Irish Groundwater Newsletter

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2018 was a memorable year in terms of Irish hydrogeology because of the summer drought. A comparable meteorological event had not occurred in Ireland since 1976. Appropriately, an article in this issue of the Groundwater Newsletter by Philip Maher of the E.P.A., describes and analyses the response of groundwater in Ireland to the drought. Also included in the *Articles* section of the Newsletter are reports on progress towards completing a water abstraction and control regime for Ireland; the development of a second phase of source protection work for groundwater-based Group Water Schemes; and the Local Authority Waters programme (LAWPRO).

The results of recent hydrogeological research in Ireland are represented by two contributions detailing investigations into karst but from very different perspectives. The first by Philip Schuler et al., is concerned with quantifying coastal discharges of groundwater on the south side of Galway Bay. The second by Lloyd Vaz et al., analyses the geothermal potential of Palaeokarst in Ireland.

The final section of the Newsletter, Hydrogeological News, reports matters of interest from IAH Ireland (including a report on the 2018 field trip and conference), IAH International (Bruce Misstear) and Geological Survey Ireland. The GSI report includes (*Page 21*) a call by Monica Lee for hydrogeology in Ireland to cease being "a hidden profession looking at a hidden resource" and for its practitioners to promote their expertise more vigorously. This is an important topic and one that could perhaps be explored further in future issues of this newsletter and/or elsewhere.

Issue 58 concludes with a list of recent publications related to hydrogeology in Ireland and a list of upcoming events of interest.

Thus far the groundwater Newsletter has been produced on a biannual basis. However, this is set to change, The next issue will be in the middle of 2020 and thereafter annually in the early autumn.

Geological Survey
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Monica Lee, Groundwater Section, GSI
Katie Tedd, Melissa O Keeffe and David Drew, Editors

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Cover photo: Thermal image of fieldtrip participants. Photo by Rebecca Bradford

Articles

Water Abstraction Registration and Control Regime

Matt Craig
Hydrometric & Groundwater Programme, Environmental Protection Agency

Proposed new Water Bill will provide an overarching framework for water management.

Abstraction control regime

Ireland currently relies on the Water Supplies Act 1942 in relation to the management of water abstractions, although in the intervening decades other legislation has been introduced to the statute book that indirectly supports the management of water resources. A register of water abstractions, and an associated water abstraction control regime are specific requirements of the Water Framework Directive (WFD). The European Union (Water Policy) (Abstractions Registration) Regulations 2018 (S.I. No. 261 of 2018) require that people who abstract 25 cubic meters (25,000 litres) of water or more per day register their water abstraction with the EPA. The deadline for registration of existing abstractions was November 16th, 2018, with new abstractions to be registered within one month of being commissioned.

These Regulations satisfy the first WFD requirement in relation to capturing where water is abstracted from and in what quantities. Subsequently, the Department of Housing, Planning and Local Government published a consultation paper on the associated control regime in 2018. The final Water Bill will provide an overarching framework for water management, under which current and future water legislation will fall, including any future abstraction control regime. Thereafter the Water Supplies Act 1942 and the water abstraction sections of other Water Acts would be repealed.

The consultation paper indicates that the EPA would be the primary licensing authority for abstractions, and proposes volumetric thresholds whereby a licence would be required, as well as indicating that the overall control regime should be risk based. In this regard, all abstractions greater than 2,000 cubic meters of water per day and any abstractions between 250 and 2,000 cubic meters of water per day that are identified

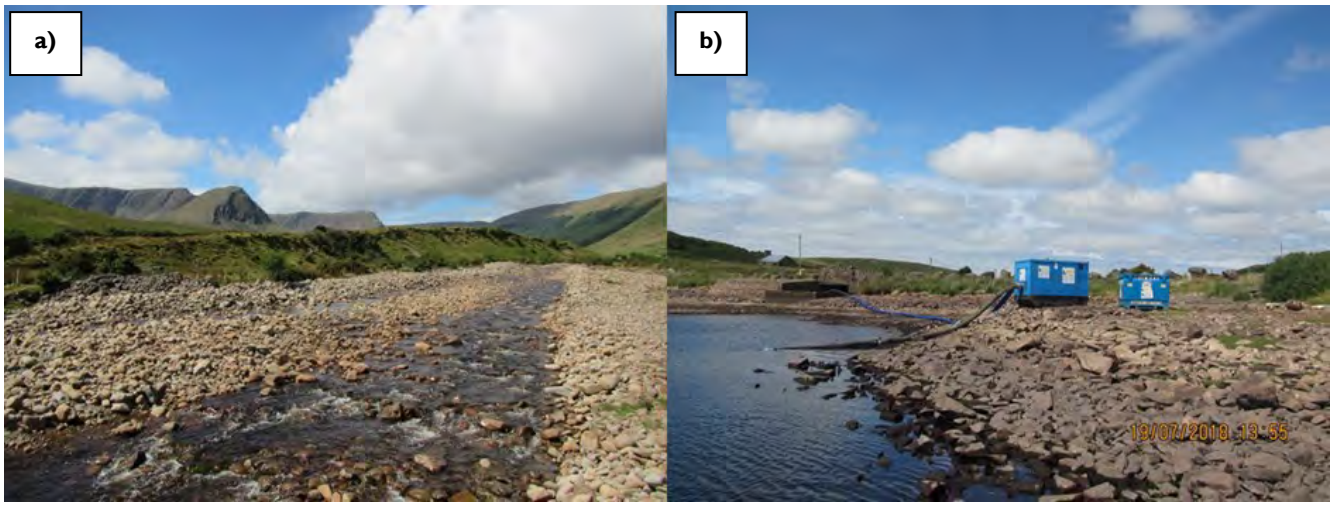


Figure 1 Figure 1: a) Naturally occurring low flows encountered in the Owenbrin River, County Mayo (photo: Hugh Feeley, EPA) and b) low lake water levels and active water supply management at Lough Keel, County Donegal (photo: Caroline Plant, EPA) during the summer of 2018

as being a significant pressure to the environmental objectives of the WFD would require an EPA licence. The consultation paper also indicates that the EPA should consult on any abstraction control regime it proposes under the Water Bill, including its basis for determining if an abstraction is identified as being a significant pressure. If the activity associated with the abstraction already requires an Integrated Pollution Control or Industrial Emissions Directive licence, then the abstraction controls can be incorporated through the existing licence.

Irrespective of volume, all abstractors of water would be required to follow a set of general binding rules associated with the operation and maintenance of the abstraction and, as per the requirement of S.I. No. 261 of 2018, all abstractions greater than 25 cubic meters should be registered with the EPA. The General Binding Rules include; constructing and maintaining boreholes and associated headworks to minimise leakage and prevent pollution, along with an indication that there should be a mechanism for measuring the rate of abstraction and a requirement to properly decommission abstractions in a safe manner.

The consultation paper highlights that any future abstraction control regime has the potential to have a knock-on effect on other legislation and regulatory functions. Interactions with the Planning and Development Acts, Water Service Acts, Public Health Acts, Sanitary Service Acts, Electricity Supply Acts and Fisheries Acts are referenced as legislation that have been considered in relation to the abstraction control regime, although the consultation paper indicates that there are no proposals to amend the Electric Supply or Fisheries Acts.

Abstraction Pressures

WFD assessments from both the 2009-15 and 2018-21 River Basin Management Plans highlight that abstractions are not anticipated to be a major issue in terms of the environmental objectives of the WFD. Nonetheless, the Management Plans highlight a need to systematically record information on abstractions to assess and identify those abstractions that are a significant pressure on environmental objectives of water bodies in Ireland.

The summer drought of 2018 has further heightened the need to actively manage water resources in a sustainable manner, with certain water bodies identified as being under severe stress to provide sufficient quantities of water for water supply. This, coupled with requirement to manage and protect the ecology and function/use of our waters, and the need to develop an understanding of the potential hydrological response to climatic change, clearly highlight that taking a "hands off" approach to water resource management in Ireland will lead to problems at some point in the future.

The Water Abstraction Register

Once an initial request has been made to the EPA for access to the Water Abstraction Module on the EDEN web portal (https://www.edenireland.ie), registration of an abstraction is made directly within that Water Abstraction Module. Instructions for registering and links to the EDEN web portal are provided on the EPA website (http://www.epa.ie/pubs/advice/water/waterabstraction/). Upon completion of the registration process, the registrant will receive an abstraction registration code.

In addition to providing advice and technical workshops with sectoral stakeholder groups during the period of registration, the EPA has provided online documents, including a Quick Abstraction Volume Estimator, worked examples, FAQs and info-videos to support the registration process. Further support has been provided and is available by contacting edenabstractionsupport@epa.ie.

By mid-January 2019, 1,435 abstractions had

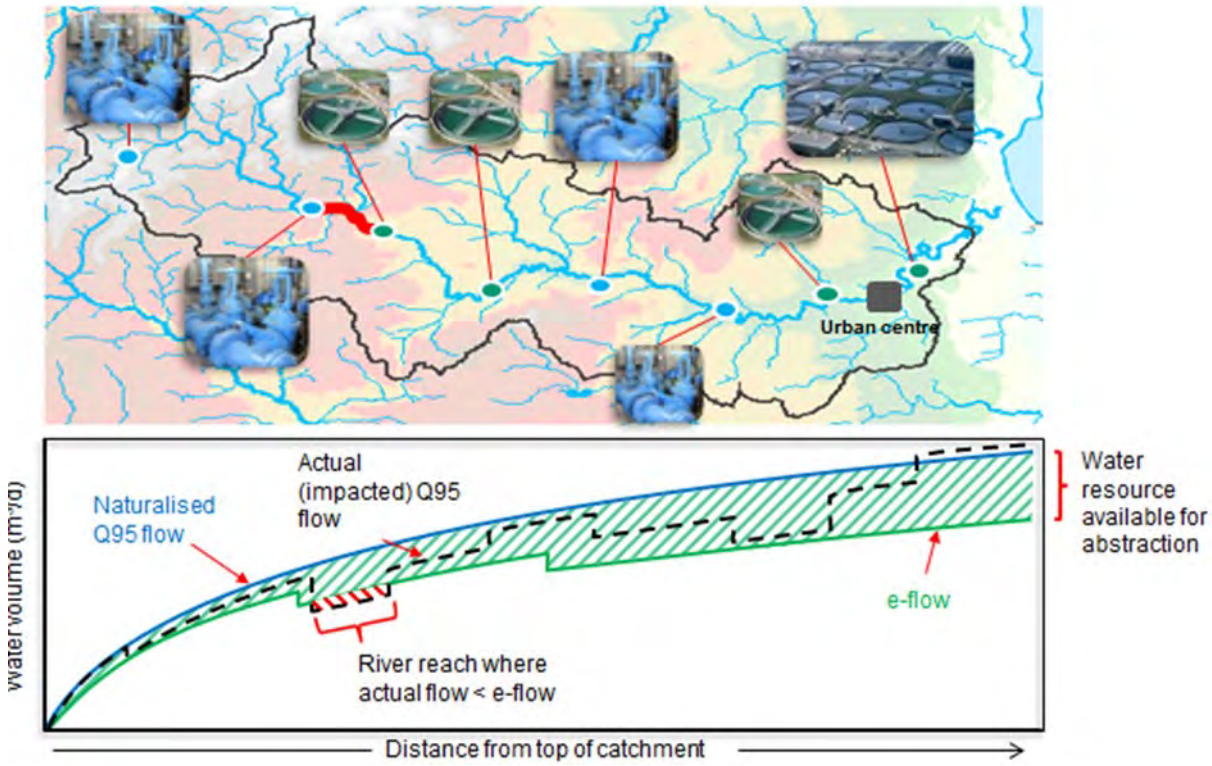


Figure 2: Schematic showing the cumulative assessment of artificial influences on river flows and management of water resources in the context of environmental flow

been registered, relating to approximately 2,300 individual abstraction points. The 2018-21 River Basin Management Plan estimated that approximately 3,000 abstractions are expected to be registered and subsequent sectoral engagement suggest a further 1,000 abstractions are still to be registered, primarily relating to the agricultural and golf course sectors. Currently the EPA is following up with sectoral representatives to encourage further registration of abstractions.

Future Abstraction Management

Approximately 82 percent of the population of Ireland are supplied water from surface water sources, although numerically the total number of schemes and small supplies sourced from surface water make up less than 25 percent of the total number of schemes and small supplies in Ireland. In addition, there are many tens of thousands of smaller domestic abstractions, most which abstract water from private wells.

Historically, the location and development of abstraction points has not been accompanied by a wider cumulative assessment of available water resources. Consequently, the absence of a formal abstraction control regime meant that it was only when a planned abstraction was identified as having the potential to impact on water quality, or other uses/users of water further down the catchment, that there was greater scrutiny of the proposed abstraction. This, coupled with many of the larger abstractions in Ireland originally being developed prior to more rigorous planning approval requirements, has resulted in many water abstractions being sourced from rivers, lakes and groundwater that are not able to sustainably support the future demands being sought in the context of development and population growth. The current Greater Dublin Water Supply is an example of one such scheme where there is now a risk that it will not be able to support the projected demand for water from the Greater Dublin Area, and this eventuality nearly came to pass during the drought of 2018.

