitoring locations upstream, where rates determined from solute responses and classical flow gauging corresponded, a comparable relationship was not observed where the river flowed across the deep alluvium, nor was a progressive increase in discharge rate observed as the river's catchment increased. Instead, flow measurements indicated that river discharge plateaued as the Nuenna River passed onto the deeper alluvium. At the same time the mass of tracer observed at downstream monitoring points declined progressively, to a point 4.1 km downstream where no tracer was observed, even though the monitoring period exceeded calculated travel times in the river by a factor of three.

Investigation findings suggest that groundwater-surface water interactions in the Nuenna catchment are more complex than simple hydrological models suggest (See Figure 2a). The loss of tracer and near-constant flow rates along the course of the river, once it crosses the area of deeper alluvium, suggest that not all water discharging to the river remains as surface water. Indeed, the disappearance of the tracer points to river water discharging to alluvium, while groundwater discharges from it to the river channel in a dynamic process of surface water/alluvial groundwater exchange (Figure 2b).

The study's outcomes hint at the complexity of groundwater-surface water interactions that may occur in other Irish catchments. Combined flow gauging and tracer testing provides a useful and inexpensive means of investigating these processes. In the case of the Nuenna River, results have indicated that groundwater can flow parallel to a river's overall course in alluvial plains. Failure to consider this process may result in misleading conclusions using flow gauging data derived from fixed discharge monitoring features, as ungauged groundwater can by-passes hydrometric monitoring points at catchment outlets. This in turn can have important implications for catchment flow balances and recharge calculations based upon them, should the quantity of by-passing water be a significant proportion of total flow. As a corollary to this point, results suggest that discharge data from weirs located on permeable deposits should be considered with caution; tracer testing can prove of assistance in investigating this issue.

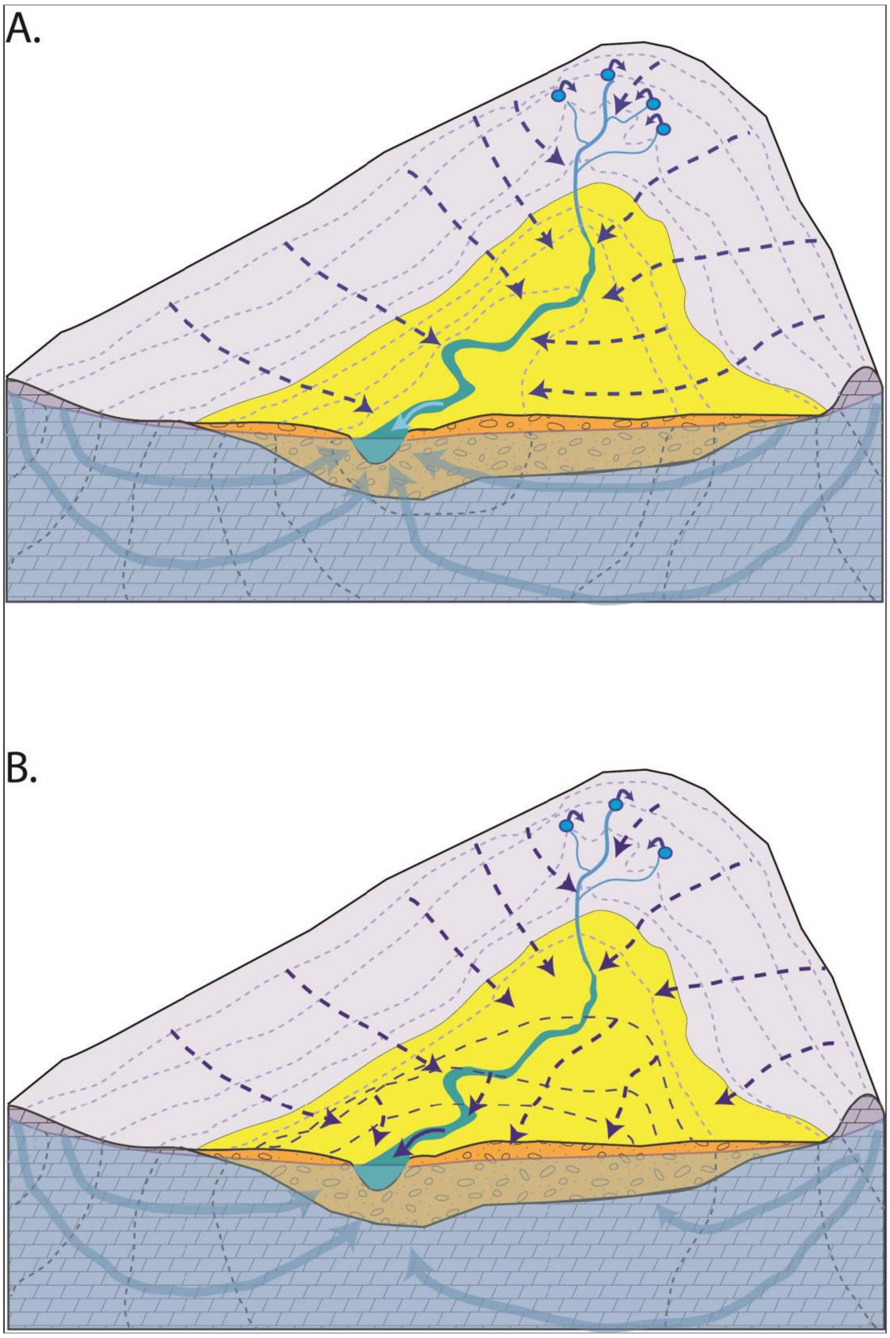

Figure 2: Groundwater surface water exchange (a) Classical model in which all groundwater discharges to the river. (b) Proposed modified model based on tracer test results. The latter model shows groundwater in the alluvium flowing parallel to the overall river course and actively exchanging water with the river as it flows downstream.

Localising and assessing groundwater discharge to lakes using natural environmental tracers

Jean Wilson, Department of Botany, Trinity College Dublin

Using temperature and Radon as natural environmental tracers in the first step in quantifying the role of groundwater in lake water and nutrient budgets. Examples from Loughs Owel and Ennell, Westmeath.

Introduction

Nearly all surface water features interact with groundwater which means that pollution of surface water features can cause deterioration in groundwater quality and conversely, contamination of groundwater can degrade surface water systems. Groundwater-surface water interactions therefore may significantly impact water chemistry, water quality, biology and ecology and recent studies identify groundwater inputs as one of the main drivers of eutrophication in lakes (Shaw et al., 2013). Despite acknowledgement of its potential impact, groundwater discharge and associated nutrient loading to lakes remains a poorly-understood and often overlooked process particularly when implementing water monitoring and management programmes in Ireland. This is because groundwater discharge is spatially and temporally heterogeneous which renders locating and quantifying groundwater inputs an extremely difficult and challenging task.

Groundwater discharge is a potentially significant source and pathway of freshwater and nutrients to lakes with implications for the type and extent of monitoring required to fulfil national and international environmental policy objectives such as those defined as part of the EPA's Integrated Catchment Management (ICM) strategy to achieving second cycle Water Framework Directive targets. ICM necessitates a holistic and integrated approach to the management of land, biodiversity, water and community resources at the catchment scale (Williams, 2012) which requires catchments to be viewed in three dimensions to facilitate a full and complete understanding of where water comes from and how it moves above, below and through the landscape (Daly et al., 2014). This calls for efficient tools to evaluate groundwater as a pollution source within a catchment and requires knowledge of the sources of groundwater contamination and associated transport pathways as well as the geochemical processes occurring along these pathways that control the absolute nutrient flux to surface waters (Crow and Meek, 2009).

Here, the application of two natural environmental tracers, temperature and radon, to localise and qualitatively assess groundwater discharge to lakes, is illustrated. This work comprises the first step towards more in-depth and subsequent quantitative investigations that clarify the role of groundwater in lake water and nutrient budgets (Lewandowski et al., 2015). The approach is demonstrated for two

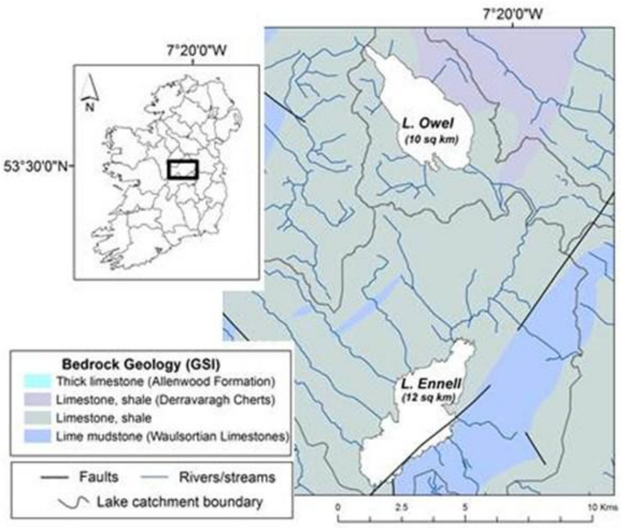

Figure 1: Location map of the study are illustrating Loughs Owel and Ennell, Co. Westmeath and underlying bedrock geology sourced from the GSI.

lakes in Westmeath, Lough Owel and Lough Ennell (Fig. 1).

Using temperature as a tracer for groundwater discharge

Temperature has been used very successfully to study groundwater discharge to lakes by comparing the relatively constant temperature of groundwater with that of surface waters which fluctuate with season (Wilson and Rocha, 2016). In Ireland, during summer months, groundwater discharges manifest in satellite imagery as cool thermal signals relative to receiving waters (Wilson and Rocha, 2012). Surface water temperature patterns were generated from publically available Landsat thermal imagery[1] and used to localise potential groundwater inputs to Loughs Owel and Ennell captured as cold anomalous plumes visibly emanating from lake margins (Fig. 2).

For Lough Owel (Fig. 2 (a)), the temperature map clearly isolates a cool thermal plume adjacent to the eastern shoreline; while for Lough Ennell (Fig. 2 (b)), the pattern of surface temperature appears to be linked to inflow from streams and a large fault (which may also be facilitating the flow of groundwater into the lake) along the eastern shoreline. The temperature maps illustrate the degree to which remote sensing of heat emission from water surfaces can inform a study seeking to localise (potential) groundwater inputs to lakes. Conclusive statements on the presence, magnitude and significance of groundwater discharge however cannot be made using remote sensing alone – the results must be verified and validated with support from quantitative tracers.

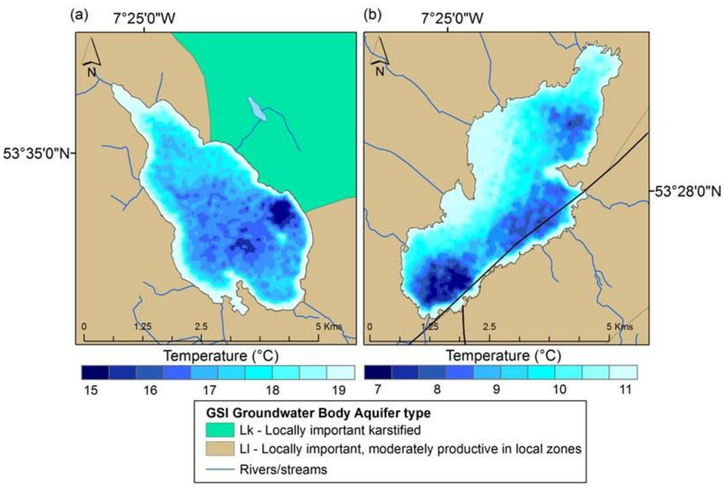

Figure 2: Surface water temperature maps generated from Landsat thermal imagery acquired for (a) Lough Owel on July 20th 2013 and (b) Lough Ennell on April 18th 2014.

Using radon as a tracer for groundwater discharge

The distinctive and measurable difference that exists between radon concentrations in groundwater relative to surface water is the fundamental basis for using radon to trace groundwater discharge to lakes. Radon is present in most rocks and dissolves into groundwater held within aquifers. It is a radioactive and conservative gas with a half-life of 3.82 days. When radon-rich groundwater is exposed to the atmosphere, any radon present degasses immediately which produces sharp concentration gradients at the groundwater-surface water interface. Sources of lake radon include inputs from direct groundwater discharge i.e. seepage from the aquifer; indirect groundwater discharge i.e. the groundwater component of discharging rivers or streams; and sediment diffusion. Radon losses from the lake include atmospheric degassing and radioactive decay.