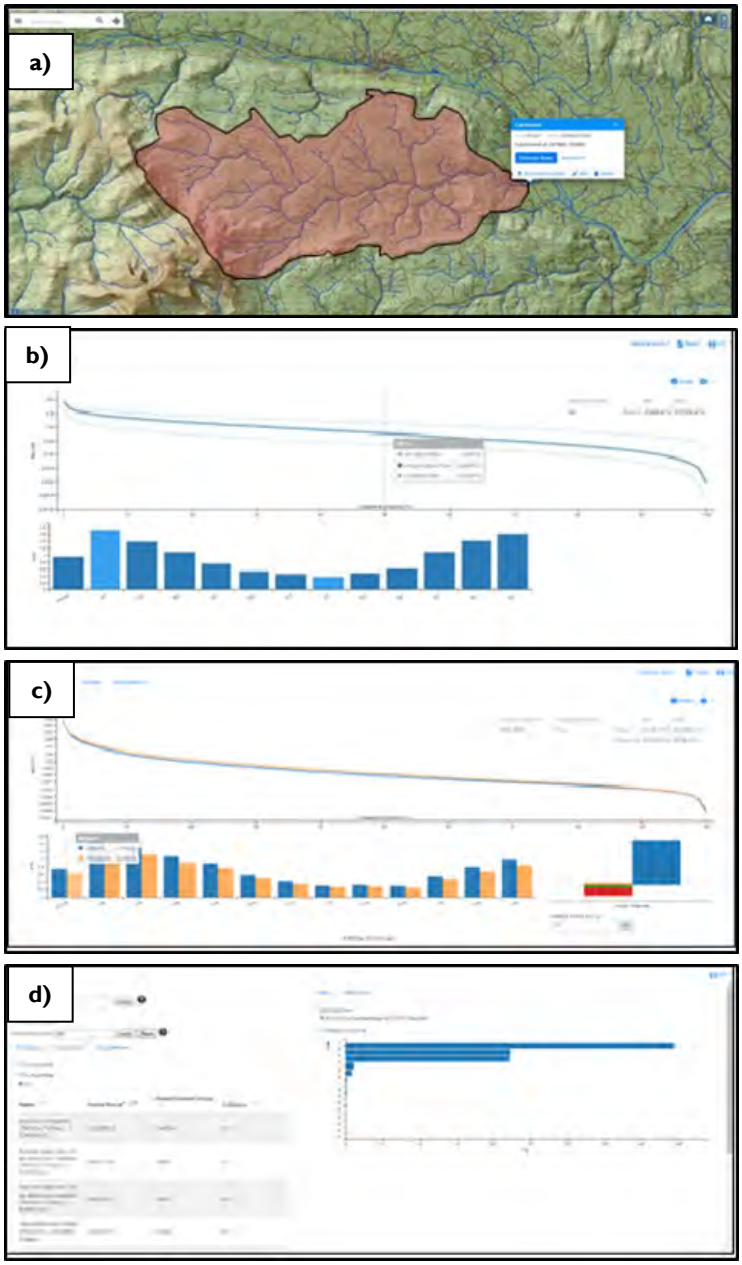


Figure 3: An example of Wallingford Hydrological Solutions Qube model outputs:
a) Upgradient catchment delineation,
b) Production of naturalised flow statistics,
c) Summary of cumulative influences on catchment water resource,
d) Comparison of influenced and naturalised flow

Consequently, assessment and the subsequent management of water resources is critical if we are to sustainably supply water, and at the same time leave adequate water to support the ecology, function and uses of our rivers, lakes and groundwater. The assessment of water resources must be cumulative, taking account of flows and water levels, abstractions and discharges, as well as any water transfers/diversions that may occur. Allowances must be given for the water required to sustain the ecology, and wider function and uses of water, otherwise known as environmental flows, and these should take account of the potential impacts caused by the abstraction at any location downstream of the abstraction.

In this regard, the EPA commissioned Wallingford Hydrological Solutions to develop their Qube water resource application for Ireland, taking account of updated hydrogeological descriptors (from the EPA Hydrotool model) and updated flow information. This application provides tools to determine the naturalised and influenced flow in rivers, which can then be compared against environmental flow criteria to determine if existing abstraction volumes or proposed future abstractions / increased volumes pose a risk to the flow required to support the ecology and wider function / uses of the river.

The EPA will review its discharge dataset and will incorporate updated abstraction data, taken from the abstraction register, to the Qube application, and will re-run the e-flow screening undertaken for the 2018-21 River Basin Management Plan to provide a high-level risk screening. This will identify those water bodies and associated abstractions that require further investigation in advance, or part of, any future abstraction control regime.

Articles

Impact of the 2018 Drought on Groundwater Levels in Ireland

Philip Maher
Hydrometric & Groundwater Programme, Environmental Protection Agency

The effects of the 2018 summer drought in Ireland are assessed using water level data from 49 boreholes.

Introduction

The EPA's National Groundwater Monitoring Network includes monitoring of groundwater levels in approximately 127 boreholes. Roughly half of these boreholes are in six nested clusters in poorly productive aquifers across the country, with the remainder focused on monitoring groundwater levels in the more productive aquifers in Ireland. This article reviews groundwater levels from this network in the context of the 2018 drought.

The minimum groundwater levels recorded during 2018, across 49 stations in the network, were reviewed and compared to historic minimum groundwater levels. The stations analysed for this article comprise at least one monitoring point from each of the nested catchments and those remaining sites in the network with validated data at the time of writing. Dataloggers have been used to record water levels at all monitoring stations since 2008 (2011 in the case of the nested catchments). Groundwater level data recorded before the installation of dataloggers is from manual dip measurements and in some cases, paper chart logging equipment.

Was the 2018 drought a record low for groundwater levels compared to previous years?

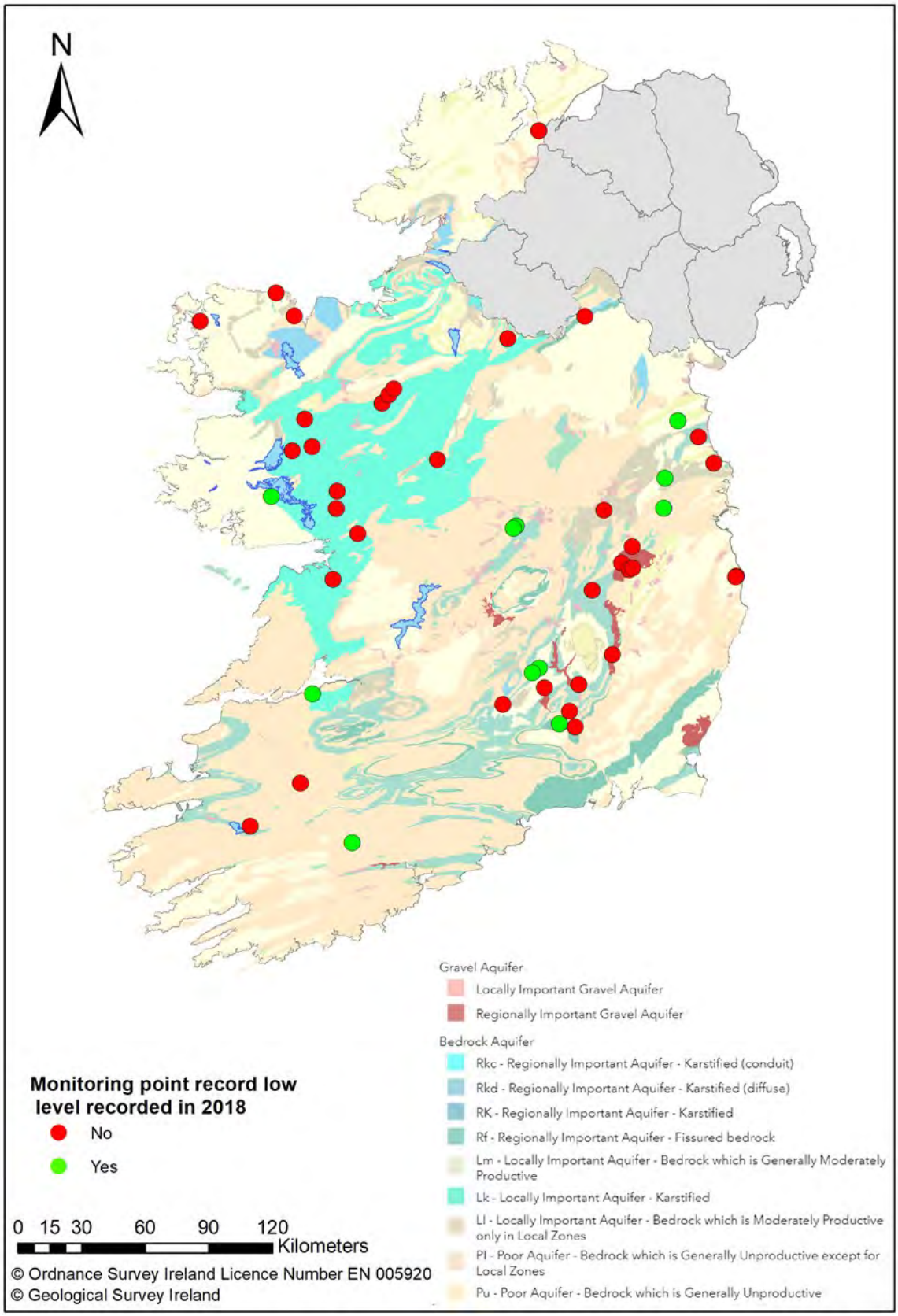
Twenty two of the 49 monitoring points in the dataset were monitored for the first time during or after 2008. Of these 22 boreholes; twelve recorded their lowest groundwater level in 2018, with lower groundwater levels being recorded at another time in the past decade at the remaining ten boreholes (refer to Map 1). Thus, for about half of the more recently monitored boreholes, 2018 saw a record low groundwater level over the past decade.

Records for 27 boreholes where there was groundwater level monitoring prior to 2008 were also examined. Several of these stations have groundwater level data recorded since the 1970s and 1980s, when they were installed and monitored by the GSI/OPW; including Borrismore Creek in Kilkenny, 1975 (Figure 1); Rathduff in Kilkenny, 1981 (Figure 2); and Oldtown in Kilkenny, 1980 (Figure 3).

Only one of these 27 boreholes (Borrismore Creek) had its lowest ever water level recorded in 2018, and the groundwater level recorded was only 7 cm less than the previous record low level, recorded in 1990. Based on the data captured from the National Groundwater Monitoring Network, this would imply that the 2018 drought did not result in exceptionally low groundwater levels in Ireland, as almost all records show the record low being recorded prior to 2018.

What were the regional variations in low groundwater levels in 2018?

The hydrological year runs from October to September, i.e. it starts when groundwater levels are expected to be at their lowest at the end of the summer / early autumn. Map 2 shows the month in which the minimum groundwater level was recorded during 2018 in



Map 1 – Borehole locations where the minimum groundwater levels recorded during 2018 were the lowest recorded for that borehole

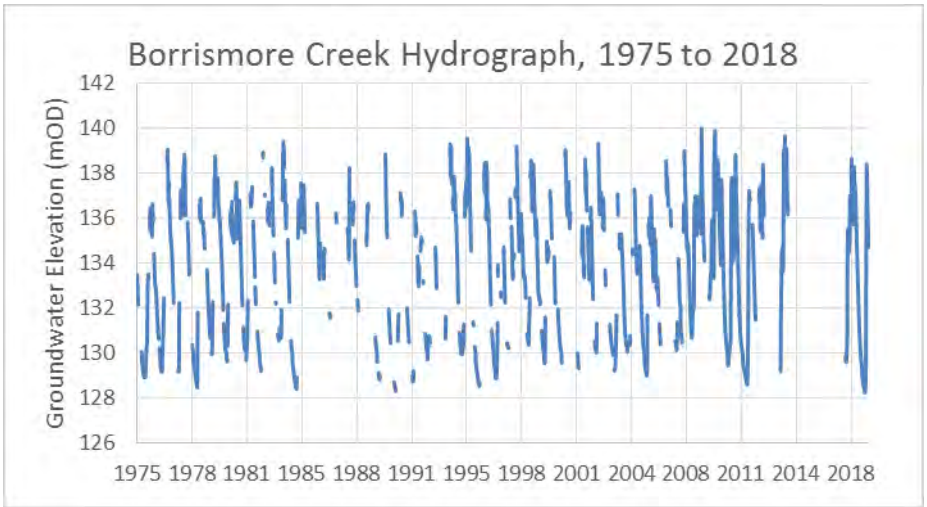


Figure 1 Groundwater levels at the Borrismore Creek borehole in Kilkenny

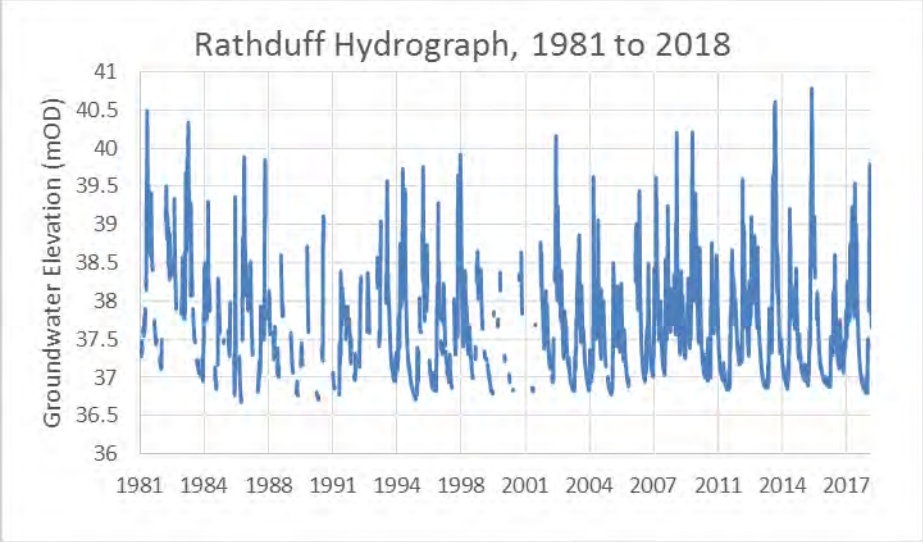


Figure 1 Groundwater levels at the Rathduff borehole in Kilkenny

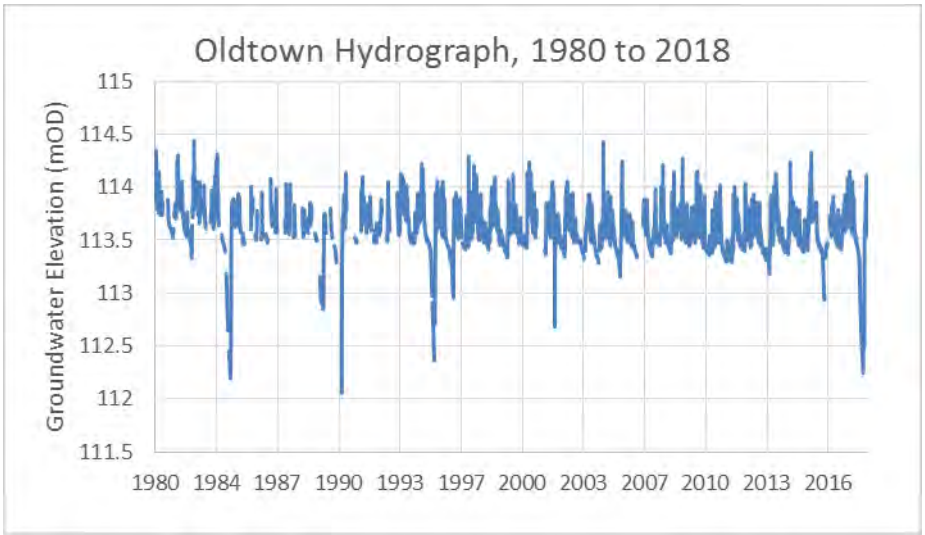
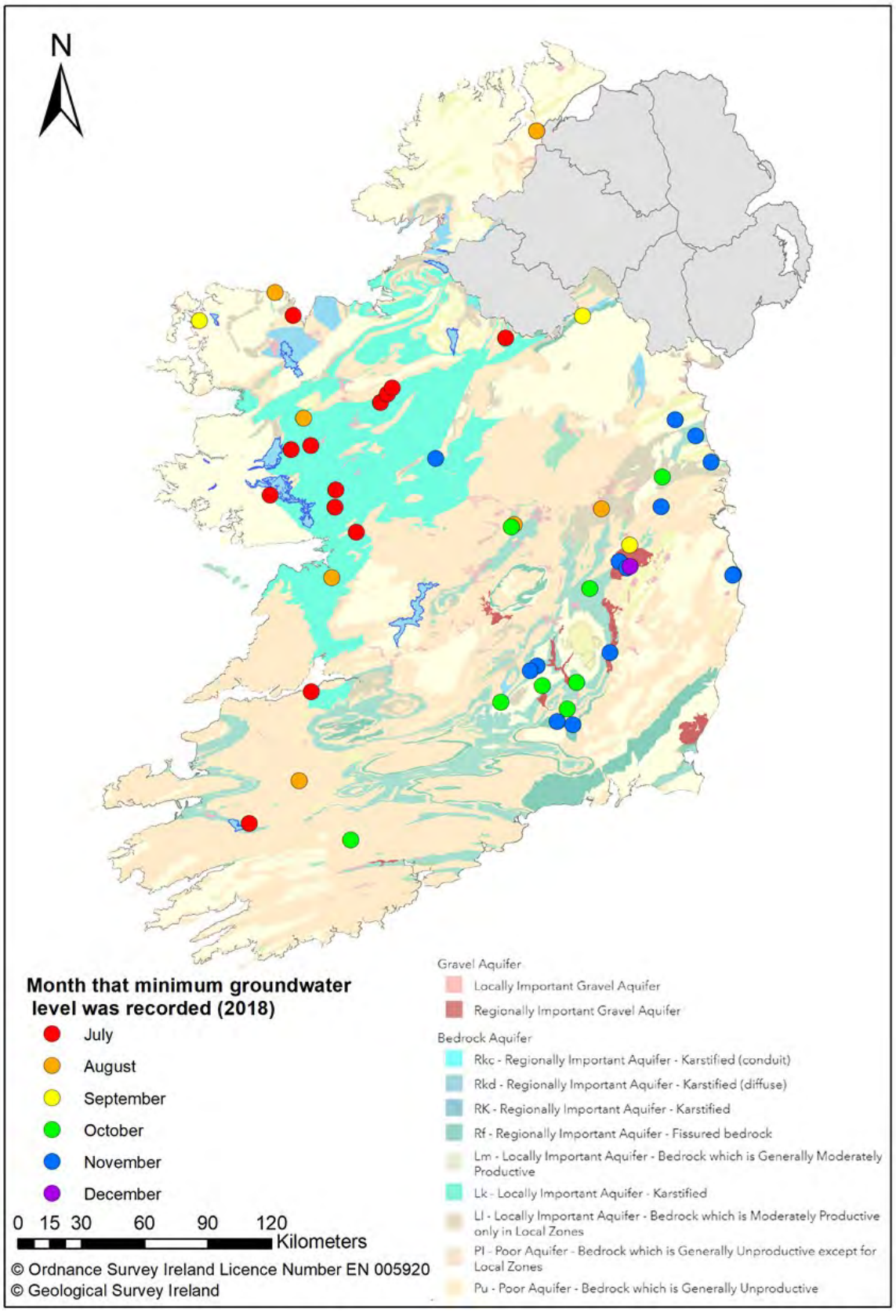


Figure 1 Groundwater levels at the Oldtown borehole in Kilkenny

the 49 boreholes assessed. There is a clear spatial pattern in the month in which the minimum groundwater level was recorded. Monitoring stations in the west of the country reached their lowest levels a few months before those in the east of the country, with minimum levels recorded in the west of Ireland in July and August, in contrast to the midlands and east of the country where the lowest levels were recorded in October and November.

This is unsurprising, as the drought broke in late July and early August on the western seaboard, whereas more prolonged spells of rainfall did not arrive to the midlands and east until November. This phenomenon has been mirrored in surface water, where water levels in some of the midlands lakes e.g. Lough Owel and Bane, are well below seasonal norms and it is these areas that will have a shorter recovery period and are more likely to become stressed in 2019 in the event of low rainfall.



Map 2 – Month in which the minimum groundwater level was recorded at each borehole during 2018

Articles

Developing a plan to protect drinking water into the future for the GWS sector

Coran Kelly *Tobin Consulting Engineers*

Developing practical measures that can be employed to protect the catchment areas of group water schemes.

Background and Objectives

The Source Protection Strategy Phase II was announced in the 2018 Autumn edition of the Rural Water Newsletter (http://nfgws.ie/wp-content/uploads/2018/10/Autumn-2018-web.pdf). The National Federation of Group Water Schemes (NFGWS), Geological Survey Ireland and Dundalk Institute of Technology are progressing a second phase of source protection work for the private Group Water Schemes (GWSs) Sector. The overall objective is to safeguard Group Water Scheme's water quality by identifying practical measures within each catchment to protect drinking water sources from current or future pollution risks. The pilot study covers groundwater fed schemes and one surface water fed scheme (Table 1). This article relates to the groundwater fed schemes. The selected schemes represent small, medium and large schemes in terms of abstraction, hydrogeological complexity and size of the 'Zone of Contribution'. The project is managed through a steering and operations committee. Specific objectives include:

→ Identifying 'critical source areas' that pose a risk to the water quality.

→ Identifying specific measures and management that would reduce the risk of contaminating including measures to raise awareness across different sectors of the community (e.g. land users, consumers, schools, general public) in collaboration with other organisations engaged in similar projects. This will be produced in a Source Protection Plan.

Some of the work and results to date

- Field mapping in the Rathcroghan area of about 5 km^2 revealed new karst features. The mapping exercise highlighted the hydrogeological complexity and the resources that would be needed to complete 'critical source area' mapping over the entire area of the catchment (180 km^2). The smaller, less

Table 1 Group Water Schemes identified for the pilot studies; * denotes GWSs in the Rathcroghan area

County	Group Water Scheme	Number of Domestic Connections	Groundwater / Surface water	Estimated daily abstraction (m^3/day)	Abstraction Threshold (m^3/day)
Roscommon	Castlestrange GWS	15	Groundwater	10	0 - 25
Roscommon	Brusna GWS	142	Groundwater	147	25 - 250
Roscommon	Gorthaganny GWS	143	Groundwater	90	25 - 250
Roscommon	Peake/Mantua GWS*	38	Groundwater	80	25 - 250
Roscommon	Corracreigh GWS*	354	Groundwater	265	250 - 1000
Roscommon	Mid Roscommon GWS*	750	Groundwater	737	250 - 1000
Roscommon	Oran Ballintubber GWS*	390	Groundwater	414	250 - 1000
Roscommon	Pollacat Springs GWS*	395	Groundwater	426	250 - 1000
Westmeath	Multyfarnham GWS	213	Groundwater	340	250 - 1000
Monaghan	Stranooden GWS	1112	Surface water	1929	>1000

Figure 1 Meeting agricultural advisers at a sinking stream in Rathcroghan to discussion mitigation options

Figure 2 Field walkover with David Kelly, founding member of Mid-Roscommon GWS

complex areas (Brusna, Multyfarnham, Gorthaganny) were quicker to map.

- Raw water quality sampling indicated relatively poor raw quality across the schemes in the Rathcroghan area where is it is extensively karstified with many sinking streams connected to the water supply springs. The raw water quality in the other schemes is relatively good.
- Communications and engagement with stakeholders included the group water schemes, agricultural advisers, home owners, schools and farmers, including a Knowledge Transfer discussion group.
- Critical source mapping and the water quality data are essential pieces of evidence based information to determine targeted measures to improve and protect water quality.

Mitigation Measures

The NFGWS is drawing up measures in the context of agri-schemes, research, current good practice, and current advice. The measures range from 'do nothing' scenarios to conservative, and potentially prohibitive, measures. Measures should have co-benefits with environmental aims around biodiversity, reduction of greenhouse emissions and ecosystem services. The measures fall into categories of 1) current good practice and regulation, 2) actions additional to improvements in current good practice and regulation, 3) Agri-environmental schemes and 4) formal recognition provision/improvement of ecosystem services. Communications, awareness and education are also considered as part of the bundle of measures. A combination and range of options may be required to meet the water quality objectives for the different schemes and also within different parts of the catchments at Rathcroghan. For the pilot schemes where the water quality is relatively good, the measures, apart from those expected generally, relate to communications and awareness and promotion of good water quality. With these catchments the task is about small improvements and maintaining a good quality status, with an emphasis on good planning, education and awareness.

Septic tanks may be a significant risk in the catchments. Under the current regulations, maintenance is the responsibility of the home owner. Whilst no specifically funded measure has been identified by this pilot, it is recommended that there are inspections (and therefore engagement with Local Authorities), and community communications events to remind owners of their obligations and the risk to drinking water, and possibly to review some additional supports such as 'community

desludging' where needed.

With regard to agriculture, existing measures include measures from previous and current agri -environmental schemes and from prescribed good agricultural practices.

The following non-exhaustive list of specific measures has been identified during the pilot:

- Fencing (single strand, sheep fencing) along water courses leading into swallow holes.
- Proper positioning livestock drinkers/feeders away from water courses, rock outcrop and karst features.
- Insertion of buffer strips (willow, hedge, vegetation, grass, variable distance/slope).
- Mounded banks/berms.
- Alternative water sources for livestock (nose pumps).
- Weed licking to replace spraying and possibly community organised.
- Planting trees generally to assist with shade which helps reduce water demand of cattle.
- Sediment traps in drains on relatively steep slopes that are conveying sediment into swallow holes.

There are other measures that are related to nutrient management include:

- Soil sampling in combination with nutrient planning
- Reduce fertiliser use
- Existing agri-environmental scheme and grant aided measures (e.g. dribble bars)
- Stocking density and sward management
- Slurry spreading management
- Appropriate livestock for ground conditions – parts of the land cannot take a heavy herd.