Surface water radon activity concentrations were measured during one-day surveys of Owel and Ennell to expose radon "hotspots" as localised groundwater sources/entry points. We use spatial analyses to qualify radon as an effective means to localise and follow groundwater inputs across lakes. Measured radon activity concentrations were plotted using GPS data recorded concurrently during the surveys and interpolated within a GIS to produce maps of the spatial distribution of lake radon activity (Fig. 3). The results confirm the presence of groundwater in both lakes; radon activity levels are within the range of values reported for lakes elsewhere

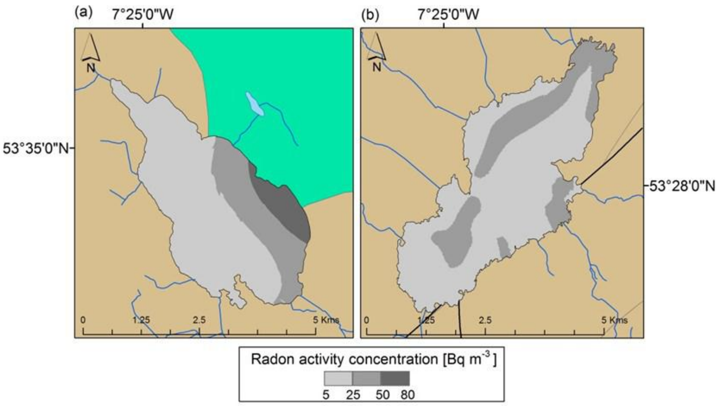

Figure 3: Lake radon activity concentrations (becquerel per metre cubed, bqm-3) recorded for (a) Owel and (b) Ennell on April 1st 2014 and 19th March 2015 respectively.

(Dimova et al., 2013). The maps highlight elevated radon activity values along lake margins and reveal an internal groundwater source (spring) within Ennell.

To help develop simple conceptual flow models of how groundwater and surface water is interacting with lakes, the temperature and radon data are mapped with information describing lake physical characteristics including local geology, presence of surface water features and faults for example. Furthermore, to ensure that the most dominant and consistent pattern of groundwater inputs evident from the radon data are revealed as well as providing a means for between lake comparisons, standardised radon anomaly[2] values were calculated and mapped.

The data for Owel (Fig. 4 (a)) show that the greatest radon anomaly values are associated with groundwater inputs from the eastern shoreline which positively correlates with the temperature data for the lake generated from satellite imagery (Fig. 2(a)). Both tracers reveal an anomaly at this location and clearly highlight a direct groundwater entry point to the lake. Moreover, research completed by Groves (2009) identified regional groundwater flow paths into Owel as well as karst features that included a spring; which positively correlate with the radon anomaly data produced as part of this study (Fig. 5).

Limitations to the use of temperature and radon as tracers of groundwater discharge

Advances in remote sensing provide a relatively inexpensive tool with which to detect thermal signals that can be used to develop our conceptual understanding of the flow mechanisms operating in a lake. This holds true so long as the imagery acquired has sufficient spatial resolution to resolve temperature gradients that might reveal cold water plumes potentially linked to the inflow of groundwater. While it is acknowledged that high resolution thermal data obtained from other systems including aircraft sensors, drones or Unmanned Aerial Vehicles (UAVs) for example might further elucidate temperature differences beyond the capability of Landsat; these systems while effective would be cost-prohibitive in terms of their use and application as part of national assessments of groundwater-lake interactions.

The radon survey measurements successfully identify locations and relative amounts of groundwater inflow to Owel and Ennell. The data as presented though does not quantitatively distinguish between direct groundwater discharge from the aquifer and indirect groundwater discharge from groundwater-fed surface water inputs. However, evaluating the potential occurrence and understanding where groundwater

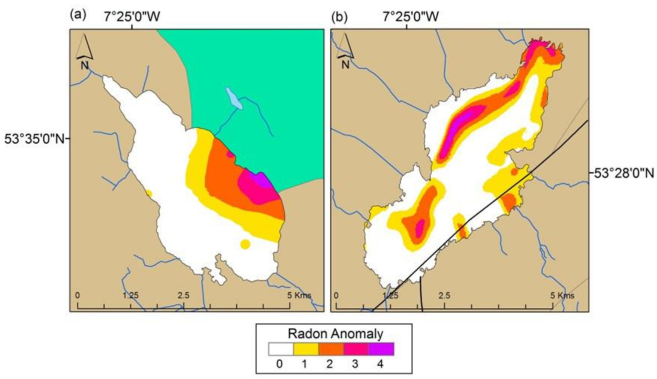

Figure 4: Standardised radon anomaly values clearly highlight groundwater entry points along lake margins as well as internal sources of groundwater to (a) Lough Owel and (b) Lough Ennell.

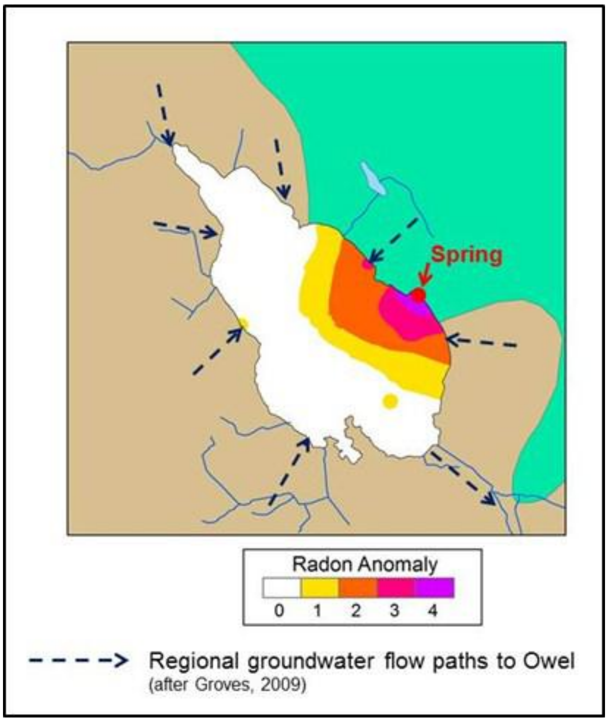

Figure 5: Comparison of radon anomaly values from a survey of Lough Owel completed April 1st 2014 and output from a hydrogeological investigation to map karst features (springs) and regional groundwater flow paths by Groves (2009).

discharge occurs using temperature and radon as tracers, is a significant step towards addressing knowledge gaps that presently exist in terms of evidence-based information on groundwater-lake interactions in Ireland. Moreover, subsequent quantitative estimates of groundwater discharge can be completed using additional radon measurements as part of mass balance approach. Further information on the application of radon as a quantitative tracer of groundwater discharge to lakes completed as part of the CONNECT project (2012-W-MS-13) is available to download from EPA Safer[3].

Acknowledgements

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[1] Landsat data is available to download from USGS GLOVIS http://glovis.usgs.gov/

[2] Standardised radon anomaly (dimensionless) is the difference between radon activity at each sample point on the lake and the average radon activity across the lake, divided by standard deviation.

[3] http://erc.epa.ie/safer/iso19115/displayISO19115.jsp?isoID=3085

Getting the pathogens out of groundwater - how, why and where

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The important roles of the physical and chemical characteristics of a groundwater system for the removal of pathogens.

Few people relish the thought of having to drink contaminated water. In fact if you told most people that there were pathogenic microorganisms in their supply they would be concerned - and rightly so. Despite significant advances in recent years, the World Health Organisation estimates that in a typical year over 1.5 million people die worldwide as a result of consuming contaminated water, while the number who suffered acute illness from pathogens, salmonella, cryptosporidium etc., is considerably higher.

Although the burden of waterborne illness falls mainly on developing countries, outbreaks across the EU and North America demonstrate that nowhere can consider itself immune. A limited number of focused investigations, typically following catastrophic disease outbreaks, show that most waterborne illness can be related to contaminated surface water supplies, while groundwater is generally considered safer. But why? The general view taken by many is that it takes much longer for contaminants to enter groundwater supplies; given sufficient time, pathogenic microorganisms adapted to the warm, nutrient-rich conditions of the innards of warm blooded animals cannot survive in harsher subsurface environments and they gradually lose their capacity to cause infection. Rules of thumb adopted in many countries aimed at protecting groundwater supplies, use this concept and assume that during periods of between 30 days and 100 days after existing host organisms (including people,) die-off leads to pathogen free water.

So, problem solved! Disinfection of water supplies requires pollutants with pathogens to take longer than 100 days to reach a drinking water supply? Travel times longer than this will result in clean water? Unfortunately this is not strictly speaking true, and in fact other processes typically play a more important role in keeping our groundwater clean. Experiments that involve passing contaminated water through saturated sands show that the sands can remove significant proportions of total suspended loads, including microorganisms, in short periods of time - much shorter than the time taken for suspended pathogens to die off. So something else is at play. But what? Filtration is an obvious candidate. It is easy to think of microorganisms getting caught between sand grains while water flows on. However, a reality check is in order. When we consider the differences in size between microorganisms and sand pores this mechanism doesn't appear so effective. For example, if we take a 1mm diameter pore and a typical bacteria-sized particle (1µm), calculations show that passing a bacterium through this would be the equivalent of throwing a tennis ball though the open doors of an aircraft hangar. It's even more extreme with smaller particles, like viruses (with diameters 10s of nm), where it would be akin to the ball passing through a $1km^2$ opening – and yet the microorganisms are removed. In fact more viruses are removed than bacteria. Even more surprisingly comparably-sized microbes are often removed differently.

These issues have been the focus of laboratory-based research for some years. Investigations have shown that microorganism removal arises because of a number of inter-related factors, of which the biology of the microorganism is but

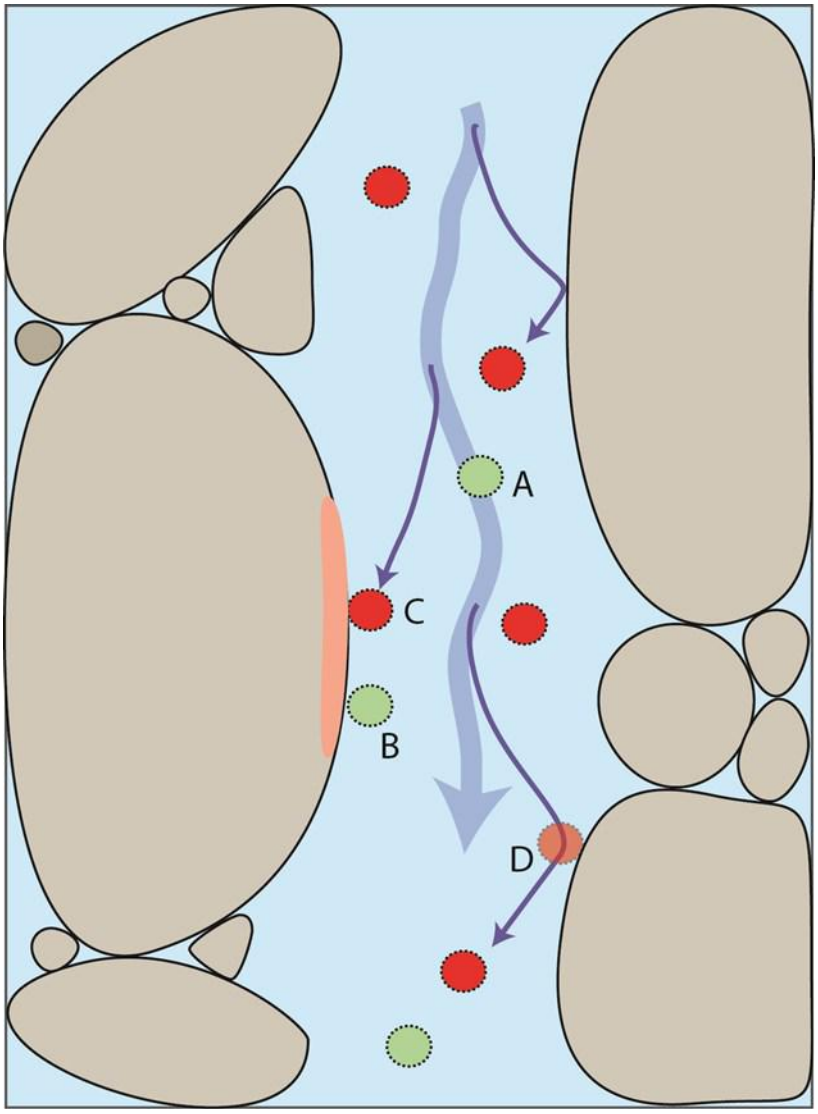

Figure: Schematic diagram summarising the processes that influence micro-organism attenuation in aquifers. Red circles represent microorganisms capable of infection, while green circles represent those no longer capable of infecting. Although the well-known (A) loss of infective capacity in suspension can contribute to the capacity of aquifers to disinfect water, (B) comparable process acting on pathogens deposited on aquifer surfaces can also play a role. Deposition onto aquifer surfaces is perhaps the most critical process that is overlooked. This can be (C) irreversible, or (D) reversible, depending on the chemical conditions in the system.

one. In fact when we factor this out and consider microorganisms as colloid-sized abiotic particles we see that removal is strongly influenced by the inter relationship between flow dynamics, particle size, particle surface chemistry, the filter characteristics (matrix grain size and surface chemistry) and the chemistry of the water transporting the particles. What is surprising for many in this whole process is the importance of chemistry. In fact it is fundamental and forms a critical element of the filtration theory that explains the removal of microorganisms, while accounting for all the physical and chemical variables listed. In short the theory considers removal in two stages; particles up to five microns mainly collide with grain surfaces through Brownian motion (in which smaller particles move around in suspension more than larger particles). The frequency of collision is dominated by the physical characteristics of the system. On the other hand, not all collisions are successful. The probability of the particles sticking is expressed by a term dominated by the chemical characteristics of the system. Combining both terms provides a time-dependant rate at which microorganisms are removed by filtration.