Some Interim Conclusions

⇒ Landowners, agricultural consultants showed a willingness to engage and are very interested in the groundwater aspects and the link between land use activities to drinking water quality and water quality generally.

⇒ The pilot is progressing the development of a 'living' source protection plan. Field scale mapping and communications and awareness are essential. Agricultural advisers will be very important to the development of source protection plans in conjunction with local authorities working with septic tank owners and other parties.

⇒ It is important to set out the water quality objectives generally, and specifically for each scheme, in order to provide the link between critical source areas and measures. This requires a current high resolution untreated ('raw') water quality dataset.

⇒ Developing a plan in large karst areas will be an iterative process.

⇒ Developing a plan in relatively small and hydrogeologically less complicated catchments, e.g., Brusna or Multyfarnham is more readily achievable.

⇒ In order to develop and implement plans in large catchments, significant resources are required to identify all the critical source areas and implement effective measures.

⇒ In order to progress the advancement of source protection plans and through discussion, the steering committee recommended the production of a framework document will apply to both surface water and groundwater supplies and will outline a multi-barrier approach that fits with the NFGWS Quality Assurance System.

⇒ The steering committee has also recommended that selected measures will be trialled in selected critical source areas.

The Local Authority Waters Programme
Working together for healthy waters

Carol McCarthy *Local Authority Water Programme*

An overview of the second River Basin Management Plan (2018-2021) for Ireland.

River Basin Management Plan

Ireland published its second River Basin Management Plan in 2018. The Plan, which covers the period from 2018 - 2021, outlines a collaborative, evidence-based blueprint to protect and improve the quality of our groundwaters, rivers, lakes, estuaries and coastal waters. New national, regional and local structures have been established to ensure a coordinated approach to problem solving, policy development and on-the-ground delivery. Where national scale measures are insufficient to bring about an improvement in water quality, local supporting measures will be prioritised to ensure the implementation of the 'right measure in the right place'.

Figure 1 The 190 Priority areas for action

190 Priority Areas for Action

190 catchment areas have been prioritised for action where evidence suggests that they could achieve their status objectives during this cycle or that they would facilitate the progression of pilots in sub-catchments with more complex issues requiring multidisciplinary and cross agency approaches.

Local Authority Waters Programme (LAWPRO)

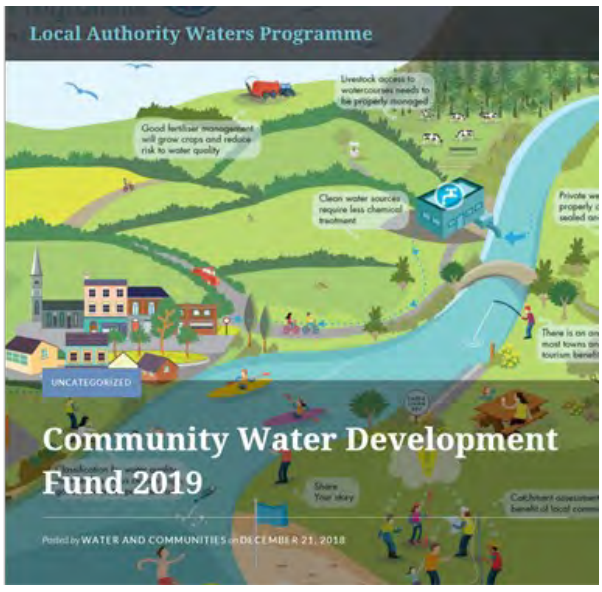
In 2016, the Local Authority Waters Programme was established to support and coordinate the efforts of public bodies working in areas connected with water quality. The programme has two elements:

1. The Communities Team has 12 Community Water Officers working from various local authority offices across the country. It has been the main tool for engagement and consultation on the second cycle of the Plan and will play a key role in the preparation for cycle 3. It supports and activates communities and stakeholders in the delivery of local water projects and initiatives. The team also works with rivers trusts and catchment partnerships which are developing across the country. It provides an essential link between active communities and various funding streams such as LEADER

Figure 2 LA waters programme team

and Local Agenda 21. The Programme, in partnership with IFI and Waterways Ireland, sponsors the 'Waters and Communities' Tidy Towns Award for local communities helping to preserve, promote and fully utilise their local natural water heritage.

2. The Catchments Assessment Team is an interdisciplinary team of 36 scientists (established in mid-2018) to provide the local evidence base to put the 'right measure in the right place'. This involves on-the-ground catchment assessments and collaboration with communities, landowners, and public bodies to develop and implement workable solutions.



Community Water Development Fund

The Community Water Development Fund, administered by the Programme, aims to support communities in progressing water related projects and initiatives, delivering benefits locally whilst also helping to meet the objectives of the Plan. The fund is open to all community and voluntary groups to assist in the protection and management of water quality, both locally and in the wider catchment. This can include the development of a catchment partnership or river/lake trust, and delivery of local projects to protect and improve water quality in a local waterbody. The fund will enable communities to get more involved in the management of their local water environment, delivering multiple benefits for present and future generations. The 2019 open call for applications closed on 12th February, 2019.

Agricultural Sustainability Support and Advice Programme (ASSAP)

The Agricultural Sustainability Support and Advisory Programme was established to collaborate with the Catchments Assessment Team, where agriculture is a significant pressure. 30 advisors based within Teagasc & ten dairy co-operatives, will work with farmers on a voluntary basis to affect behavioural change, through

improved knowledge transfer and advice. This agricultural programme is funded by two government departments and the dairy industry and it is expected that up to 5,000 farmers will receive free advice and support. A further 18,000 dairy farmers will receive advice on sustainable farming practices under the Dairy Sustainability Ireland initiative.

The initiative has a co-ordination group (Teagasc, Dairy industry and LAWPRO) to manage the programme which is financed by DAFM, DHPLG and the dairy industry. This group meets regularly with the farmer organisation groups (IFA, ICMSA, ICSA, ICOS, Macra na Feirme and INHFA) to ensure they are fully aware of the programme and its progress and to help agree its farmer facing elements.

Governance

Plan implementation is supported by a strong governance structure which was developed in 2015 and which is detailed in the Plan. The structure is underpinned by five regional operational committees where all implementing bodies meet quarterly to discuss progress in their regions. The committees are chaired by local authority Directors of Service and supported by LAWPRO staff. Membership of the committees includes local authorities, ASSAP advisors, EPA, IFI, OPW, Irish Water, NPWS, GSI, Teagasc, NFGWS, SFPA, Marine Institute, Waterways Ireland, BIM, Bórd na Mona, DAFM, DHPLG, Forest Service and Coillte. The NIEA and the Loughs Agency also attend the Border Region meetings to facilitate cross-border collaboration. Many pilot projects and EIPs are also in operation in the water area across the country and these are also represented at the operational committees.

Catchment Assessment

In 2018, there was a specific focus on training

Catchment assessment training

the catchment assessment teams in integrated catchment management and local catchment assessment techniques. The Team also developed five regional implementation plans, setting out the expected work programmes to 2021.

The Catchments Assessment Team have commenced systematically assessing each of the 190 Areas for Action (containing 726 water bodies). They will then recommend implementation of measures to bring these areas into compliance with their WFD objectives and support the relevant public bodies and land

Catchment assessment cycle

Figure 3 Riverside farmer engagement

managers in that implementation. The teams are taking a collaborative approach and will work with the responsible bodies to encourage effective implementation of measures to restore good water quality, which in turn will bring multiple benefits for the wider community and the environment. Any measures identified will be supported by scientific evidence and will be targeted at specific local areas where they can make the most contribution to water quality improvements in that catchment.

Catchment Assessment commences with a desk study where all the latest data is analysed and an understanding of flow paths within the catchment is developed. The next step is engaging with the local communities which is facilitated by the Community Water Officer and supported by the ASSAP advisor. This is followed by stream walks and field assessments. Once the specific causes of poor water quality are identified, the Team will agree measures with the responsible bodies and support implementation. One of the strengths of the programme is that the teams will focus on all pressures together.

Where agricultural land management measures are identified, the teams work with the Agricultural Sustainability Support and Advisory Programme which focuses on knowledge transfer and collaboration, aimed at driving behavioural change towards best practice and more sustainable farming practices. The advisors follow community information meetings with a farmer specific meeting streamside, including demonstrations and discussions. The advice they provide to individual farmers in the area for action is free and confidential and focuses on field scale practical measures and behavioural change that can support improved water quality in their area.

High Status Sites

The EPA's recent Water Indicators 2017 report shows a continuation in the trend of a loss of high quality rivers (14 fewer sites in 2017 than in the period from 2013-2015).

As recommended in the Plan, a Blue Dot Programme is being developed which will focus on the preservation and restoration of Ireland's High Status or Blue Dot sites. A multi-agency working group has been set up to develop the Programme. A Blue Dot Scientist has been appointed within the Catchments Assessment Team to support the work of the Programme and ensure suitable actions are fully co-ordinated in those areas.

Promoting the Profession – Engineers Ireland 'The State of Ireland 2018 Report: A review of water/wastewater and flooding Infrastructure in Ireland'. Summary of 'The State of Ireland 2018' report

Monica Lee, Geological Survey Ireland

Over the last eight years Engineers Ireland has produced annual reports on 'The State of Ireland: A review of the infrastructure in Ireland'. This series of reports are described by Caroline Spillane, Engineers Ireland's Director General, as 'expert-led assessment of the key elements of our system of infrastructure…' which '… seeks to inform decision making on the planning, design and delivery of infrastructure to ensure the prosperity of Irish society'.

In 2018, the report focused on 1) water and wastewater and 2) flooding infrastructure. Two panels of engineers and other professionals were established to assess, discuss and then grade (see Figure 2) the infrastructure for each of these sectors. Two-year and five-year priority actions needed to improve the performance of these infrastructure networks were recommended. The final grade and recommendations were reached by consensus with the overarching goals stated as protecting public health, the natural environment and supporting future development.

The panels for these two sectors covered a range of expertise and included representatives from:

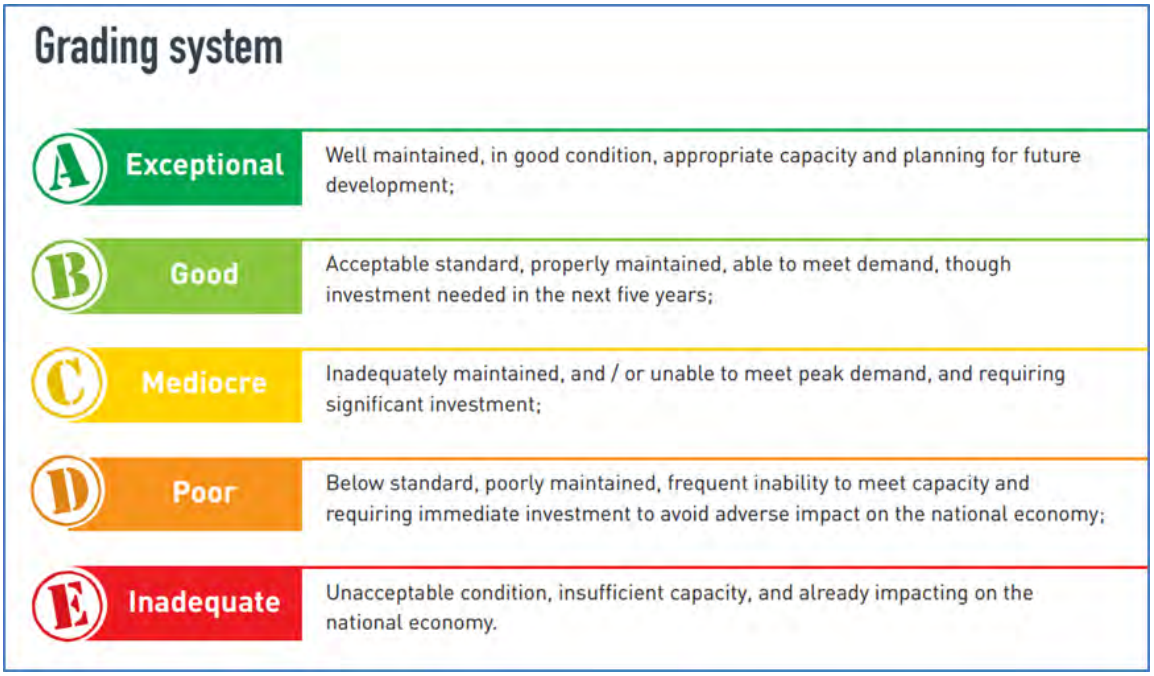


Figure 1. Engineers Ireland State of Ireland 2018 scorecard.

- Department of Communications, Climate Action and Environment,
- Department of Housing, Planning and Local Government (DHPLG),
- Department for Infrastructure Northern Ireland,
- Dublin City Council,
- University College Dublin,
- Environmental Protection Agency,
- Geological Survey Ireland,
- Health Service Executive,
- Inland Fisheries Ireland,
- Irish Water,
- National Federation of Group Water Schemes (NFGWS),
- National University of Ireland Galway,
- Northern Irish Water,
- Met Éireann,
- Office of Public Works,
- Transport Infrastructure Ireland,
- a range of consultants that directly work in the water, wastewater and flooding sectors,
- and Engineers Ireland, including Richard Manton who pulled all of the information together.