Laboratory studies are all very well, but they are typically completed under highly controlled and homogeneous conditions – a far cry from the situation encountered in natural deposits, and aquifers in particular. As hydrogeologists we know that compositional and textural heterogeneities operate across a range of scales and complicate matters. However, all is not lost. Tracer tests in sand and gravel aquifers show that filtration theory can work and that it can be used to predict attenuation in natural deposits. In fact, studies in Germany and Switzerland have shown that assumed travel times from (the main) sand and gravel aquifers were over 100 times faster than expected; rates of microorganism removal were, as a result, much lower. And yet the water was relatively clean, despite the presence of numerous contamination sources. In fact, study results showed that internal aquifer structure and the properties of the overlying deposits played a critical role in protecting water quality. More detailed examination showed fine grained units separated the main productive horizons in the aquifer from pollutant sources and helped to prolong travel times. This in turn facilitated both increased filtration, and the loss of infective capacity in microorganisms.

So all this work in Germany and Switzerland, is it relevant to Irish aquifers? Examination of outcrops of sand and gravel aquifers across the country give reason to believe that a comparable investigative approach to that followed on mainland Europe could provide valuable insights to the threat posed by pathogens (and other pollutants). After all, the same fundamental principles controlling attenuation apply. On the other hand, most of Ireland's groundwater resources come from bedrock aquifers. Predicting processes and responses in fissured units are a different matter and really up the ante for determining attenuation. Filtration theory has been developed for granular systems. Transport through fissures, is not explicitly considered, yet the same fundamental concepts of collision frequency, coupled with the chances of particles sticking to aquifer surfaces, appear appropriate. In fact, field investigations confirm this and show that attenuation by a form of filtration can also occur in fissured (karstified) rock, which assists in protecting water quality. Unfortunately, results indicate that microorganisms removed from suspension can take longer to lose their capacity to infect. (Comparable processes have been observed in soils, where bacteria, indicative of faecal pollution, have been shown to survive for more than a year.) This would not be problematic, were it not for the fact that these microorganisms can be released back into water, long after the source of pollution has gone should the chemistry of the groundwater change, as is often the way in karst. Once again, artificial tracer tests completed by our Swiss colleagues have noted just this.

All of these studies show that the geo-ecological services provided by rocks and soils in purifying our water supplies should not be taken for granted. More to the point, a one-size-fits-all approach does not apply to the removal of pathogens from drinking water supplies. The capacity of the ground to remove pathogens before they reach wells or springs forms an important means of providing safe water to consumers with significantly reduced monetary and environmental costs. As land use intensifies across Ireland in years to come, understanding this topic more deeply shows considerable promise to help provide clean water to consumers in a more sustainable way.

If you would like to know more about the research behind this article the following two papers may be of interest:

Flynn R. and Sinreich, M. 2010. Characterisation of virus transport and attenuation in epikarst using short pulse and prolonged injection multi-tracer testing. Water Research, Vol 44 (4), 1138-1149.

doi:10.1016/j.watres.2009.11.032

Flynn, R., Mallen, G., Engel, M., Ahmed, A. and Rossi, P. 2015. Characterizing Aquifer Heterogeneity Using Bacterial and Bacteriophage Tracers. Journal of Environmental Quality, Vol 44 (5) 1448-1458.

doi:10.2134/jeq2015.02.0117

Groundwater pathogens and disease: viruses

Paul Hynds, Dublin Institute of Technology

This article is the second of a series of three that describe the different pathogens that can impact on groundwater sources in Ireland. The first (on bacteria) was published in Issue 51 of the newsletter.

Introduction

The current article, the second in a series of three, provides a review of viruses as potential groundwater contaminants, their sources, pathways and subsequent potential human health effects. Previous groundwater related viral outbreaks are discussed, with analytical methods also outlined.

Human enteric viruses are causative agents for many non-bacterial gastrointestinal tract infections in both developed and developing regions (Okoh et al., 2010). There are over 140 distinct known types of human pathogenic virus (Gray, 2004), with those of most concern being the enteric (gut-associated) viruses which cause gastrointestinal illnesses (Sellwood & Dadswell, 1991; Oliver et al., 2003). From a public health perspective, the three most commonly diagnosed water-borne enteric viruses are rotavirus, adenovirus and norovirus.

Rotavirus

Rotavirus is a double-stranded RNA virus (taxonomic family Reoviridae) and the most common global cause of severe diarrhoea in infants and young children (Glass, 2006). It is highly resistant in the natural environment and may be found in groundwater contaminated with faeces from infected humans i.e. ingress from broken sewage systems, domestic wastewater systems, etc. (Macler & Merkle, 2000; Borchardt et al., 2011). Previous studies (Azadpour-Keeley & Ward, 2005) have found that enteric viruses can survive for weeks in groundwater environments; Sobsey et al (1995) previously reported little, if any, inactivation of viruses in samples from a deep well in North Carolina over an 8-week period.

Rotavirus associated gastroenteritis is primarily seen as a pediatric illness, with symptoms including vomiting and watery diarrhea; Glass (2006) reporting that in the absence of rehydration therapy, an infected child may lose up to 10% body weight over a 24-48-hour period. Infections typically occur during winter epidemics with high levels of secondary (person-to-person) transmission (CDC, 2006). As few as 10 viral particles are enough to cause symptomatic illness. Waterborne outbreaks associated with contaminated wells have been reported by Kukkula et al. (1997), Frost et al. (2002), Gallay et al. (2006) and Koroglu et al. (2011). There is a documented seasonal pattern in Ireland associated with rotavirus infection, with peaks typically occurring in early spring, in concurrence with the lambing season (Craun et al., 1997). During the 6-year period 2004-2009, the overall incidence of notified rotaviral infections in Ireland remained relatively constant, with an average of 2000-2500 notified cases per year. However, as noted by Coffey et al. (2007), this is almost certainly a small proportion of the total number cases of infection as most patients probably do not seek medical attention.

Norovirus

Norovirus is an RNA virus (taxonomic family Caliciviridae) , identified as the leading cause (≈90%) of epidemic non-bacterial outbreaks of gastroenteritis, both globally (Lindesmith et al., 2003) and in Ireland (Kearney et al., 2007).

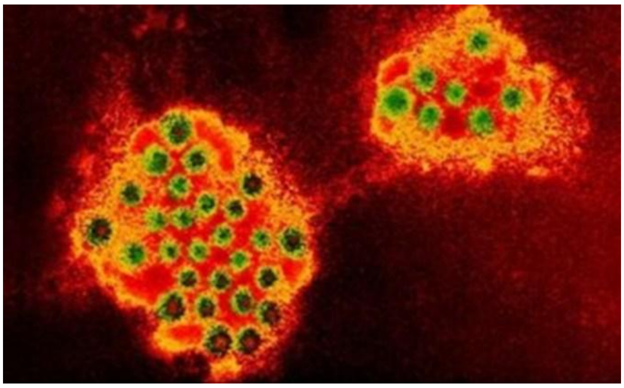

Figure: Norovirus GII (the most prevalent strain in Ireland) under a scanning electron microscope (SEM)

Contamination of drinking water is primarily linked to sewage or human faeces (Nygard et al., 2003; Said et al., 2008; Lee, 2011; Giammanco et al., 2015), with outbreaks frequently associated with "closed-communities" i.e. hospitals, retirement homes, crèches, cruise ships, etc. (Gallimore et al., 2005).

Norovirus (previously called Norwalk-like viruses and more commonly known as the "winter vomiting bug") causes gastroenteritis in all age groups (Coffey et al., 2007). The disease is usually self-limiting, and characterized by nausea, vomiting, diarrhoea, and abdominal pain. General lethargy, weakness, muscle aches, headache, and low-grade fever may also occur (Zheng et al., 2010).

Consumers drinking water from a contaminated well in central Wyoming, suspected as having been contaminated by sewage, were found to be 4.5 times more likely to present with gastroenteric symptoms than those who had not consumed from the well (Parshionikar et al., 2003). Manuala et al. (2005) report that most norovirus contamination events occurring in Finland are attributable to groundwater, with almost 50% of groundwater outbreaks associated with private water wells. Reporting on a norovirus outbreak associated with a private well in a dolomite aquifer in northeast Wisconsin, Borchardt et al. (2011) found that 229 restaurant patrons were affected during the incident, which was positively confirmed as being due to ingress of septic tank effluent to a nearby private well. A water-associated outbreak at a hotel in the west of Ireland in 2001 resulted in 462 illnesses (Coffey et al., 2007). Recent figures indicate that approximately 1% of the Irish population will contract noroviral infection during a typical winter season, with this rising to 3-5% during particularly high periods (HSPC, 2014).

Adenovirus

Adenoviruses are double-stranded DNA viruses comprising at least 51 distinct serotypes, one third of which are capable of causing human infection (Mena & Gerba, 2009). A recent study found that adenovirus remained relatively stable in seeded groundwater at 10oC for at least 160 days and up to 301 days (Rigotto et al., 2010). This is a concern, as 10^{o}C is comparable with annual mean groundwater temperatures in Ireland. The same study found an approximate 1-log (90%) adenovirus reduction after 160 days at 19^{o}C.

Outbreaks of adenovirus-associated respiratory disease are more common in the late winter, spring, and early summer; however, adenovirus infections can occur throughout the year (CDC, 2010), with children and the immune-compromised generally more severely impacted by adenovirus infections (Mena & Gerba, 2009). Studies have shown that adenoviruses survive longer in water than other viruses (Ogorzaly, 2010). Two notable drinking water outbreaks associated with adenovirus have been documented in Finland (Kukkula et al., 1997) and Albania (Divizia et al., 2004), with Mena & Gerba (2009) reporting that adenovirus is responsible for more recreational waterborne outbreaks than any other enteric virus. The waterborne adenovirus reported by Kukkula et al. (1997) is of particular interest; ingress of contaminated river water into a well was found to be the source of the outbreak. In all, 1500-3000 people, accounting for 25-50% of the affected community, were infected. Laboratory findings confirmed adenovirus as a causative agent.

Laboratory Analysis

The primary challenge posed by viral contamination of groundwater sources, is that viruses are typically present at relatively low concentrations; thus very large samples (10-100L) are required for isolation. Additionally, a specialised concentration step (adsorption-elution, precipitation or ultrafiltration) is needed prior to isolation and detection. Moreover, previous research has found that faecal indicator organisms (faecal coliforms, E. coli, intestinal enterococci) are not good indicators of enteric virus presence or quantity (Gerba et al., 1979; Ferguson et al., 2012). Accordingly, clinical samples, particularly stool samples, are the main target for analyses and subsequent waterborne virus data collation.

There are currently three primary analytical methods used for viral detection and quantification, namely; plaque assays, immunological detection and molecular detection methods. Viral plaques are visible viral structures formed within nutrient media (e.g. agar) containing specific bacterial cultures. Viruses replicate and spread in the media, generating regions of bacterial cell destruction called plaques. These plaques are visible and may be easily counted, allowing for virus quantification; however, this method is labour-intensive, requires the filtration of very large samples and takes up to 7 days. Additionally, only one virus type may be targeted using this method. The majority of immunological methods for enteric viruses are based on antigen (substances evoking antibody production) detection and employ a number of technologies including enzyme immunoassay, latex agglutination, or immune-chromatography. A number of commercial products have been developed and are available for the detection of enteric viruses in suspended stool samples; however, to date, no similar immunological techniques have been developed for analysis of potentially contaminated water samples, due to the aforementioned likely low viral concentrations.

Typically, molecular techniques rely on detecting specific RNA sequences, representing improved specificity and sensitivity. Molecular techniques allowing the amplification of target RNA sequences, particularly reverse-transcriptase polymerase-chain reaction (RT-PCR), have advanced enteric virus detection; particularly in non-clinical (i.e. water) samples, although elution and filtration are still necessary. RT-PCR is capable of detecting a single virus within 24 hours and has the advantage of allowing for quantification. Multiplex PCR methods have been developed that allow the detection of more than one virus type, in the same assay.

Summary

To date, no waterborne viral outbreaks associated with groundwater usage or consumption have been reported in Ireland. However, this is not surprising as it is likely that the majority of infected consumers do not seek medical attention. Further, where medical advice is sought, in the absence of routine stool sample analysis, misdiagnosis may be common, therefore the health burden is likely to be underestimated, particularly as viral illnesses are typically self-limiting in healthy adults. As set out above, viral contamination of groundwater sources has been commonly reported in both developed and developing countries, leading to both endemic and epidemic conditions. Therefore, it is recommended that well users suffering from potential viral symptoms seek medical advice and inform their medical practitioner of their drinking water source and discuss the likelihood of viral contamination and infection, particularly if young children or elderly residents are using the same source.