For water/wastewater infrastructure, assessments were undertaken for i) water resources, ii) public water supply, iii) public wastewater and iv) private water supply and wastewater. In the flooding sector, in order to work towards holistic flood risk management for the protection of public health, critical infrastructure and the natural environment, the state of current infrastructure for i) river, ii) coastal, iii) urban, iv) rural and v) groundwater flooding was assessed.

Over a three month period, which included 4 meetings, internal and external discussions and completing grading and assessment forms, the consensus on the grades was a 'C' for each of these sectors, which is further described as:

'Inadequately maintained, and / or unable to meet peak demand, and requiring significant investment'.

More detail and description is given in the report and a summary of the grades for the sub-sectors chosen is shown in Table 1.

The recommendations – 13 two-year actions and 8 five-year actions for water/wastewater; 7 two-year actions and 9 five-year actions for flooding – originated from different parties around the table and were developed through discussions within the group. The scope of recommendations reflected the wide range of professionals on the panels. The recommendations covered:

- Quantifiable and/or hard infrastructural needs (e.g. upgrading of treatment plants, eliminating the discharge of untreated effluent, reduction of water leakage from the networks, implement (structural) flood plans),
- Provision and implementation of source protection plans/drinking water safety plans, also in line with Water Framework Directive needs;
- Improve communications – within the sector, with the public and to inform policy needs – through stakeholder/cross-sectoral groups, public engagement campaigns and education programmes;
- Proactive planning for future demographic and climate change forecasts;
- Planned and maintained data collection and analyses programmes and investment in research.

The report also included more general assessments of the communications, energy, transport and waste sectors[1]. These sectors were also giv-

en a rating of 'C'. The entire report was completed within a six month period and launched on the 4th July 2018 by Minister for Business, Enterprise and Innovation, Heather Humphreys T.D.

A note on the process

The process was interesting, informative and open to input, with the experience around the table steering the content and decisions. From a groundwater and environmental point of view, having bodies such as the DHPLG, EPA, GSI, HSE, NFGWS and academic institutes, with support from organisations such as Irish Water and IFI, was beneficial. These groups were able to complement the hard infrastructural knowledge by further emphasising the importance other areas such as environmental considerations; the impact of land-use management and planning; the need for data collection/analyses and research, as well as communications, education and outreach.

Overall, the process demonstrated how having a diverse but representative advisory panel can make the output more holistic and presumably increase the likelihood of success if the recommendations are implemented. It also provided a networking and upskilling opportunity to help understanding the complexity of issues and views around the table.

Promoting the profession

The benefits of this type of document are wide ranging. An assessment of the current status of a sector implicitly highlights a need to fill any

Table 1. Assessment of chosen water/wastewater and flooding infrastructure sub-sectors

Sector/Subsector	Sub-category	Grade
Water/Wastewater		***C***
Water Resources	Source protection	D
	Source availability	C
	Abstraction	C
Public Water Supply	Large scale treatment	C
	Small scale treatment	D
	Distribution network	D
	Demand management	C
Public Wastewater	Collection	C
	Large scale treatment	C
	Small scale treatment	E
	Sludge management and treatment	D
Private Water Supply and Wastewater	Private Group Water Schemes	C
	Private wells	D
	Domestic wastewater	D
Flooding		***C***
River		C
Coastal		D
Urban		C
Rural		C
Groundwater		C

[1]More in-depth assessments by expert panels have rotated through these different sectors over the previous years.

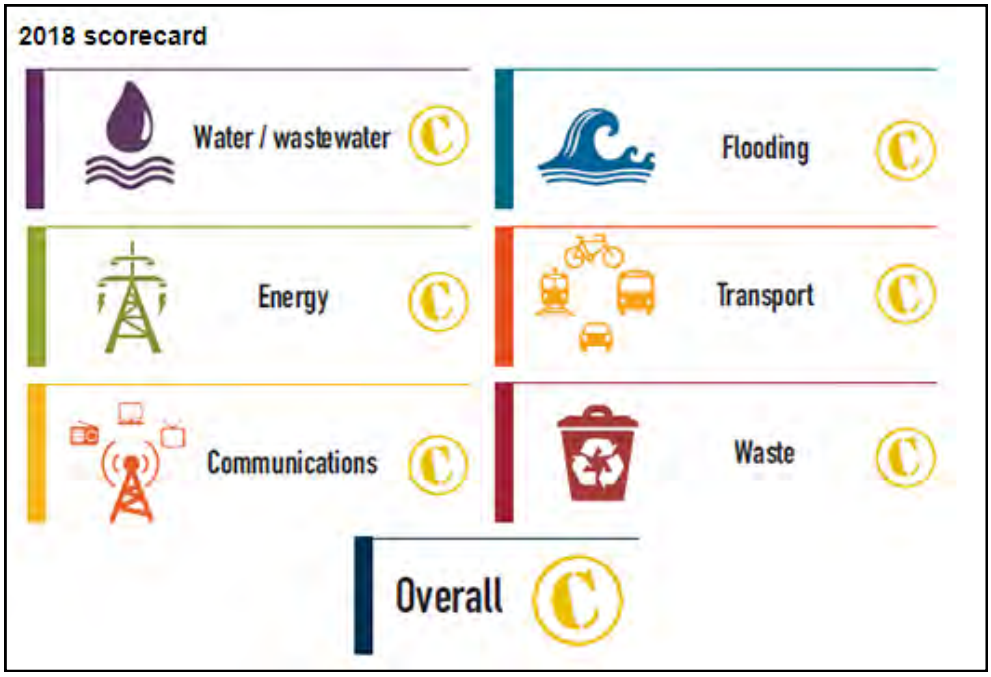


Figure 2. Infrastructure Grading System.

gaps identified, which includes forecasts of future needs. Even when an assessment is high level, such as in the State of Ireland reports, it clearly signals the current and future needs for the different technically qualified people and is therefore a very useful and important document to inform future roadmaps for policy-makers and educational institutions, amongst others. More generally, this straightforward document also highlights the need and importance of technically qualified people to any reader, which helps to raise awareness.

In the case of Engineers Ireland, their focus is the current and future needs for engineers although the 2018 water/wastewater and flooding report also highlighted the needs for hydrogeologists, hydrologists and environmental scientists.

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Engineers Ireland State of Ireland Reports (2011-2018). http://www.engineersireland.ie/communications/publication-archive.aspx

Promoting Geology

On this point of promoting the profession, given that hydrogeology sometimes seems to be a hidden profession looking at a hidden resource, is this something that the hydrogeological community should now follow suite? Perhaps even a once-off report highlighting the importance of, and need for, the hydrogeologist in hydrogeological, water resource, environmental and infrastructural projects would be a useful document to promote the need to include groundwater expertise – and particularly when dealing with challenges of Irish hydrogeology. Certainly there are many case study examples of excellent and important work and presenting these may help to demystify the science and raise awareness to policy makers, other professionals, educational institutions and, more generally, people who need to know about groundwater or groundwater related topics and issues. Food for thought?

Quantifying submarine and intertidal groundwater discharge and linearity of the coastal karst aquifer Bell Harbour

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Understanding the hydrology of a coastal karst aquifer

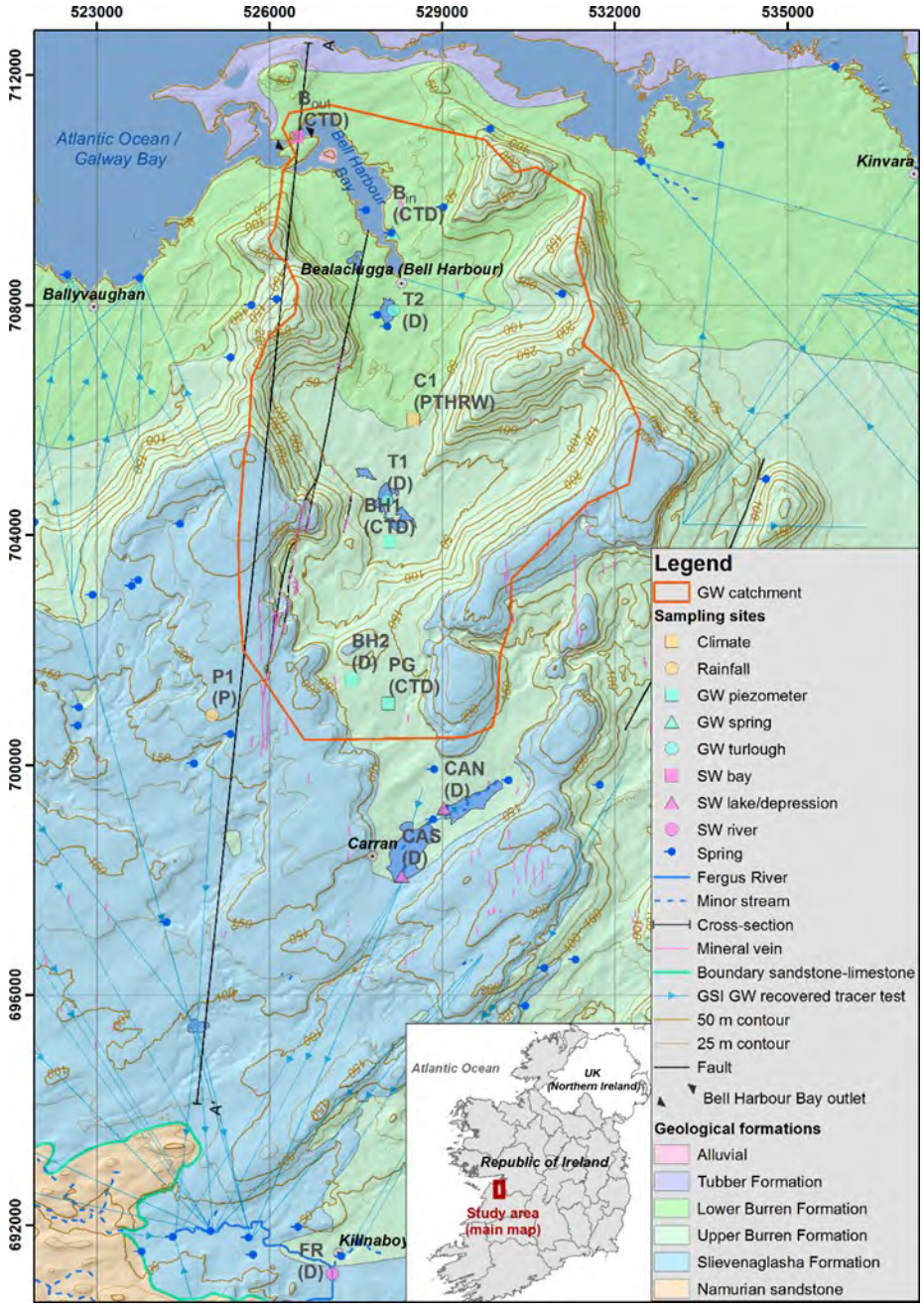

Figure 1: Groundwater catchment of Bell Harbour, including topography, geology, previous successful tracer studies, and the hydroclimatic monitoring network partly used in this study.

Introduction

The hydrogeology of the north-eastern part of Burren limestone plateau south of Bell Harbour (Bealaclugga) has received increasing attention over the recent past. The first catchment boundaries for a 'Bell Harbour catchment' were sketched by Drew (1990) anticipating that drainage occurs to the north via intertidal springs at Bell Harbour and Pouldoody. This conceptual understanding was maintained by Perriquet, et al. (2014) as well as McCormack et al. (2017) who assumed a catchment size of 50-56 km^2 although notably, the extent and location of the southern boundary was subject to uncertainty. Bunce and Drew (2017) suggested that groundwater may flow along mineral veins discharging into Galway Bay, following potentially N-NNW trending Variscan veins (Moore and Walsh, 2013). Indications of the existence of such hydraulically active channels include the 90 m deep cave Poll Gonzo (Bunce, 2010), and the recently excavated 'sinkhole', Deelin Pot.

Indeed, both of them have recently been proven to be hydraulically connected to Galway Bay by tracer tests (Schuler, et al., 2018b). Karst features in the catchment that have been identified using geophysics include a shallow conduit along the base of the valley as well as discharging submarine sinkholes in the bay (McCormack et al., 2017; O'Connell et al., 2018). Most recently, a systematic approach linking meteorological data, water level fluctuations within a turlough and two open boreholes and estimated submarine and intertidal groundwater discharge was combined with uni-/bivariate statistical analysis and semi-distributed numerical modelling using high resolution spatio-temporal time series (Schuler, et al., 2018a). The results of this study suggest that this part of the Burren is drained seasonally via intertidal springs along the coast, and perennially via submarine groundwater discharge (SGD) into Galway Bay.

The quantitative study of coastal karstified carbonate aquifers is relevant for understanding recharge, flow and discharge dynamics. Furthermore, this helps to interpret interactions between groundwater resources and the marine. For example, the discharge of coastal aquifers and associated nutrient loading originating from landuse may enhance the development of toxic algal blooms, promote the development of jellyfish or harmful micro- or macroalgae.

Hence, the purpose of this article is to highlight the usefulness of bivariate statistical analysis and the estimation of Submarine intertidal Groundwater Discharge (SiGD) in understanding certain aquifer behaviour, as exemplified by the karst catchment of Bell Harbour Bay.