References are given in the text.

Private wells, groundwater vulnerability and public health

Paul Hynds, Dublin Institute of Technology

Investigations into confirmed VTEC infections in Republic of Ireland show a higher level of concurrence with their likely receptor (private well), than with their likely source (cattle).

Ireland is a country characterised by a high (and longstanding) reliance on private water wells and on-site domestic wastewater treatment, a highly dispersed yet relatively dense rural settlement pattern (Scott & Murray, 2009), a unique agricultural profile and diverse localised (hydro)geological settings. This has resulted in the development of an almost "perfect storm" with respect to potential groundwater contamination and subsequent waterborne human infection. Recent reports indicate significantly (and consistently) increasing rates of verotoxigenic E. coli (VTEC) infection within the national population over the past decade, and cite a likely association between confirmed cases and previous exposure to private wells (Garvey & McKeown, 2011; Garvey et al., 2015). Moreover, recent work estimates that Irish private well users are significantly (5-6 times) more likely to acquire a symptomatic VTEC infection than their urban counterparts (Hynds et al., 2014). Similarly, a recently completed study of 989 laboratory confirmed VTEC infections in the Republic of Ireland during the 6 year period 2008-2013 has found that while geo-referenced infections were significantly associated with cattle density as expected, an

Figure: Left: A poorly protected hand-dug well in Co. Offaly; Right: A well protected borehole with 275mm groundwater clearance in Co Offaly.

even more significant association resulted between infection occurrence and locally derived private well density. Thus, results demonstrate that a majority of infections are waterborne and exhibit a higher level of concurrence with their likely receptor (private well), than with their likely source (cattle). The aforementioned study is the first to directly examine the incidence rate of confirmed infections as opposed to the likelihood of infection based upon groundwater quality. Additionally, it is important to remember that waterborne human infection also carries with it an economic cost; a previous Canadian study (Majowicz et al., 2006) suggests that a single case of gastroenteritis incurs a mean total cost of €715-965 when all associated expenses are considered (doctors visit(s), medication, days absent from work/school, etc.). (Study figures have been updated to account for currency and inflation).

However, it's not all bad news; an increased appreciation of the potential health effects associated with private wells has led to a marked increase in associated research over the past 8-10 year period (Bacci, 2011; Hynds, 2012; O'Dwyer, 2014; Morrissey, 2014; Fennell, in preparation). Thus, our understanding of the mechanisms of private well contamination, the likely human health effects and, subsequently, evidence-based approaches to both groundwater and source protection are also increasing.

Recent work carried out in Trinity College Dublin strove to elucidate the mechanisms of private well contamination in Ireland, in addition to quantifying the effect of well user awareness on contamination probability and the overall human health burden attributable to well contamination in Ireland (Hynds, 2012). The study assessed 262 private wells located within 6 geologically distinct study areas; one of the primary findings was that 70-80% of contamination occurs at and is driven by factors at the "local scale" i.e. contaminant sources and pathways are specific to the individual receptor (i.e. well) and its immediate zone of contribution. Thus, generalised contamination of all or part of an aquifer is relatively rare in Ireland. Additionally, and perhaps counter-intuitively, higher rates of contamination were found in categorically Low vulnerability areas (45%) than in High/Extreme vulnerability areas (11-44%). Thus, in terms of individual private sources, groundwater vulnerability classification is just one of a number of variables which should be considered when assessing contamination likelihood.

Based on the collated data, several (n = 11) "source susceptibility" models were developed for various well clusters and classifications (i.e. boreholes, hand-dug wells, wells situated in Low, High and Extreme groundwater vulnerability categories). Source susceptibility was defined as a measure of the likelihood of an individual source (well) being contaminated based upon all potential contamination drivers (e.g. climate, well location, construction and maintenance, local hydrogeological setting and contaminant sources). Perhaps of most interest was the fact that all finalised models included "source-specific" wellhead variables as contamination predictors. These included the presence of a secure wellhead boundary, the presence of an appropriate wellhead cover, adequate well liner clearance above ground (or chamber floor) level and the overall level of on-site and wellhead maintenance. Accordingly, irrespective of climate and local geological setting which are obviously beyond the well owners control, there are several "alterable" well-specific variables that can be improved to reduce the likelihood of contaminant ingress. Moreover, model interpretation suggests that, depending on geological setting, antecedent precipitation periods (i.e. precipitation volume occurring locally over a defined period prior to groundwater sampling) of 120 hours (Low vulnerability) to 30 days (High/Extreme vulnerability) were significantly associated with the presence of contaminants. Thus, it is recommended that water quality testing be carried out at least five days after significant cumulative rainfall. A survey of well owners found that water quality testing had not previously been carried out in approximately 40% of cases and where it had been undertaken, a large proportion of testing was undertaken less than once per year. It is worth noting that temporal sampling of 15 selected wells (33% of which were heavily contaminated upon initial sampling) found that 93% of wells exhibited heavy contamination at least once during a 21-month period, thus highlighting the temporary (and perhaps superficial) nature of "one-off" testing. Furthermore, the significance of shorter antecedent precipitation periods in Low vulnerability areas suggests that rapid contamination mechanisms dominate in these areas and are associated with surface runoff (i.e. appropriate above ground wellhead construction particularly important), while slower infiltration and recharge processes dominate in High/ Extreme vulnerability areas. Accordingly, results indicate that a somewhat counter-intuitive interpretation of the groundwater vulnerability index may be appropriate when considering individual unregulated water wells in Ireland. This is due to likely inadequate well head protection that allows surface runoff to enter the borehole.

Research carried out at the University of Limerick aimed to assess private well vulnerability to E. coli contamination in the Midwest region of Ireland (O'Dwyer, 2014). In total, 132 private wells were sampled three times over the study period (1 year) and an assessment of potential predictors (n = 15) of vulnerability was assessed under three categories: Intrinsic (environmental), Specific (land usage) and Infrastructural (well design). Corroborating the aforementioned Trinity College study, the variability of private well vulnerability was complex with several predictors found to be conducive to E. coli contamination including soil permeability, rainfall (mm), cattle and septic tank density in addition to the depth (m) and type of well. At a well user level, it was found that in general, the level of knowledge of well infrastructure and maintenance was low; 29.5% (n = 39) of households were unaware of the depth of their well and only 30.4% (n = 40) of participants had their water tested previously. However, subsequent to testing, 23% of participants (n = 30) went on to install a treatment system, offering an optimistic viewpoint for future public engagement and education.

Previous and ongoing studies have and will offer valuable insights into pathogen ingress mechanisms associated with private water wells, as well as social awareness and stewardship. Further work is needed in relation to microbial source tracking, geostatistical analysis of waterborne infection and modelling the effects of a changing climate on groundwater resources. Access to clean, safe drinking water is fundamental for a healthy population, both socially and economically; thus every effort should be made to safeguard this extremely valuable natural resource for current and future generations.

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New Research in Hydrogeology

This section of the Irish Groundwater Newsletter contains summary reports on hydrogeological research being carried out in Ireland. Due to the multi-institutional nature of many of the projects there is an inevitable overlap between some of the reports. Many thanks to the individuals who coordinated the reports from each institution. If you know of research which should be included please contact the editors at groundwaternewsletter@gsi.ie.

Summary of Groundwater research spoke

The new Irish Centre for Research in Applied Geosciences (iCRAG) was established in 2015 by Science Foundation Ireland (SFI) with funding of €18m along with an additional €8m from industry partners. The overall aim of iCRAG is to transform applied geoscience research in Ireland, delivering economic impact for a broad range of application areas and industries.

The iCRAG research programme spans a spectrum of application areas linked to Applied Geosciences. Research 'spokes' in Raw Materials, Marine, Groundwater and Hydrocarbons are built around four enabling 'platforms' within the iCRAG Hub, including Geophysics, Geochemistry, 3D Model datasets

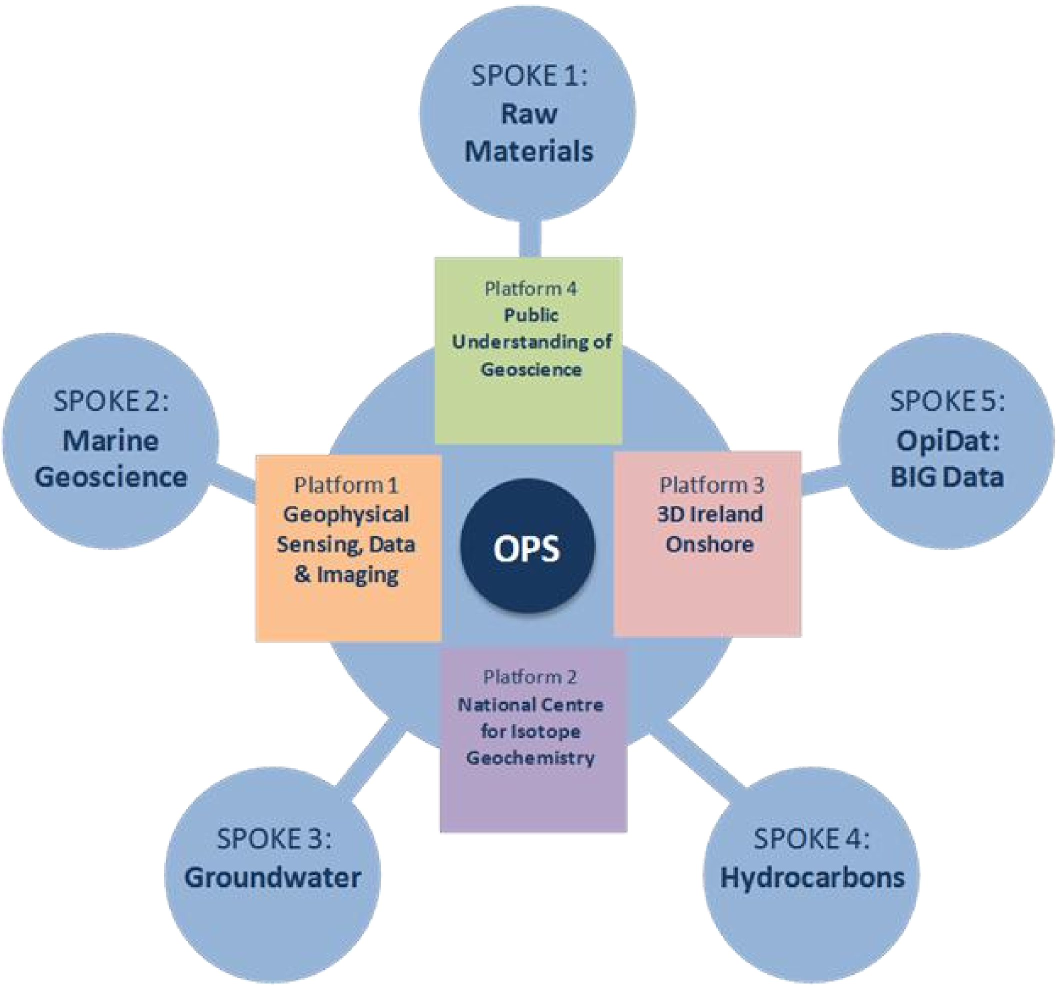

Figure: iCRAG structure of hub and spoke activities.

and Public Perception/Understanding (see Figure 1). Spokes were selected to build on demonstrable islands of scientific excellence and to leverage the maximum economic impact for Ireland. The Centre structure will promote the exchange of ideas, data and methodologies between and within spokes and platforms, with cohesion derived from shared analytical and modelling techniques and pervasive cross-cutting themes such as fluid flow, rock deformation and sedimentation.

The groundwater research spoke is being led by Laurence Gill (TCD) and Frank McDermott (UCD), with other Principal Investigators being Bruce Misstear (TCD), Catherine Coxon (TCD), Carlos Rocha (TCD), John Walsh (UCD), Tiernan Henry (NUIG) and Karl Richards (Teagasc). This research programme has been devised to provide innovative methodologies, measurements and models to improve our understanding of ongoing and future threats to groundwater quantity and quality. This will allow improved forecasting of the impacts of contemporary environmental challenges such as land-use change (e.g. agricultural intensification) and climate change. Our research will focus on the hydrogeology of fractured/fissured aquifers in order to characterise both flow and contaminant transport processes more accurately. The overall programme has been divided into two generic Targeted Projects, which umbrella several individual research projects, as follows.