Study area

The Bell Harbour catchment area was conservatively delineated as 56 km^2 (Figure 1). The elevation ranges between 0 masl in the north and approx. 340 masl on top of the escarpments. The entire catchment is underlain by highly karstified Lower Carboniferous limestone, which is at least 510 m thickness and dipping 2 - 3 degrees to the south.

Surface water features are limited to the seasonally flooded Carron depression, which is an upland polje-like feature, fed by surrounding springs and rainfall recharge. Carron consists of a northern (CAN) and southern (CAS) part drained by sinkholes. In turn, groundwater-driven features, such as turloughs, exist in the lower part of the catchments, i.e. Gortboyheen, Luirk and Muckinish responding to the piezometry of the surrounding aquifer. Rainfall directly infiltrates, providing concentrated and diffuse recharge without surface runoff. Within the aquifer, flows concentrate towards larger openings, i.e. conduits, heading towards the north, which discharge via shallow SiGD into Bell Harbour Bay and via SGD into Galway Bay.

Methods

The methods used in this study are a) cross-correlation analysis; and b) estimating SiGD using a mass-balance approach.

SiGD was estimated using a 'pollution flushing model' for tidal embayments (Barber, 2003). The method is a spatially uniform, zero-dimensional approach, using the volume of the bay and the tidal water level fluctuation. In this study, electrical conductivity (EC) was used to quantify the freshwater discharge into the bay, observed offshore at the outlet of Bell Harbour Bay (Bout, Figure 1) compared to the natural background EC of the sea.

Cross-correlation was applied based on the simplified assumption that the time series can be regarded as bivariate stochastic processes that are stationary (Box and Jenkins, 1976; Jukić and Denić-Jukić, 2015). Even if stationarity is not totally valid in the context of highly dynamic karst systems, cross-correlation has been widely applied measuring what can be understood as 'average dynamic' response. Cross-correlation measures the strength of the linear relationship

between two time series, ranging between +1 (perfectly correlated) and -1 (perfectly anti-correlated. Further, a lag-time informs about the delay as response between an input and output time series. In karst hydrology, cross-correlation has been used by several authors to characterise input-output relationships, e.g. between rainfall (input) and groundwater discharge or piezometric head (output).

Results

Estimating SiGD

Figure 2a shows the daily rainfall along with estimated SiGD into Bell Harbour Bay at B in (Figure 1), as calculated from the min / max. EC records at the end of ebb and flood tides observed at Bout and application of the 'pollution flushing model'. In addition, the groundwater level observed at BH1 is also plotted (Figure 2b).

The magnitude of the EC time series amplitude at the end of the bay is the direct result of differences in salinity at the end of the ebb tide and during the flood tide. Hence, higher amplitudes suggest increased dilution of sea water in the bay with groundwater discharge, which is translated into higher SiGD (Figure 2a).

In spring 2016, SiGD reached a peak discharge of 4.1 m^3/s. Conversely, during summer and autumn 2016, the discharge from the bay clearly drops and largely varies between close to 0 and 0.5 m^3/s even though rainfall continued to be persistent. Hence, during these periods significant rainfall events do not appear to cause a corresponding increase in SiGD.

However, the pattern of SiGD may be linked to the piezometric head in the aquifer observed in BH1 (Figure 2b). As can be seen the discharge of the aquifer as SiGD seems to be more correlated with elevated groundwater levels than with rainfall events.

Cross-correlation analysis

Cross-correlation was applied to evaluate relationships between rainfall, borehole water level

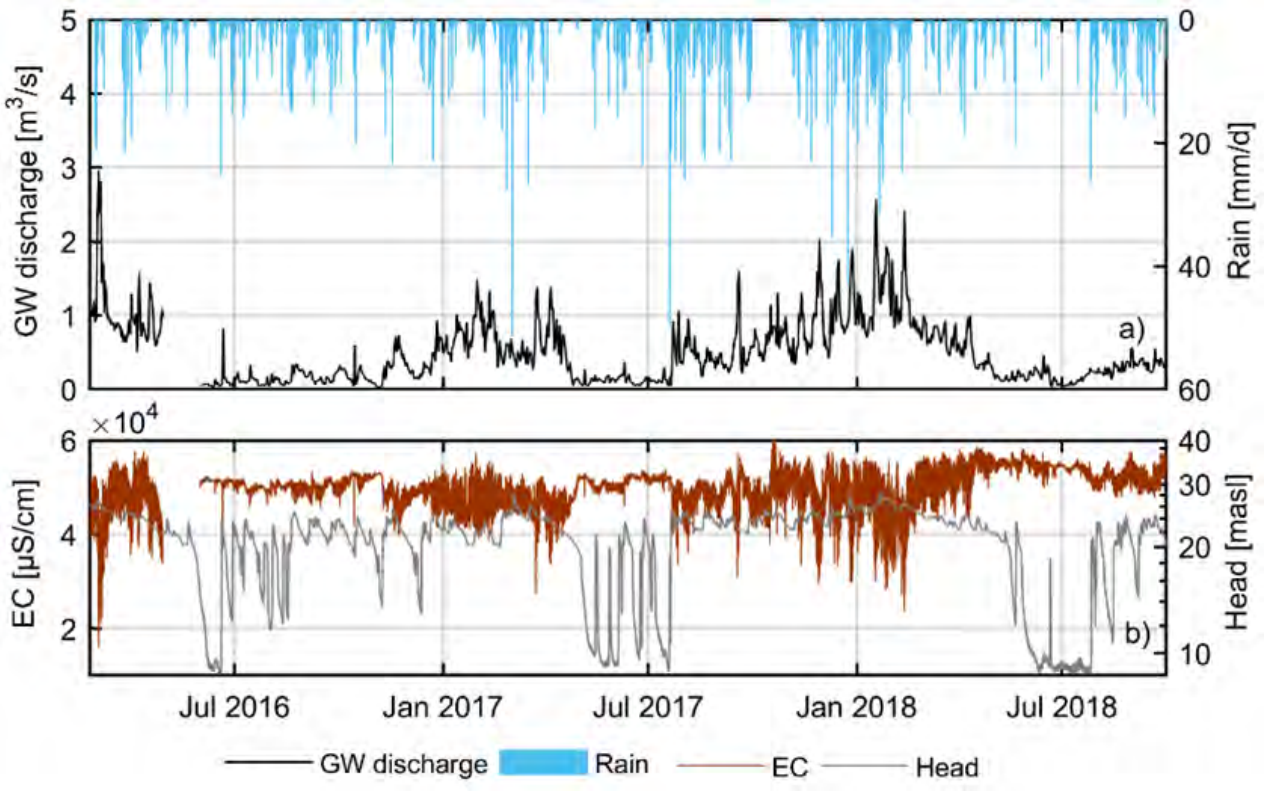

Figure 2a Estimated SiGD in m^3/s at Bell Harbour Bay and rainfall in mm/d; b) minimum and maximum EC values in µS/cm of ebb and flood tide observed at SiGD1+2 and hourly piezometric head (log scale) at BH1 in masl.

and SiGD time series in order to: a) infer drivers for SiGD, b) quantify catchment dynamics and c) provide quantitative information from which more accurate catchment boundaries can be defined.

Relevant cross-correlation coefficients (CCC) are mapped in Figure 3. Each arrow links an input time series (start of arrow) with an output time series (end of arrow). The combination of arrow and the +/- of the lag time indicates the direction of dynamics: if the lag is positive, the direction of the input-output response follows the arrow; if the lag is negative, the direction of dynamics is in the reverse direction to the arrow. It should also be noted that the CCC results highlight the degree of linearity.

The results show that all lag times are relatively low, suggesting quick dynamics between the observed locations. Furthermore, all CCCs are positive ranging between +0.26 and +0.88, while lag times range between -1 d and +130 h.

The lowest CCC of +0.26 (which implies no significant relationship) is between rainfall and SiGD. In turn, CCCs between borehole and Carron water levels against SiGD are much larger ranging between +0.59 and +0.88. A relatively strong linearity of +0.59 and +0.69 is observed between BH1/T1 and SiGD. Strikingly, linearity of the same or even higher magnitude (+0.69/ +0.71) is revealed between CAS/CAN and SiGD. An even higher CCC was estimated between CAN and T1 (+0.83) and CAS and T1 (+0.88). It should be noted that such high coefficient values would be considered to be extremely high for hydrological systems.

Conclusions and discussion

The coastal aquifer of Bell Harbour is highly karstified resulting in rapid recharge and complex flow and discharge dynamics. Long-term time series were used to better understand some of the dynamics:

- Highly variable EC concentrations in the tidal water draining from Bell Harbour Bay imply

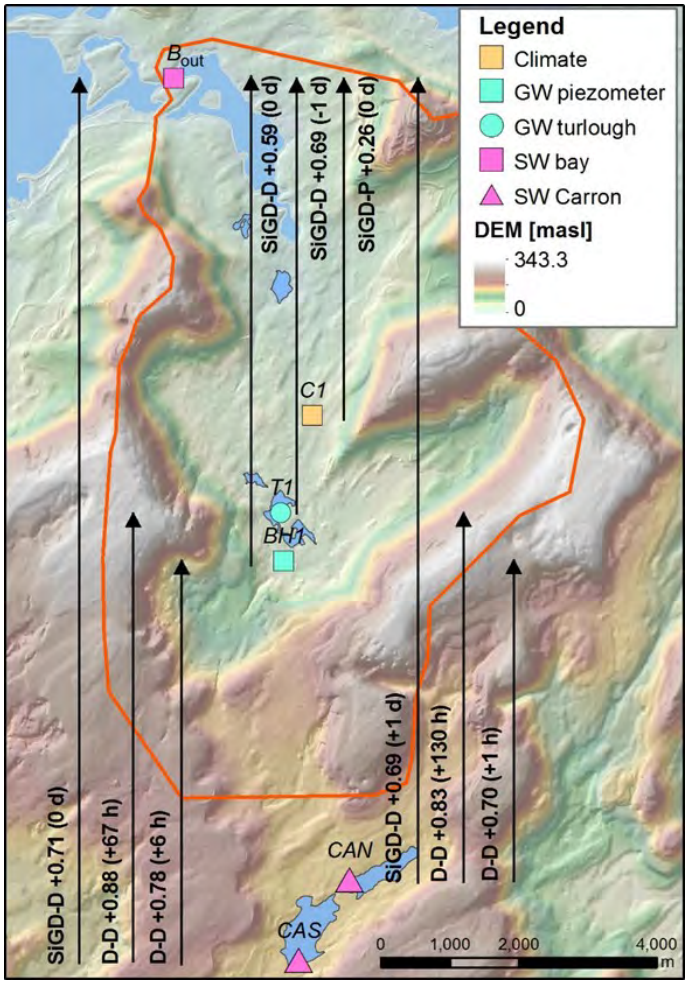

Figure 3: Cross-correlation coefficients with lag times in day (d) or hours (h) for time series of rainfall (C1), borehole (BH1), turlough Gortboyheen (T1), Carron South (CAS) and Carron North (CAN) and estimated SiGD (Bout); D = depth, P = rainfall, SiGD = submarine intertidal groundwater discharge; GW = groundwater; SW = surface water. Arrows indicate the direction from input to output connecting the two sampling sites to which the CCC and lag time refer to.

associated fluctuation of SiGD into the bay. During summer, SiGD is very low, while during winter, an increase can be observed. Hence, the regime of SiGD is seasonal;

- Individual surges or drops of SiGD can be linked to the piezometric head in BH1;
- The SiGD regime shows a relatively high linearity with observed water levels in the catchment, suggesting that SiGD is associated with the piezometry observed in the aquifer;
- Short lag times of CCCs suggest rapid recharge, flow and discharge dynamics in the catchment in

the range of hours;

- Exceptionally high CCCs between CAS/CAN and T1/SiGD raise the question of how or why such high values occur – potentially through a connection?

One conclusion from the study therefore is that the seasonal variation of EC in Bell Harbour Bay is caused by the seasonality of SiGD into the bay. During summer, little to no dilution of sea water can be observed as a result of discharged groundwater, even during periods of rainfall (and taking increased evapotranspiration rates into account). This is different from autumn to spring where obvious dilutions in salinity are measured in the bay, which must be associated with increases in SiGD. Hence, this seasonality has been interpreted as an overflow mechanism from a large underlying karst conduit drainage system.

The high CCC between CAS/CAN and the other observed groundwater related time series is also very interesting. Conceptually, the flooding and discharge dynamics of Carron and Gortboyheen (for example), might be considered to be unrelated and yet the time series indicate a very high degree of linearity. The question is therefore, what is causing such high linearity between the two seasonal lakes: is it merely coincidental given the proximity of the two features, or are perhaps Carron and Gortboyheen at least seasonally associated, such that the potentiometric head in Carron can influence the head down at Gortboyheen (via either direct flow or maybe pressure transfer)? This, however, needs further investigation to come to a conclusion, such as a quantitative tracer study between Carron and the Fergus river, for example.