Targeted Project 3.1: Geological & Climate Change Impacts on Groundwater Quantity

- Characterisation of diffuse recharge into karst aquifers using chemical and numerical modeling techniques [P.I. Laurence Gill]
- Impacts of changing climate on groundwater recharge in low storativity fractured-rock aquifers [P.I. Bruce Misstear]
- Ecosystem services provided by groundwater dependent wetlands in karst areas [P.I. Laurence Gill]
- Quantification of the flow and recharge characteristics of potential geothermal system. [P.I. John Walsh]
- Quantitative assessment of the impact of faults and related karst networks on groundwater flow [P.I. John Walsh]

Targeted Project 3.2: Land-use & Climate Change Impacts on Groundwater Quality

- Emerging organic contaminants arising in rural environments: investigations in karst and fractured bedrock aquifers [P.I.s: Catherine Coxon & Karl Richards]
- An investigation of arsenic sources, speciation and mobilization processes in selected Irish aquifers [Frank McDermott]
- An investigation of uranium occurrence, sources and mobilization processes in selected Irish groundwaters [Frank McDermott]
- The impact of on-site wastewater effluent on karst springs [P.I. Laurence Gill]
- An investigation of metal occurrence, sources and mobilization processes in selected Irish groundwaters associated with mines [Tiernan Henry]
- Effects of Groundwater-Surface water Interactions (GSI) on the biogeochemistry of coastal areas hosting aquaculture activities [Carlos Rocha]

Three research projects iCRAG started in September 2015, with the rest due to start in September 2016. These posts are now being advertised at: icrag-centre.org/vacancies/

Frank McDermott / John Walsh
University College Dublin

Groundwater is a major part of the recently launched **iCRAG** and Earth and Ocean Sciences (EOS) staff and students are contributing to this work. The ***occurrence, distribution and movement of metals in groundwater*** is the area that EOS are focused on in particular. Tiernan Henry and Liam Morrison are co-PIs (with Prof Frank McDermott in UCD) on two iCRAG PhD studies, one of which (a study of ***arsenic occurrences and distribution in groundwater*** in the Northwest and Southeast being completed by Alex Russell) is underway. The other project, focused on ***uranium in groundwater***, will be starting this year. These projects pick up and overlap with Ellen McGrory's Griffiths funded-PhD on arsenic distribution in groundwater in Mayo and north Louth which is nearing completion. Tiernan Henry and John Murray are co-PIs on another iCRAG project that they are aiming to get started in September this year; it will fit in with the other projects and will focus on ***metals in groundwater in mined areas of Ireland***.

Yvonne O'Connell is preparing to submit her Griffiths' funded PhD and is currently preparing two papers for publication: one is focused on work we have been doing on the ***Dromiskin sand and gravel aquifer in mid-Louth***, and the other, with Ted McCormack in TCD, is focused on better understanding the plumbing of the ***coastal karst aquifers in south Galway.***

Sarah Blake's PhD (IRETHERM-funded) on ***warm springs west of Dublin*** is now completed and she has been successfully using multivariate statistical analyses techniques on the chemistry data from the sampled wells and springs. The results show strong relationships of specific Rare Earth Element (REE) with major anions and cations and clearly show the distinctiveness of certain of the spring waters. Sarah has presented her data and findings at IGRM this year and last year and she will present at the upcoming EGU General Assembly in Vienna in April. Contact: Sarah Blake (sblake@cp.dias.ie)

Sara Vero (Teagasc Walsh Fellow) has been successfully awarded her PhD. Her project was co-supervised by Mark Healy (Civil Engineering, NUIG) and Tiernan Henry and was focused on ***soil water characteristics and assessing equilibrium in soil drainage***. She has just started a post-doctoral research position in Kansas State University, where she will be doing unsaturated zone research on their multi-catchment prairie grassland.

With EU Life funding a research MSc project will get underway this summer based in the Burren. Tiernan Henry and Gesche Kindermann (Applied Ecology Unit) will supervise this community based research project which will focus on ***catchment mapping*** with TY secondary school students from Lisdoonvarna (with John Sims).

Four of the EOS 2016 graduates are completing groundwater MSc programmes in Birmingham, Strathclyde and Newcastle with a larger cohort from this year's 4th year class hoping to get into the same or similar groundwater programmes.

Jean O'Dwyer is collating data with UCC and DIT researchers to create a detailed, national, statistical model of ***groundwater vulnerability to microbiological contamination***. A research group on 'Water and Health' has been created and includes Dr Jean O'Dwyer, Professor Catherine Adley (UL), Dr Una Fallon (HSE-E), Dr Coilín ÓhAiseadha (HPSC), Dr Paul Hynds (DIT) and Dr Margaret Morris Downes (HSE-MW). The group are looking at the ***role of groundwater in transmitting VTEC infection***; a pathogenic, notifiable strain of E. coli. Jean has been trained on the HSE's Computerised Infectious Disease Reporting system for this purpose, and has georeferenced all cases of VTEC infection in Ireland since 2008 and amalgamated the locations with census data pertaining to infrastructure, agriculture and demographics. Future work will focus on incidences of VTEC infection along with hydrogeological and climatological parameters to create VTEC vulnerability maps for groundwater. Contact: Jean.ODwyer@ul.ie.

Niall Walsh, Geography Dept (Mary Immaculate College) commenced a research masters in 2015 entitled 'A palaeolimnological assessment of reference conditions at ***Lough Gur***, Co Limerick, to inform ***catchment management and lake restoration***'. Lough Gur is underlain by a diffuse flow karst aquifer which makes the lake extremely vulnerable to contamination. The water quality in Lough Gur is classed as hypertrophic by the EPA. The sediment-based project aims to contribute data on the onset of nutrient enrichment. The project is being co-supervised by Dr. Norman Allott (TCD) with inputs from Richard Langford and Anne Goggin Limerick City and County Council.

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

The Schools of Natural Sciences and Engineering in Trinity College are a major partner in the new SFI funded **iCRAG**. In the groundwater research "spoke" TCD has started 3 new research projects in September 2015, supervised by Bruce Misstear, Catherine Coxon and Laurence Gill (see details below), with an additional 4 PhDs currently being advertised (See: icrag-centre.org/) to start in September 2016 on the subjects of:

- Groundwater terrestrial dependent ecosystems
- Contamination of karst springs by on-site wastewater and
- Submarine groundwater discharge

The first iCRAG research projects started in September 2015. Three projects in the groundwater spoke in TCD are as follows:

1. Characterisation of ***diffuse recharge into karst*** aquifers using chemical and numerical modelling techniques

The project aims to differentiate between diffuse and conduit flow pathways into a karst network using both chemical (isotopic and trace element water quality) and spring hydrograph source separation techniques. The aim is then to develop numerical models of different karst networks with a focus on characterising the fissure flow more accurately as well as linking this to contaminant transport. Contact: Philip Schuler (schulerp@tcd.ie) and Laurence Gill (laurence.gill@tcd.ie)

2. Impacts of ***changing climate on groundwater recharge*** in low storativity fractured-rock aquifers

The aim is to investigate the effects of forecast changes in climate parameters on groundwater recharge. Whilst climate change projections involve considerable uncertainties (in future emissions; in effects of warming on rainfall; in the models used), nevertheless predictions for some groundwater-dependent catchments in Ireland suggest that summers may be longer and drier, with longer periods of soil moisture deficit, and that the number of intense rainfall events leading to flooding will increase, all suggesting that that groundwater recharge may be reduced. The project objectives are to investigate:

- How bedrock properties affect the response of Irish aquifers to present and future recharge.
- How climate change impacts on our regional groundwater resources.
- How climate change impacts on dependent wetlands (GWDTEs).
- How climate change impacts on Source Protection Areas (SPAs).

Contact: Èlia Cantoni (cantonil@tcd.ie) and Bruce Misstear (bmisster@tcd.ie)

3. ***Emerging organic contaminants*** arising in rural environments: investigations in karst and fractured bedrock aquifers

The objective of this project is to investigate the occurrence of synthetic organic compounds arising from rural activities in Irish karst and fractured bedrock aquifers. The primary focus is on agricultural antiparasitic agents. The project aims to determine the controlling factors (both source and pathway) on these occurrences.

Contact: Damien Moone (mooneyd2@tcd.ie) and Catherine Coxon (cecoxon@tcd.ie). Co-supervisors: Karl Richards & Per-Erik Mellander (Teagasc Johnstown Castle), Martin Danaher (Teagasc Ashtown), Laurence Gill (TCD)

Laurence Gill and David O'Connell (post-doc) have received a GSI Short Call research grant for a project entitled, "Characteristics of stable isotope fractionations during ***reactive transport of phosphate in groundwater*** *discharging* to a groundwater fed lake (Lough Gur, Co Limerick)", which started in December 2015.

On-going School of Engineering research

The Environmental Engineering research group continues to carry out the EPA funded project (2012-W-MS-12) to quantify the ***impact of on-site wastewater effluent*** on rivers and wells. The groundwater related part of this project is focused on studying private wells across four different areas, two characterised as Low vulnerability (in Co Wexford and Cavan) and two characterised as Extreme vulnerability (in Co Wexford and Kilkenny). Following the one-off monitoring of 216 wells for contamination and a survey for pollutant source susceptibility, 24 wells (6 per area) have been sampled once per month since July 2015 to build up a temporal picture. The research is attempting to identify robust chemical and/or microbiological fingerprinting methods (with the Dept of Microbiology in NUIG) for on-site effluent contaminants in both surface water and groundwater environments. Contact: Chris Fennell (fennelca@tcd.ie) and Donata Dubber (dubberd@tcd.ie).

Environmental Engineering also has an on-going postdoctoral fellowship funded by the Irish Research Council and the GSI in collaboration with the Swiss Institute for Speleology and Karst Studies (SISKA) to develop ***numerical models of two Irish karst catchments*** using the KARSYS methodology (as developed by SISKA). The project is focussing on two areas, Bell Harbour catchment in the Burren and the Shanballymore/ Castletownroach spring catchments (north Cork). Contact Ted McCormack (mccormte@tcd.ie).

Research by the group also continues into the ***transport and attenuation of on-site effluent contaminants*** with a new project in collaboration with the Dept of Mathematics in Limerick to develop numerical models of pollutant transport from on-site systems to groundwater. Two field sites have been constructed and instrumented in Co Limerick in different soil types and sampling of nutrients, organics and bacterial pollution to determine vadose zone contaminant transport and attenuation is on-going. Contact: Jan Knappe (jan.knappe@tcd.ie).

A research collaboration between Environmental Engineering and the Dept of Geology has continued using rare earth elements as tracers of flow pathways in two karst catchments, on the lowland karst catchment in south Galway and another in north Cork (centred on Shanballymore spring). Contact: Laurence Gill (laurence.gill@tcd.ie) and Balz Kamber (kamberbs@tcd.ie)

Bruce Misstear continues as a Vice President of IAH. He is currently working on ways to enhance the Association's educational activities, including the preparation of strategic overview papers and further development of the IAH website. Bruce and his co-author David Banks have prepared a second edition of their textbook Water Wells and Boreholes, which will be published by Wiley later this year or early 2017.

On-going School of Natural Sciences research

The joint TCD Teagasc project on ***nitrogen attenuation along delivery pathways in agricultural catchments*** is nearing completion. The project PhD student, Eoin McAleer, working under the supervision of Catherine Coxon (TCD), Per-Erik Mellander and Karl Richards (Teagasc), presented his research findings at the Catchment Science Conference in Wexford in September 2015, and at the IAH Irish Group Open Forum and the Irish Geological Research Meeting in February 2016. Contact Eoin McAleer (Eoin.McAleer@teagasc.ie).

Aoife Delaney's PhD project on ***ecology and hydrology of coastal dune slacks***, with Jane Stout and Catherine Coxon, is also scheduled for completion in autumn 2016. Contact: Aoife Delaney (amdelane@tcd.ie).

The EPA STRIVE funded CONNECT project undertaken by Jean Wilson together with Carlos Rocha and Catherine Coxon, which sought to develop tools to identify and evaluate ***groundwater discharge to Irish lakes and transitional / coastal waters***, is now complete. An end of project workshop was held in the GSI in October 2015 and the final report will be available from the EPA shortly. Contact Jean Wilson (jewilson@tcd.ie).

The EPA STRIVE project on the development of an ecohydrology framework for ***setting environmental flow standards for Irish rivers***, undertaken by Katherine Webster, Katie Tedd, Catherine Coxon and Ian Donohue, has also been completed: a workshop was held in November 2015 and the final report will be available from the EPA this year. (Contact Katie.Tedd@gsi.ie or cecoxon@tcd.ie).

The UCD School of Earth Sciences has 4 PhD projects on groundwater-related research, 2 of which are in the recruitment phase. The first is a project entitled '***Quantitative analysis of***

fracture systems and their impact on flow pathways in Irish bedrock aquifers' which is an EPA Strive PhD Studentship conducted by John Paul Moore and supervised by John Walsh and Tom Manzocchi of the Fault Analysis Group, in collaboration with Taly Hunter-Williams (GSI) and Ulrich Ofterdinger (QUB). John Paul is currently writing up his PhD for a finish later in 2016. Contact John Paul Moore (johnpaul@fag.ucd.ie), John Walsh (john.walsh@ucd.ie) and Tom Manzocchi (tom.manzocchi@ucd.ie)

The remaining 3 projects are in the context of the newly founded Irish Centre for Research in Applied Geosciences (iCRAG): **see separate entry about iCRAG in this newsletter**. Those projects are investigations of:

(i) ***Arsenic sources, speciation and mobilization*** processes in selected Irish aquifers,

(ii) ***Uranium occurrence, sources and mobilization processes*** in selected Irish groundwaters and

(iii) Quantitative assessment of the ***impact of faults, fractures and related karst networks on groundwater flow***.