In summary this article has highlighted the use and relevance of the methods used on high-resolution and long-term (>1 year) monitoring data in order to help to understand flow processes in such complex karst catchment. For example, rainfall exhibits little direct influence onto the discharge into the bay. Instead, freshwater discharge into the bay must be approached by knowledge of the groundwater dynamics within the aquifer, i.e. the rainfall-discharge relationship is largely influenced by the aquifer's flow paths.

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Geothermal Potential of Irish Palaeokarst

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Investigation of Geothermal Potential in the Irish Carboniferous Palaeokarst using Oil & Gas exploration techniques

Introduction

Limestone (and dolomite) is susceptible to dissolution when it encounters mildly acidic water. This results in the formation of topography known as 'Karst' which is characterised by a drainage system of caves and sinkholes. Almost half of the island of Ireland is underlain by limestone, of which a high proportion has been karstified. The karstification is believed to be extending to depths of >2km in the subsurface in some areas. Recent studies have identified regional tectonic inversion of the island in the Tertiary period, causing limestones to be uplifted, thus becoming more susceptible to karstification. In addition to the evidence for Tertiary uplift and karstification, there are indications that similar processes occurred in the Jurassic and Permian in Ireland (Drew & Jones, 2000).This would imply that older (and therefore, deeper) limestones such as the Waulsortian may have been karstified; and if karsts were preserved at considerable depth, it is believed that these limestones could be exploited for deep geothermal energy.

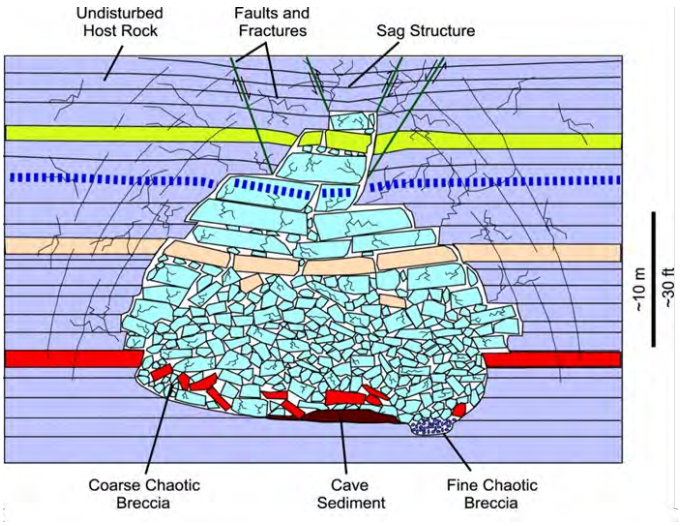

Figure 1. Burial evolution of a palaeocave system (Loucks R, 1999)

In accordance with Ireland's National Climate Mitigation Plan (July 2017) and the Geological Survey of Ireland (GSI)'s current Research Roadmap, the authors were awarded a GSI short-call research project in 2017. The research focused on investigating geothermal potential of the Irish Carboniferous karstified limestones at depth.

Oil and gas analogue

The Ellenburger Group of the Permian Basin in West Texas, USA, is part of a Lower Ordovician carbonate platform sequence. The Ellenburger group is a prolific oil producer. The oil is being produced from a 'collapsed (coalesced) palaeocave' formed due to karstification of the limestone formation. Such 'collapsed coalesced palaeocaves' may be characterised by reservoirs that are hundreds to thousands of metres across, thousands of metres long, and tens to hundreds of metres thick. Internal spatial complexity is high, resulting from the collapse and coalescing of numerous passages and cave-wall and cave-ceiling strata. These breccias and fractures are commonly major reservoirs in the Ellenburger Group as they have good porosity and permeability that allows the storage or flow of oil (and water). Hydrocarbon production ranges from as shallow as 856 ft (261m) in West Era field in Cooke County, Texas, to as deep as 25,735 ft (7844m) in McComb field in Pecos County, Texas. (Loucks R. , 2003).

If we were able to find potential 'collapsed coalesced palaeocaves' in the deep Waulsortian Limestones onshore Ireland, we could exploit

similar highly porous and permeable limestones for deep geothermal energy.

Strategy

The investigation strategy was to identify from the literature and anecdotal evidence where karst features might occur at depths of more than 800m (a minimum depth for finding warm hydrothermal fluids). The database included data from various public sources (borehole data, well logs, bedrock geology, aquifer maps etc), as well as recently acquired seismic data kindly provided by Hannan Metals Limited for the purpose of this study.

Good quality hydrocarbon reservoirs are proven in karsts as in the Ellenburger Group, thus, techniques and lessons learned from the oil and gas exploration industry were applied to the data to investigate the potential for geothermal energy as part of this study.

Findings

Of the two main Carboniferous basins, in which the Waulsortian mudbank limestone, one of the most extensive limestone formations onshore Ireland, formed viz. Dublin Basin and Shannon Trough, the latter was determined to host the Waulsortian Limestones at potentially greater depths. It was important to prove that the Waulsortian at depth had been karstified (at some time in the past) and that enhanced porosity and permeability due to karstification had been preserved. With the available sources of data, evidence of karstification was gathered as described below:

- ***Karst features in outcrop/borehole data:*** Anecdotal evidence and that from borehole drilling reports and core descriptions clearly record occurrences of cavities and breccias that are related to karstification and possibly collapse.
- ***Uplift and erosion post-dating deposition of Waulsortian:*** Post depositional uplift of carbonates may cause exposure of surfaces, making karstification more likely. Multiple episodes of uplift are recorded in the literature (Drew & Jones, 2000) and there may have been instances of Waulsortian karstification.
- ***Marine incursions***: The action of mixed marine and fresh water on carbonates makes susceptibility to karstification increase. Multiple events of marine incursion are recorded in the literature (Wilson, Permian and Mesozoic, 1981), (Fritz, Wilson, & Yurewicz, 1993).

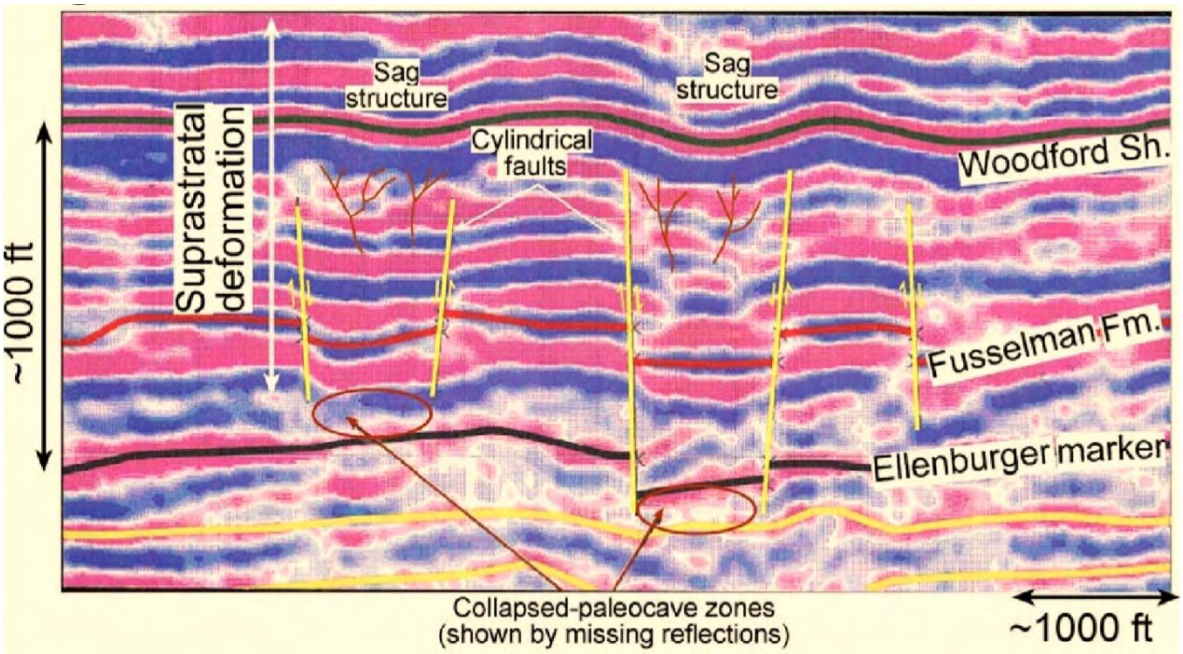

Fig 2. Seismic example over an Ellenburger palaeocave system, West Texas (Loucks R. , 1999)

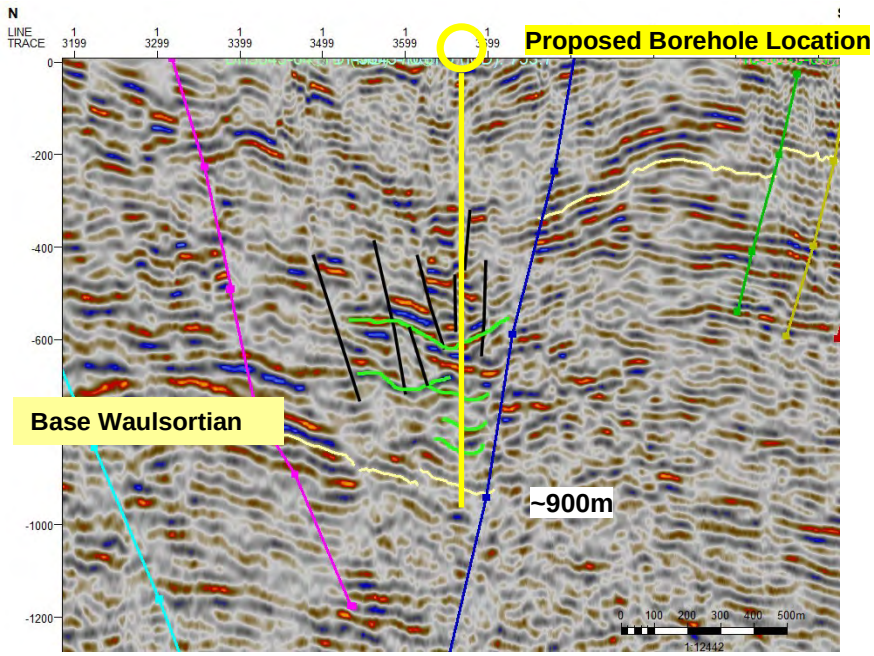

Figure 3. Proposed location for borehole to drill Kilmurry Prospect - Coalesced Collapsed Palaeocave with target at ~900m depth. Comparison with Ellenburger conceptual model. (Data Courtesy of Hannan Metals)

- ***Faults as conduits of fluid flow:*** The presence of large faults increases the potential for a formation to be karstified as these faults are likely to be conduits of upward (and downward) fluid flow.

With the evidence observed and data gathered, the project moved into its next phase – Seismic Analysis. In the Ellenburger Group, the coalesced collapsed palaeocaves were identified (interpreted) on the seismic data at locations where 'missing reflections' coincided with locations above which supra-stratal deformation (in the form of sag structures, cylindrical faults etc.) was observed (Fig 2.). The analysis aimed at identifying similar features in the 2D Seismic dataset provided by Hannan Metals, in the Kilbricken regions of the Shannon Trough, Co Clare.

Results

The base of the Waulsortian was interpreted to be as deep as 900m in one of the 2017 2D lines. With the primary objective in mind, the analysis was focused only on regions where the Base-Waulsortian was deepest. A general deepening of the Waulsortian was observed towards the south, and this is supported by regional geological mapping. One of the major faults in the south (dipping north) (blue fault in Figure 3), in the Kilmurry area, had a displacement of greater than 200m, with the depth of the Base of the Waulsortian on the hanging wall at ~900m. Large faults are known to be conduits for upwards movement of fluids from deeper sources.

Interestingly, sag patterns were observed in the high amplitude reflectors between 400m-700m above the deepest point of the Waulsortian (against the fault). The reflectivity was observed to reduce with depth; however, polygonal faults in the overlying strata appeared to be radiating from a focal point (location).

In addition, a well located 200m away, projected on the seismic line, that appeared to intersect many of these sag features, was recorded to have several zones of breccia and cavities at depth. The deepest cavity recorded was 0.35m at 710m depth.

We interpret this to be the location of a 'Coalesced Collapsed Palaeocave' at the base of the Waulsortian, caused by a collapse of overlying strata into the cave hollow, thus forming sag features and polygonal faults.

Conclusions

As a result of this preliminary research project, several conclusions can be made.