Projects (i) and (ii) are supervised by Frank McDermott, with Drs Tiernan Henry and Liam Morrison, both of NUIG, as Co-PIs. Alex Russell is the PhD student performing the Arsenic project. Contact Alex Russell (alex.russell@icrag-centre.org) and Frank McDermott (frank.mcdermott@ucd.ie).

We are currently recruiting for the Uranium PhD project. Project (iii) is also in the recruitment phase, with an anticipated start in September 2016, and will be supervised by John Walsh, Conrad Childs and Tom Manzocchi: this project will involve geological analysis and a significant component of fluid flow modelling.

Research

An overarching theme of groundwater studies carried out in Johnstown Castle Environmental Research Centre has been the characterisation of nutrient loss, pathways and attenuation capacities as well as time lags within agricultural landscapes.

More recently such studies have been more focused on the catchment scale with more insight to processes. Two Walsh Fellow projects, one on ***time lags in the unsaturated zone*** (Walsh Fellow Sara Vero) and one in the ***saturated zone*** (Walsh Fellow Eoin McAleer; contact: Eoin.McAleer@teagasc.ie) are reaching a point when insight from the two zones can be merged to give an ***overview of time lags at the catchment scale***.

In other studies both the ***hydrological and biogeochemical time lags*** are considered in multiple scales. The aim is to characterise nitrogen (N) and phosphorus (P) loss for variable typologies of soils, agricultural inputs as well as taking weather conditions, farming system, bedrock permeability and transfer pathways into account.

The role of ***P mobilisation and leaching to groundwater*** has been investigated at the catchment scale. In particular the role of soil chemistry was investigated. This formed the basis for a new Walsh Fellow project that will start in April.

The ***role of N and P mobilisation*** was also recently the topic of a French-Irish comparative study on contrasted N and P export in two groundwater-fed catchments.

In 2015, the Geological Survey of Ireland launched the new Geoscience Research Programme 2015-2020. This programme is a successor to the Griffith Geoscience Awards (2007-2015), a multi-annual programme that funded high-level research projects in Queens University Belfast, University of Ulster, NUI Galway, University College Cork, Dublin Institute for Advanced Studies, Trinity College Dublin and University College Dublin. The topics ranged from education and outreach to carbon sequestration including two 7-year projects in groundwater (QUB and NUIG).

The new Geoscience Research Programme comprises a number of funding mechanisms for researchers in Ireland. The first Short Call in 2015 funded 41 small scale short term projects (less than 12 months, less than €25,000); Groundwater and the Environment was an essential research theme within this call. Researchers from both industry and academia were funded and projects range from 'seed' projects to testing methodologies, outreach and education programmes, maps, technology development etc. Topics range from geotechnical engineering to geochemistry, geophysics, minerals, geohazards, marine mapping and groundwater. In particular, the groundwater projects include;

- Determining fractured bedrock aquifer parameters using magnetic resonance sounding to better constrain numerical groundwater models in support of catchment scale water resource management (led by QUB)
- Characterisation of stable isotope fractionations during reactive transport of phosphate in groundwater discharging to a groundwater fed lake (Lough Gur, Co. Limerick) (led by TCD)
- Linking sources of contamination of groundwater resources with naturally occurring arsenic in metasedimentary rock in Ireland (led by NUIG)
- Production of a handbook of karst for Irish hydrogeologists (led by Tobin Consulting)
- All-Ireland karst features dataset (led by GSNI)

In addition to the Short Call, the GSI have entered into partnerships with Science Foundation Ireland (through the Investigators Programme), Irish Research Council (through the Enterprise Partnership Scheme) and the Fulbright Commission (through their Scholarship and Studentship programmes) and the Irish Centre for Research in Applied Geosciences (iCRAG). These partnerships have leveraged additional funding and visibility for geoscience research in Ireland. Throughout the GSI Geoscience Research Programme these partnerships will be strengthened and further developed, with additional and new collaborations established.

2016 will see the launch of the next phase of the programme. This will include a call for Postdoctoral research positions for up to 3 years and opportunities for academic lecturing staff to concentrate on research activities. It is intended that GSI funded projects will complement non-GSI, water related research funding and support the GSI's remit in this area.

The new Geoscience Research Strategy (to be launched in 2016) outlines the Survey's priorities in terms of our research activities. Our aim is to build capacity in geoscience research, including groundwater, and engage directly and in a more impactful way with the research community. This may be through GSIs role as a Research Funder, Research Performer or Research Collaborator.

For additional information on The GSI Research Strategy, research funding programmes and currently funded projects, please see www.gsi.ie/Research.htm

Aoife Braiden (Aoife.Braiden@gsi.ie)

Ireland's waters are one of our major natural resources. Plentiful availability of good quality water offers a significant competitive advantage to sectors such as agriculture, industry and tourism, but is a resource that must be carefully managed. Improving water quality status is a national priority for Ireland.

The Environmental Protection Agency (EPA) Water Research programme has a strong focus on policy and has been driven by national regulations and European Directives. Policy-related research plays a vital role in ensuring that EU and national policies are implemented in the most cost-effective manner. A sustained water research programme is an essential component of Ireland's role in protecting its water resources and meeting its requirements under water related EU directives and national policies. The EPA Water Research programme 2014-2020 is carried out under the following five thematic areas:

Theme 1: Safe water;
Theme 2: Ecosystem services and sustainability;
Theme 3: Innovative water technologies;
Theme 4: Understanding, managing and conserving our water resources;
Theme 5: Emerging and cross-cutting issues.

More details on the EPA Water Research Pillar can be found at: EPA Water Research.

Between 2007-2015, the EPA Research Programme has funded over 100 Research Projects, with a total commitment from the EPA of approximately €20m. The range of projects funded includes desk-studies, scholarships, fellowships and large-scale multi-annual and multi-partner awards. EPA Research's water pillar deals with groundwater, surface water, transitional and coastal water; as well as wastewater, drinking, bathing and shellfish waters. More details on our projects can be found at: Water Research in Ireland 2014-2020.

Synergies and enhanced collaboration with other national funders is a key objective of the research programme which is facilitated by the Water Research Coordination Group set up by the EPA and Enterprise Ireland (EI) in 2010. Members include; Department of the Environment, Community and Local Government, Marine Institute, Science Foundation Ireland, Irish Research Council, Department of Agriculture, Food and the Marine, Office of Public Works, Geological Survey of Ireland, Inland Fisheries Ireland and Irish Water.

The EPA has developed DROPLET: an easy-to-use interactive web application for exploring information about projects which have been funded in Ireland on Water Research. DROPLET includes projects from many other funders of environmental research in Ireland. To-date, there are 468 projects listed on DROPLET. DROPLET has been very successful with over 106,118 web hits since its launch (June 2015) and is viewed worldwide.

A number of critical international linkages have also been established to promote Irish environmental research into the international arena including enhanced participation in the European Research Area (e.g. Horizon 2020, Joint Programming Initiatives, European Innovation Partnership). By ensuring that Ireland is represented in significant European initiatives related to water, the EPA will promote an increased efficiency, critical mass and impact of water research in Ireland.

Water challenges cannot be successfully tackled through the isolated effort of individual national research and innovation programmes. A significant share (more than 70%) of public spending in water research and technology development is programmed, executed and evaluated at national level. The Water Joint Programming Initiative aims at developing a coordinated and strategic approach to public national and regional research and innovation funding in Europe. Since November 2014, the Water JPI has been coordinated by France (Agency Nationale de la Recherche) and co-chaired by Ireland (EPA).

Funding Opportunities

EPA National Call:

The EPA 2016 Water Research call is expected to be announced in May/June 2016.

International Calls:

The Water and FACCE JPIs have recently launched a call for international and transnational collaborative research projects on "Sustainable management of water resources in agriculture, forestry and freshwater aquaculture sectors". The call is open since the 16th February 2016 with a closing date for the submissions pre-proposals on **19th April 2016**. A total of €25.5 million has been allocated for this call by 25 funders from 22 countries. The EPA, on behalf of the EPA and DAFM, is contributing €0.55m. Irish researchers can participate in the call (Challenge 2 only). For detailed information on how to apply and to access all the support documentation and templates, please consult the [2016 Joint Call Official Webpage]. To facilitate networking & collaboration between applicants, the Water JPI has set up a [Discussion Forum] on LinkedIn.

Water issues are addressed across the entire Horizon 2020 structure and integrated in the work programmes of LEIT and of several Societal Challenges. Within the concept of the systemic approach of Societal Challenge 'Climate action, environment, resource efficiency and raw materials', actions to boost water innovation for Europe and beyond are also addressed in the areas of the work programme on the circular economy, renaturing cities, climate-smart Europe, territorial resilience etc. More details are available on the [Horizon 2020 website.]

Topics in the Work Programme 2017 with a clear relevance to groundwater issues include, for example:

SC5-01-2017: Exploring the added value of climate services
SC5-02-2017: Integrated European regional modelling and climate prediction system
SC5-08-2017: Large-scale demonstrators on nature-based solutions for hydro-meteorological risk reduction
CIRC-02-2017: Water in the context of the circular economy
SFS-47-2017: Soil water resources management in the EU and China and its impact on agro-ecosystem functions
SFS-48-2017: Resource-efficient urban agriculture for multiple benefits
RUR-03-2017: Towards 2030: Policies and decision tools for an integrated management of natural resources
RUR-12-2017: Networking European farms to boost thematic knowledge exchanges and close the innovation gap

Alice Wemaere (a.wemaere@epa.ie)

Hydrogeological News

This section of the newsletter contains news of interest to hydrogeologists in Ireland. It includes short reports on the recent activities of the IAH Irish Chapter as well as the IAH International. It also includes other groundwater related material such as new publications that may be of interest and where groundwater features in the media. If you are involved in, or aware of, any items which may be of relevance for this section of the newsletter please contact the editors at groundwaternewsletter@gsi.ie

XX INQUA 2019 – Life on the Edge – Dublin

Date: 25th-31st July 2019

Venue: Conference Centre and nationwide

Further details:

www.iqua.ie/INQUA_2019.html

It is now official –The next INQUA Congress will be in Dublin

The INQUA (International Union for Quaternary Research) Final General Assembly were notified of the International Council's vote to award the 2019 INQUA Congress to Dublin, Ireland on Sunday August 2nd at the XIX INQUA Congress in Nagoya, Japan and the venue has been ratified.

This is a marvellous achievement for Ireland and for Irish Quaternary science and an outcome that is still hard to believe. The journey started 24 months ago at an Irish Quaternary Association (IQUA) meeting and we would like to thank everyone who has engaged with us to win this bid. The effort leading up to the bid production and at the Congress by IQUA members and by delegates and by our professional conference organiser was incredible.

The final bid document is available here.

We hope the Congress will live up to our promises in the bid and we sincerely look forward to seeing everyone in Dublin in 2019 and involving as many of the island's Quaternary scientists in the organisation as possible…

Pete Coxon
Trinity College Dublin

Groundwater in Fractured Bedrock Environments: Managing Catchment and Subsurface Resources conference

Date: Friday 10th June 2016

Venue: Queen's University Belfast

Programme and registration details:

www.geolsoc.org.uk/fracturedbedrocks

Across the UK & Ireland, fractured bedrock aquifers have been traditionally regarded as low productivity aquifers, with only limited relevance to regional groundwater resources. But it has been increasingly recognised that these complex bedrock aquifers can play an important role in catchment management and subsurface energy systems.

At shallow to intermediate depth, fractured bedrock aquifers help to sustain surface water baseflows and groundwater dependent ecosystems, provide local groundwater supplies and impact on contaminant transfers on a catchment scale. At greater depths, understanding the properties and groundwater flow regimes of these complex bedrock environments can be crucial for the successful installation of subsurface energy and storage systems.

In many scenarios, a robust understanding of fractured bedrock environments is required to assess the nature and extent of connectivity between such energy & storage systems at depth and overlying receptors in the shallow subsurface or above ground.

The conference will include contributions that address effective methods to characterise these challenging aquifer systems, provide insights into the key processes driving the groundwater flow regime and contaminant transport in such formations and make links to the structural geological framework and geomechanics that shape the nature and extent of effective flowpaths in these aquifer systems.

Follow this event on Twitter:

@geolsoc

#fracturedbedrocks

#yearofwater

Ulrich Ofterdinger
Queen's University Belfast

Irish Group

IAH (Irish Group) 2016 conference

Sustaining Ireland's Water Future: The Role of Groundwater

Owen Naughton

The 36th Annual IAH (Irish Group) Groundwater Conference will be held in the Tullamore Court Hotel on the **12th - 13th April 2016**.

For this 40th year of the Irish Group of the IAH, we are honoured to host three keynote speakers who are leaders of international hydrogeological research on specific subject matters that have direct relevance to the hydrogeological context of, and water resources management in, Ireland.

Dr. John M. Sharp is Professor of Geology at the University of Texas. His hydrogeological research covers groundwater flow in fractured rocks, regional groundwater flow in carbonate rocks, and effects of urbanization on water resources protection and management. At the IAH conference, Prof. Sharp will lend his experiences to speak on "***Sustainability of groundwater resources: conceptual evolution, opportunities & challenges***"

Dr. Beth Parker is Professor at the School of Engineering at University of Guelph, Ontario. Her research is focused on developing improved field and laboratory methods for characterisations and monitoring of industrial contaminants in sedimentary rocks, clayey deposits and heterogeneous aquifers. At the IAH conference, Prof. Parker will share her latest research findings on "***Contaminant plume characteristics in sedimentary rock aquifers: Insights from field research***".

Dr. Kevin Hiscock is Professor of Environmental Sciences at the University of East Anglia. His interdisciplinary research interests are in hydrochemistry, environmental isotopes and the impacts of land use and climate change on groundwater resources at regional and global scales. Prof. Hiscock will speak on "***Implications of Climate Change on Groundwater Resources***".

The topics of the keynote speakers will undoubtedly serve to both guide hydrogeological practitioners and challenge researchers in Ireland. Moreover, the topics were selected to enhance the technical perspectives on subject matters that are close to home, and which are covered by the conference sessions, specifically those that address resource assessment and continued implementation of the EU Water Framework Directive. As such, the conference will be a particularly useful forum for local authorities and other relevant public regulatory bodies to keep abreast with trends and the range of hydrogeological and environmental work which is ongoing and which will shape water supply and environmental protection initiatives in both Ireland in the coming years.

An registration rate of €200 is available for IAH members (€220 for non-members) until final registration on **6th April 2016**. Student or unemployed rates are €60 (or €90 for non-members).

Full programme and registration information details are available on the IAH Irish Group website at www.iah-ireland.org/annual-conference.

INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS IRISH GROUP

"Sustaining Ireland's Water Future: The Role of Groundwater"

Tuesday 12th – Wednesday 13th April 2016

Tullamore Court Hotel
Tullamore
Co. Offaly

PROGRAMME

DAY 1: 12th April 2016

08:30 Registration, tea/coffee, exhibits

09:30 Welcome: Henning Moe, President IAH Irish Group

SESSION I: KEYNOTES

09:40 **John M. Sharp** (University of Texas). Sustainability of groundwater resources: conceptual evolution, opportunities & challenges

10:20 **Beth Parker** (University of Guelph). Contaminant plume characteristics in sedimentary rock aquifers: Insights from field research

11:00 Q&A

11:15 Refreshments

SESSION II: CELEBRATING 40 YEARS OF IAH IRISH GROUP

11:45 **David Ball**. Groundwater in Irish society: Celebrating 40 years of IAH Irish Group

12:20 **Bruce Misstear** (TCD). Looking to the future: opportunities and challenges in hydrogeology training and education

12:45 Q&A

13:00 Lunch

SESSION III: GROUNDWATER FOR DECISION MAKERS

14:00 **Donal Daly** (EPA). Progress in implementation of the Water Framework Directive in Ireland

14:25 **Rob Ward** (BGS). Water Framework and Groundwater Directive Implementation: A UK perspective

14:50 **Teri Hayes** (AWN Consulting). The role of hydrogeology in Seveso III and IED licensing

15:15 **Les Brown** (Arup). Long Term Groundwater Catchment Monitoring and Quantitative Assessment at Fardrum and Roosky Turlough SAC. County Fermanagh, Northern Ireland

15:40 Q&A

15:55 Refreshments

SESSION IV: EARLY CAREER HYDROGEOLOGISTS NETWORK

16:15 **John Weatherill** (Geosyntec). Natural attenuation of chlorinated solvents in the hyporheic zone: Insights from a gaining lowland river in the UK

16:30 **Sarah Blake** (DIAS). Sources and circulation patterns of warm springs in Ireland

16:45 **Christopher Fennell** (TCD). Impacts of onsite wastewater effluent on private water wells

17:00 End of Session and Wine Reception

18:30 Social Event at Hugh Lynch's

DAY 2: 13th April 2016

09:00 Tea/coffee, exhibits

SESSION V: KEYNOTE

09:15 **Kevin Hiscock** (University of East Anglia). Implications of Climate Change on Groundwater Resources

SESSION VI: GROUNDWATER RESOURCES

09:55 **David Banks** (Holymoor Consulting Ltd. and Glasgow University). Making the red one green – renewable heat from abandoned flooded mines

10:20 **Sophie O'Connor** (GSI). Zooming in with Groundwater 3D: Focused GSI investigations in priority areas

10:45 Q&A

11:00 Refreshments

SESSION VII: RESEARCH

11:20 **Bob Harris** (University of Sheffield). Getting the buggers to listen – some observations on the trials, tribulations and success in delivering (and using) relevant scientific research

11:45 **Laurence Gill** (TCD). "It may be excreta to you, but it's my bread and butter" – research into onsite wastewater treatment

12:10 **Colin Brown** (NUIG). Groundwater research in coastal catchments: new results, new challenge

12:35 Q&A

12:50 Conference closing – Owen Naughton, Conference secretary IAH Irish Group

13:00 Lunch

TECHNICAL WORKSHOP

14:00 **TBC**

15:00 End of Session

Irish Group

IAH (Irish Group) 2015 AGM

Katie Tedd - Secretary

The IAH (Irish Group) AGM was held on 3rd November 2015 in the Geological Survey of Ireland.

The IAH (Irish Group) had a full programme of events including monthly technical discussion meetings, annual conference and fieldtrip, hydrology training course, as well as involvement in outreach activities.

Henning Moe was elected as the ***new president*** of the IAH Irish Group. Many thanks to David Drew, who stepped down as president, for his hard work and dedication to the IAH Irish Group. All other committee members remained in position.

Morgan Burke gave an update of the ***twinning initiative with Uganda***. Twinning is a recent development in IAH whereby a long-standing National Chapter works closely with a newly forming Chapter to help it become established.

Following membership support at the 2014 AGM the committee has made progress with updating the ***IAH Irish Group's status***. The IAH (Irish Group) are now registered with Revenue and the Charitable Status application process is on-going. The IAH have also availed of the Irish Geoscience Network's Public Liability Insurance.

The IAH (Irish Group)'s ***bursary scheme*** continues to be successful in supporting students studying hydrogeology. The IAH (Irish Group) are grateful to the companies who contribute to this bursary. In 2015, the following companies supported the bursary: **ARUP, David Ball, Jones Environmental Laboratories and O'Callaghan Moran**. Further details may be found on http://www.iah-ireland.org/bursaries/

Orla O'Connell and Shane Regan (Education and Publicity Secretaries) have continued working with Deakin Design to update the ***IAH (Irish Group) website***. This is still a work in progress. Please visit the website: www.iah-ireland.org and contact Orla and Shane with any feedback at educationandpublicity@iah-ireland.org

In 2015, the IAH (Irish Group) wrote to the University of Birmingham to strongly oppose the proposed closure of their MSc Hydrogeology course and to Minister Alan Kelly to express concern regarding Dunmore Cave following the 2015 annual fieldtrip to the caves.

The IAH committee have set up a twitter account. Follow us **@IAH_Ireland**

IAH (Irish Group) committee 2016

President :	Henning Moe
Secretary:	Katie Tedd
Treasurer:	Dominica Baird
Conference Secretary:	Owen Naugthon
Fieldtrip Secretary:	Aisling Whelan
Education & Publicity Secretaries:	Orla O'Connell
	Shane Regan
NI Secretary:	Paul Wilson
Burdon Secretary:	Morgan Burke
Conference Sub Committee:	Eleanor Burke
	John Dillon
	Roberta Bellini
	Sarah Casey
	Les Brown

News

Irish Group

IAH (Irish Group) 2015 Training course:

Hydrology for Hydrogeologists

Shane Regan — Education and Publicity Secretary

The recent flooding events in Ireland have again brought into focus society's close, and often turbulent, relationship with the water cycle. In recent years, there has been an increased awareness of the importance of incorporating groundwater flow in flooding episodes, particularly in western Ireland where karstic bedrock is often close to the ground surface. Hydrogeologists have thereby been increasingly tasked with understanding and analysing flood events, without necessarily having the appropriate training in the hydrological analysis techniques typically ascribed in engineering education.

On this basis, in October 2015, the IAH Irish Group organised a one day training course, entitled 'Hydrology for Hydrogeologists', to address this growing demand on groundwater specialists.

The course, hosted in the Geological Survey of Ireland and CPD certified by the Institute of Geologists Ireland, was well subscribed with over 30 people in attendance. It was delivered as a series of lectures and presentations by eight invited speakers, from academia, industry and public bodies and divided into three broad themes of:

- Hydrometry;
- Rainfall and flooding; and
- Water management.

Professor Paul Johnston (Trinity College Dublin) opened proceedings with a discussion of the importance of understanding hydraulic principles in flow measurement. Peter Newport (Office of Public Works) described the site selection criteria for flow measurement and flow rating, followed by Noel Carr and Bernard Burke (NVM Ltd) who presented the OTT instrumentation commonly used in surface water level measurement.

In the second session Dr Owen Naughton (National University of Ireland, Galway) gave an overview of the collection and interpretation of rainfall and evapotranspiration data in Ireland, after which the exciting new Flood Studies Update (FSU) portal was introduced by Oliver Nicholson (Office of Public Works).

In the final session, Dr Conor Quinlan (Environmental Protection Agency) opened with a synopsis of the national hydrometric network. This was followed by an informative talk by Duncan Faulkner (JBA Consulting Engineers) on the value of hydrograph interpretation and what we can learn by letting the data speak. Dr Tommy Bree (ESBI) closed proceedings with a contextual talk on anthropogenic impacts and water management in Ireland.

The day was very well received with all attendees providing positive feedback. We hope to carry out similar training courses in the near future. If members have any ideas for future courses please email your suggestions to Shane Regan and Orla O'Connell at educationandpublicity@iah-ireland.org.

Shane Regan
Trinity College Dublin

Irish Group

IAH (Irish Group) 2015 Annual Fieldtrip

Catchments and karst in the southeast

Aisling Whelan — field trip secretary

This year's IAH field trip was titled "Catchments and Karst in the Southeast" and brought us to Wexford and Kilkenny. The trip took place on the first weekend of October with 23 people attending over the weekend. We visited research sites as part of two catchment orientated projects: the Teagasc Agricultural Catchments Programme (ACP) in Wexford and the EPA Strive Pathways projects in the Nuenna catchment, Kilkenny. We also had the opportunity to visit the spectacular Dunmore Cave not far from the Nuenna catchment in Kilkenny.

The trip kicked off on Saturday morning at the ***Castledockerell catchment in Wexford*** where researchers from Teagasc gave us an overview of some of their work monitoring and assessing the effectiveness of measures implemented as part of the Nitrates Action Plan. Their project is also looking at whether requirements under WFD can be, and are being, met in the context of Food Harvest 2020 and other predicted future growth in the agricultural sector.

We started off the morning at a nested piezometer installation which forms the lower installation of a transect in the southern part of the catchment. Ger Shortle, programme manager, described the background to the project and gave us and overview of the range of research being undertaken. Castledockerell is one of six catchments being studied nationally and is characterised by well drained soils over a poorly productive aquifer where farming activity comprises tillage/grassland. The project focuses primarily on N and P, as these are the principle nutrients of concern with regard to water quality. In this catchment nitrogen is considered to be the main nutrient at risk of loss to water and the main pathway for loss is considered to be leaching through the soil to the groundwater. During the trip we were given an overview of some of the research done mainly into P transfer and loss.

Edward Burgess, agricultural adviser on the project, described the considerable work and time that was spent getting farmers within the catchment on board with the project, and how

Figure left: Per Erik Mellander & Ger Shortle at a nested borehole monitoring location on the southern well transect ; right: The group being shown the instrumentation at the catchment outlet monitoring station

important this aspect has been to the overall project.

Per-Erik Mellander talked us through his work investigating pathways for P transfer and loss in this catchment. To investigate various pathways, nested monitoring boreholes with installations at three levels in each borehole were constructed along two transects in the catchment. In relation to P transfer, results show that the groundwater contribution to stream TRP flux was 50% in this well drained catchment.

Leanne Roche described her interesting research into the alternative use of urea as a fertiliser instead of the more common calcium ammonium nitrate. The focus of her work was assessing the effectiveness of different inhibitors needed to reduce nitrous oxide emissions from urea - all this in the context of the need to reduce greenhouse gas emissions.

Before we left the first stop of the morning, Ian Thomas described how he developed a phosphorus critical source area index using high resolution digital elevation models (DEMs). He found that 1-2 m resolution LiDAR DEMs were optimal for modelling surface run-off pathways.

We made our way to the catchment outlet monitoring station and here David Ryan gave us an overview of the instrumentation installed on the stream that drains the catchment. Various parameters including total P, MRP and TON are monitored at an enviably high resolution and synchronous with river discharge. Over the five years of monitoring so far MRP has generally below the TV in the stream. Occasional exceedances occur, generally during summer, and are attributed to a public treatment works upstream.

Finally, Sophie Sherriff rounded off the morning by describing her work investigating suspended sediment dynamics in the catchment. She used turbidity data collected at the stream outlet locations for all six ACP catchments and found that sediment export was generally low to moderate compared to other European catchments with similar characteristics. She also

Figure left: David Drew at the entrance to Dunmore cave; right: group returning to surface from Dunmore Cave

found that greater sediment quantities were exported from catchments with poor or moderate drainage, as might be expected.

After lunch in the lovely setting of Bunclody Golf and Fishing Club, we made our way to ***Dunmore Cave in Kilkenny***. David Drew advised us from the off that there is more that is not known about the hydrogeology of Dunmore Cave than is. The existing cave is only a remnant of the original cave and had the roof of it not collapsed, exposing the cave at the surface, there is little from the topography or hydrogeology of the area to suggest a significant feature like this existed. The cave is located in a narrow inlier of Carboniferous limestone. One of the many unanswered questions David posed is why there has been so little erosion of this inlier when it is surrounded by Namurian aged rocks which would supply highly aggressive run-off? It is thought the cave dates from early Pleistocene or even Tertiary times, but this is speculative. As David guided us through the cave he described how the only dating that has been done is from uranium-thorium dating of outermost calcite layers which are of Holocene age. David described how it is clear the cave developed under different topographic and hydrogeological conditions than those prevailing today. However, we know very little about this. Unfortunately, during the visit it became apparent that the importance of the cave is appreciated by the Stage and OPW mainly as a feature of archaeological heritage, but its hydrogeological significance is not well acknowledged or understood. It was also disappointing to see that algal growth is a problem in the cave as a result of the lighting system currently used. This problem can be and is effectively managed at other public visitor caves. When we emerged from the cave David left us with a list of questions to be answered which hopefully we'll get around to doing someday.

On Saturday evening we overnighted in the lovely Marble City, where we had a very enjoyable group dinner at Hotel Kilkenny.

On the second day of the field trip we spent it in the ***Nuenna Catchment in Kilkenny***. Our first stop of the morning was Killaghy swallow hole which has developed in the front garden of a domestic house in the upper catchment. Bruce Misstear recalled work Donal Daly and late Eugene Daly had done in the catchment in the 1970's, which sparked fond memories of Eugene among those who knew him well. Bruce went on to describe how developing a water balance is a crucial first step when looking at a catchment and should be undertaken before any modelling is started. Flow accretion curves, which are good way of getting to know a catchment, were developed for the Nuenna. Bruce described how an integrated approach to hydrological modelling was undertaken, including the use of the NAM rainfall run-off model along with other techniques.

Jenny Deakin gave us an overview of the main characteristics of the Nuenna catchment - well drained and underlain by a regionally important karstified limestone aquifer which feeds the majority of the flow in the River Nuenna via large springs. The catchment has a high to extreme vulnerability rating.

The next stop was a 'boiling' spring, so-called because of the rising gas bubbles in the upward flowing groundwater (and not because of any surprising geothermal activity). Jenny outlined how chemistry was used to provide insights into different pathways. Groundwater and river chemistry is very similar showing there is a large contribution of groundwater to the river. At the catchment outlet, Monument Weir, hydrochemistry, flow and rainfall data showed that major ions and nitrate are delivered via groundwater pathways and are diluted with rain, while PO4 and ammonium are delivered via near surface pathways and increase with rain.

Catherin Coxon took the opportunity to tell us about the results of the first significant analysis of pesticides in Irish groundwater. The most

Figure left: A swallow hole making an interesting feature in a homeowner's front garden; right: Jenny Deakin at the 'boiling' spring

News

Figure left: One of EPA monitoring boreholes ; central: The group at Clomantagh Bridge and right: David Ball and Jenny Deakin at Clomantagh Bridge

commonly detected pesticides were mecoprop and 2,4-D. Interestingly, the most commonly detected compounds in concentrations above the EU Drinking Water Limit (0.01 ug/l) were degradations products i.e. exceedances occurred more frequently for degradation products than for parent ingredients.

The final stop of the trip was at ***Clomantagh Bridge*** where the EPA have three separate monitoring boreholes installed at differing depths in the subsoils, transition zone and bedrock close to the river. Alison Orr talked us through her findings on nitrate dynamics. Hydrochemical and isotopic analysis showed that nitrification is the dominated N process in the Nuenna catchment. Denitrification is not significant, unlike in the poorly productive aquifer catchments studied as part of the pathways projects.

Ray Flynn outlined research undertaken by him and Daniel Hogan looking at the interaction of groundwater and rivers. In-channel artificial tracers and point flow measurements were used to try to understand these interactions. In a section of the river where it flows over deep alluvium, flow data and tracer loss suggested that not all water discharging to the river remained as surface water. The results suggest that the classic model whereby we assume that groundwater always discharge to rivers does not hold up and the reality is more complex.

To round up the morning, Coran Kelly described his work delineating ZOC's for private Group Water Schemes within the catchment as part of national project with the GSI and NFGWS. Rather than delineate a ZOC for each source, he took the pragmatic approach of delineating one ZOC for several sources located close together. This raised the question as to whether this could, in general, be a more pragmatic and cost effective way of dealing with source protection in karst areas due to the extent of the work and cost involved in establishing with enough certainty how groundwater behaves in complex hydrogeological systems like these.

The morning generated some very interesting discussion on the findings of this recent project and how it can help us better address and manage issues from integrated catchment perspective.

We finished up the Sunday morning with lunch at the Jarrow Café in the nearby Castlecomer Discovery Park and from there made our way home after what was an interesting and enjoyable field trip.

Our thanks again to the OPW and the guides at Dunmore Cave for facilitating our visit and to all leaders/speakers for their pre-trip preparation and for their time on the weekend. Thanks also to the landowners who kindly allowed us on their land.

The guide for this field trip will be available shortly on the IAH, Irish Group's website. www.iah-ireland.org

IAH: News on the international front

Bruce Misstear—Vice President Finance & Membership, IAH

In this issue I will talk about this year's IAH congress and our anniversary celebrations, last September's congress in Rome, the new IAH mentoring scheme, and the production of the Strategic Overview Series of groundwater papers.

60th anniversary year of IAH and the Montpellier congress

This year sees the 60th anniversary of the founding of IAH (and the 40th anniversary of the Irish Group). The IAH was inaugurated at the International Geological Congress in Mexico City in 1956. The founding group were mainly Francophone – and the first IAH congress took place in Paris in 1957 - and so it is fitting that this year's congress will be held in France, in Montpellier from 25th to 29th September. The first day of the congress will include a number of presentations celebrating the anniversary, as well as talks that look to the future. For details of the congress programme see http://www.60iah2016.org/en/. I hope many members of the Irish Group will be able to attend the congress - it's a terrific way to get to know about what's happening internationally and to make friends amongst the global hydrogeological community.

2015 IAH congress, Rome

The Rome congress was a great success, with over 800 delegates and a very good scientific programme (including some excellent keynote speakers such as John Cherry and Beth Parker). The congress was held on the campus of La Sapienza University. As well as the scientific programme, delegates enjoyed the mid-week excursions to sites of hydrogeological interest around this ancient city: there were eight different trips to choose from, and I went on the visit to the Quaternary volcanic aquifers of the Latium region northeast of the city (see photos). The congress included a very enjoyable social programme – even the field excursion involved a long, leisurely lunch!

It was good to see several colleagues from our Irish Group at the congress.

Groundwater-fed volcanic lake

Artesian borehole discharging from volcanic aquifer

News

Mentoring

IAH has now established a mentoring programme, whereby early career hydrogeologists can learn from some of our more experienced members. There are three areas in which the mentoring scheme can assist:

- the scientific – providing advice and technical knowledge on various topics within the many strands of hydrogeological science;
- career options and pathways – providing guidance on job types and locations, CVs, interviews, networking, courses and training openings;
- practical experience – case studies, local hydrogeological knowledge of specific regions or aquifer types, volunteering to undertake short assignments.

If you are interested in participating in the scheme, either as a mentor or a mentee, go to: https://iah.org/knowledge/mentoring.

Strategic Overview Papers

As Professor Foster mentioned during his IAH Burdon lecture in Dublin (15th March), IAH is preparing a series of papers that highlight the linkages between hydrogeology and other sectors. To date, five of these Strategic Overview papers have been completed (or will have been completed by the time you read this):

- Food Security & Groundwater
- The Energy Sector & Groundwater
- Resilient Cities & Groundwater
- Ecosystem Conservation & Groundwater
- Human Health & Groundwater

A sixth paper on Groundwater & Global Change is currently being written. These papers are being made available on the IAH website at https://iah.org/news/iah-strategic-overview-series.

And finally…….

You can find out more about IAH activities on the main IAH website at https://iah.org/. This includes details of how to join the Association. The full annual membership fee is €80 if you wish to receive a paper copy of Hydrogeology Journal as part of your membership, or €70 if you receive the journal online. Students can join for as little as €19 (with the online journal option).

Bruce Misstear,
Vice President Finance & Membership
International Association of Hydrogeologists

Previous issues available at

www.gsi.ie

The contributors are responsible for the content of the material in this Newsletter. The views expressed are not necessarily those of the Geological Survey of Ireland.

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If you are involved in an event which you would like to be advertised in the groundwater newsletter please email details to groundwaternewsletter@gsi.ie

Upcoming Events

31 Mar 2016	**Irish Association for Economic Geology course** - Radisson Blu, Athlone David Stewart - "Practical sampling and analytical QA/QC" www.iaeg.org
8 Apr 2016	**Open University Geological Society Field Trip** - Kilroot Salt Mine Email: ireland@ougs.org
12-13 Apr 2016	**IAH (Irish Group) annual conference** - Tullamore Court Hotel "Sustaining Ireland's water future: the role of groundwater" www.iah-ireland.org
17-22 Apr 2016	**European Geological Union General Assembly** - Vienna, Austria http://www.egu2016.eu/
19 Apr 2016	**Inaugural Hanrahan Lecture** - Engineers Ireland, Dublin Eric Farrell - Irish Glacial and interglacial soils www.igi.ie
20 April 2016	**GeolSoc's NI Regional Group** - Queen's University Belfast Eric Grunsky - "The use of geochemical survey data for predictive geologic mapping at regional and continental scales" Email: GeolSocNI@gmail.com
21 Apr 2016	**Irish Meteorological Society Lecture** - The Custom House, Dublin Xuefeng Cui - Land Use in the Earth System
21 Apr 2016	**WWT Water Ireland conference** - Pillo Hotel, Ashbourne www.wwt-ireland.net
25 April 2016	**GeolSoc's NI Regional Group** - Queen's University Belfast Frits Agterberg - "New statistical model for future worldwide mineral resource management" Email: GeolSocNI@gmail.com
3 May 2016	**IAH (Irish Group) TDM** - GSI and webcast Les Brown (ARUP) - "Hell and High Water - Artur Kozlowski's contribution to Irish karst hydrogeology " www.iah-ireland.org
5-7 May 2016	**Conference of Irish Geographers** - St Patrick's College, DCU "Memory, identity and landscape - Geographical perspectives" www.conferenceofirishgeographers.ie
31 May 2016	**IAH (Irish Group) TDM / NGWA Darcy Lecturer** - GSI and webcast Ty Ferré (University of Arizona) "Rethinking the relationship between data and models" www.ngwa.org and www.iah-ireland.org
8-9 Jun 2016	EPA National Water Event - Galway
10 Jun 2016	**Groundwater in Fractured Bedrock Environments conference** - Queens University Belfast www.geolsoc.org.uk
11-12 Jun 2016	**Open University Geological Society Field Trip** - Co Fermanagh Email: ireland@ougs.org
21-22 Jun 2016	**Inaugural International Conference on Natural and Constructed Wetlands** - NUIG "Interactions between Scientists and Engineers" www.conference.ie
20 Aug 2016	**Open University Geological Society Field Trip** - Whitehead and Islandmagee, Co Antrim Email: ireland@ougs.org
25-29 Sep 2016	**IAH Congress** - Montpellier, France "Groundwater and society: 60 years of IAH" www.60IAH2016.org
TBC Oct 2016	**IAH (Irish Group) annual fieldtrip** Email Aisling Whelan: fieldtrip@iah-ireland.org
23-27 Oct 2016	**IWA Regional Conference** - DCU Diffuse Pollution and Catchment Management www.dpcm2016.com

The editors welcome feedback on the contents of this issue and the changes to the newsletter, as well as suggestions for contributions to the next issue.

Please contact: Groundwaternewsletter@gsi.ie

Contributions for the next issue should arrive before **16 Sep 2016.**