- The anecdotal evidence of cavities, brecciated zones, missed sections at depth from mineral

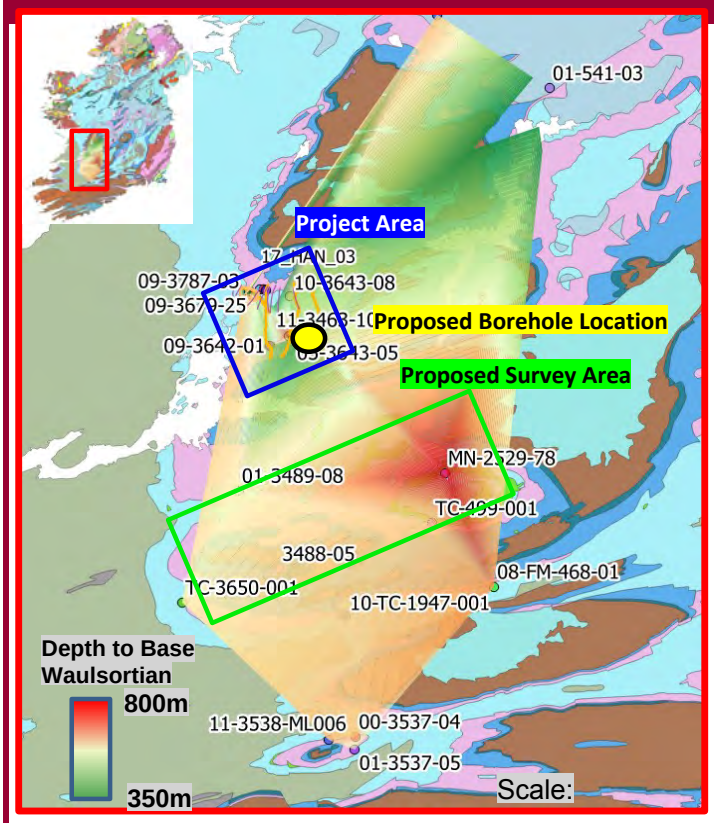

Figure 4. Depth to Base Waulsortian as described in released deep boreholes

exploration drilling in Ireland is confirmed from borehole records.

- Review of Palaeozoic geology in Europe (N. Belgium) and the US (W. Texas) confirms the existence of porous and permeable carbonate reservoirs preserved at depth associated with karstification.
- New seismic data acquired from mineral exploration onshore Ireland displays features indicative of coalesced collapsed palaeocave systems at depth as observed in the Ellenburger Group, W. Texas.
- An opportunity exists to collaborate with the mineral exploration sector to drill a deep exploratory research borehole to test the 'coalesced collapsed palaeocave' exploration model.

Recommendations

Drill the proposed "Kilmurry Prospect" to verify seismic interpretation of karst indicators, intersecting a collapsed paleocave at ~900m depth with a potential for temperatures of up to 30°C.

Acquire Petrophysical logs while drilling to better characterise the stratigraphy and create a more constrained model for identifying karst indicators on seismic.

Acquire seismic data, (preferably 3D Seismic) further south where the Waulsortian is predicted to be deeper.

Acknowledgements

This research project was funded by the GSI as part of their short call programme. The authors acknowledge the significant input to this project from Michael Hudson of Hannan Metals Ltd. who kindly provided access to seismic and borehole data; Sarah Blake, Murray Hitzman, John Walsh, Jennifer Craig, John Conneally, and Koen Torremans of iCRAG who assisted the work; Gareth Ll. Jones and Paul Gordon who provided extensive references and anecdotal evidence of deep karst not recorded in drilling reports.

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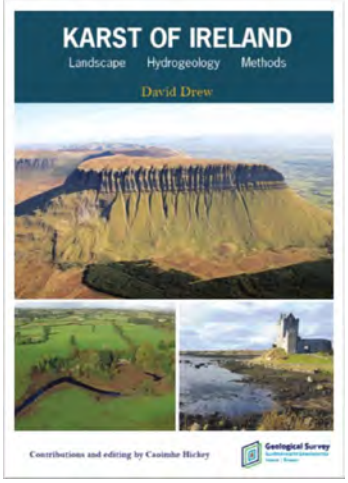
Hydrogeological News

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

Geological Survey Ireland launches new book on Irish Karst: 'Karst of Ireland: Landscape - Hydrogeology - Methods' by David Drew

Taly Hunter Williams, Monica Lee and Siobhán Power, Geological Survey Ireland.



On Tuesday 15th January, more than 120 people – the largest gathering that GSI's lecture theatre has ever hosted – made their way through a dark evening to attend the launch of the GSI's latest publication, 'Karst of Ireland'. This new book is a practical guide for all manner of professionals who will come into contact with karst through their work (e.g., groundwater specialists, environmental scientists, engineers, planners, public health specialists, ecologists, environmental regulators), many of whom do not have a geological background. The book also has a lot to offer to people with a general interest in the Irish landscape.

So why do you need to know about karst, and what is karst? Karst is literally and metaphorically part of the bedrock of Ireland. The limestone of Ireland formed over 300 million years ago when we were in the tropics and covered by warm, shallow seas. Karst landscapes, including caves, comprise some of the most spectacular scenery globally and Ireland is no exception. The Burren in County Clare is famously limestone and the Allwee and Doolin Caves are karst features in the limestone – their international geological importance contributed to the Burren and Cliffs of Moher gaining UNESCO Global Geopark status. Karst lakes, known as turloughs in Ireland, are important features of the Irish countryside, particularly west of the Shannon and people living and working in areas close to a turlough understand the significance of karst in farming, land and flood management, and planning. Karst rocks are a major source of drinking water in Ireland and world-wide, both as groundwater wells and as natural spring wells. The presence of natural spring wells in Ireland has a cultural legacy as some have associations with the ori-

David Drew talking about karst at the Karst of Ireland book launch. Photo @GsiGroundwater

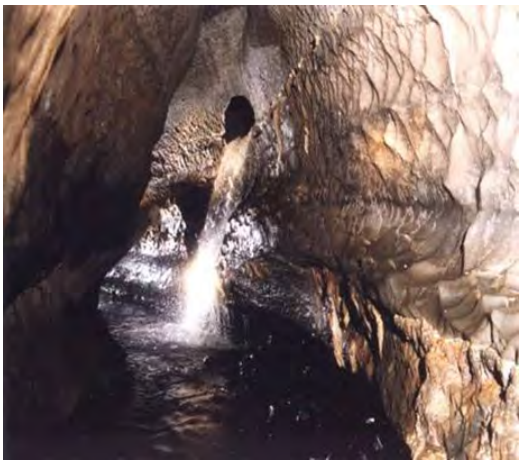


Image a) North Scarp of the Burren plateau, County Clare (photograph by David Drew). Image b) Polldubh South Cave, County Clare (photograph by Colin Bunce).

gins of places names, local saints and cures.

Over 40% of Ireland's bedrock is limestone and much of this is now karst due to dissolution of the limestone by rainwater. Some of the most populated areas in Ireland, including the cities of Dublin and Limerick and large parts of Galway and Cork cities, are on karstified limestone. Industry, agriculture, leisure and tourism in many parts of the country are influenced by, or may influence, the karst beneath. Therefore, a specialist understanding of karst is necessary for successful development and environmental management.

This beautifully produced 318 page full colour, A4 publication is written both for professionals and for others with an interest in karst. David Drew guides the reader through the complexities of the karst landscape by introducing karst in an international context and then focusing on the karst of Ireland. The reader is taken on a regional tour of Irish karst and then provided with a national, hydrogeological perspective of karst. Investigative methods are then described and the book concludes with some practical case studies, which will hopefully be increased in the future.

David provides the 'mental image' of karstified areas that is needed for effective environmental management through clear descriptions and excellent photographs, illustrations and charts. This book is not only a legacy of David's work and passion but also provides a springboard to increase and improve our knowledge – and more effective environmental management – for future professionals and enthusiasts.

From an initial suggestion (and push!) by Donal Daly, David has succinctly pulled together his 45 years' of experience in applied research and practical investigative work, the majority of which has been in Ireland, to provide this revealing guide on Irish Karst and how to further our understanding of karst. This book dovetails his karst knowledge with the work of the past and present hydrogeologists – in particular GSI's Caoimhe Hickey – and has used the extensive data within GSI to support his assessments and conclusions. The book also includes practical contributions from the academic and consultancy sectors.

The Karst of Ireland book has been funded mainly by the Geological Survey Ireland Geoscience Research Programme with additional funding from the Environmental Protection Agency and contributions in kind from the GSI, Trinity College Dublin, Tobin Consulting Engineers, Donal Daly and Paul Johnston.

The Karst of Ireland book is available locally or through the GSI Customer Centre and online shop, or through the Government Publications Office for €20.

New collaboration between European Geological Surveys on Groundwater projects

Taly Hunter Williams, Geological Survey Ireland

Under a new initiative called 'GeoERA', Geological Survey Ireland is involved in a number of projects with other Geological Surveys in Europe. Forty-five national and regional Geological Survey Organisations (GSOs) from 32 European countries have joined forces to develop an ERA-NET Co-Fund Action. The collaboration and co-operation between the Geological Surveys has been very successful to date in developing the projects, and getting them up and running, and Irish hydrogeology and mapping will benefit from the knowledge transfer from other Geological Surveys.

The full title of the initiative is "Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe", and the main objective of GeoERA is to contribute to the optimal use and management of the subsurface. There are three projects under the Groundwater theme, all of which GSI is participating in:

HOVER – "Hydrological processes and Geological settings over Europe controlling dissolved geogenic and anthropogenic elements in groundwater of relevance to human health and the status of dependent ecosystems". Key Work Packages for GSI are: WP3: Hydrogeochemistry and health: Mapping groundwater characteristics for the management of aquifers naturally enriched in dissolved elements; WP4: Linking aquifer microbial ecology and diversity to contaminant transforming processes at European groundwater-surface water transition zones; WP5: Nitrate and pesticides transport from soil to groundwater receptors; and WP7: Harmonized vulnerability to pollution mapping of the upper aquifer.

TACTIC – "Tools for Assessment of ClimaTe change ImpaCt on groundwater and adaptation Strategies". Key Work Packages are: WP3: Integrated groundwater – surface water assessment of climate change and WP4: Assessing groundwater recharge and vulnerability to climate change.

RESOURCE – "Resources of groundwater harmonized at cross-border and pan- European scale". Work Packages GSI is involved in are: WP5 CHAKA: Typology of karst aquifers and recommendations for their management and WP6 Pan-EU Groundwater Resources Map.

Other themes are Geoenergy, which includes geothermal, and Raw Materials. GSI is involved with projects from these themes also. All three themes which will deliver information via the Geological Information Platform.

Work on the projects started last autumn, which are due to complete in June 2021. As the projects progress, we will provide updates on the individual work packages. For more information in the meantime, please contact taly.hunterwilliams@gsi.ie or see the project website: http://geoera.eu/ .

Catchment CARE

Taly Hunter Williams, Geological Survey Ireland

CatchmentCARE (Community Actions for Resilient Eco-systems) is an EU-funded project that aims to improve freshwater quality in cross-border river basins.

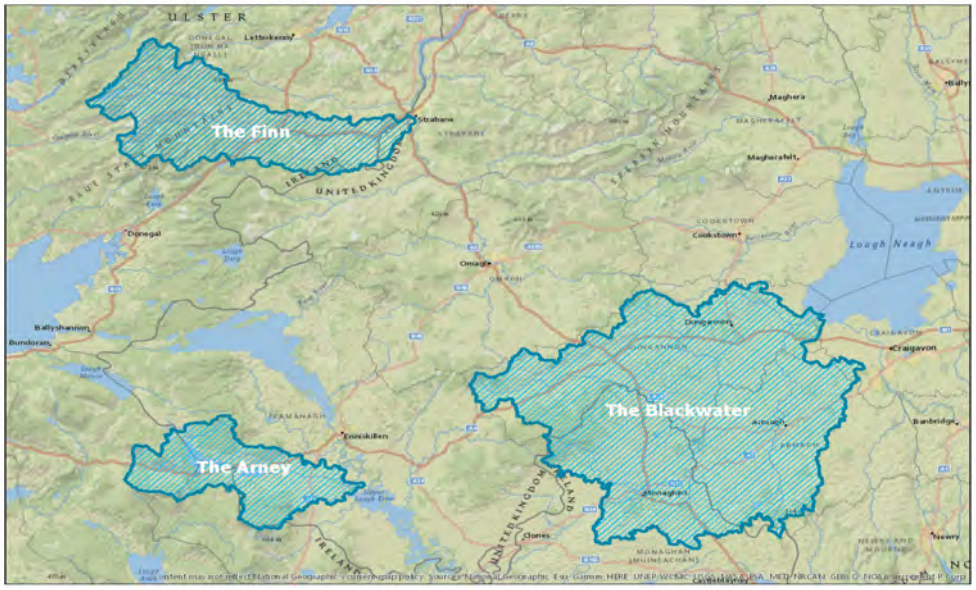
The CatchmentCARE Project will establish three water quality improvement projects in the Finn (Donegal-Tyrone); Arney (FermanaghLeitrim-Cavan) and Blackwater (ArmaghTyrone-Monaghan) Catchments and install 50 boreholes across the region. This will be achieved through a combination of policy actions, catchment actions and community actions. The Project will ensure the following criteria remain in focus throughout: • Measurable impact on water quality; • Transferable beyond the three catchments; • Contribute to a project legacy.

The project, which is 60 months in duration, has a partnership of eight from Ireland and Northern Ireland. The partners each have key expertise which is reflected in the 'Work Package' lead roles shared across the partnership: • Donegal County Council Lead Partner / Project Management WP • Agri-Food and Bioscience Institute Legacy WP • Armagh City, Banbridge & Craigavon Borough Council Communications WP • British Geological Survey / Geological Survey Ireland Groundwater WP • Inland Fisheries Ireland Scoping & Action Targeting WP • Loughs Agency Water Body Actions in Catchments WP • Ulster University Catchment Land Use Actions WP.

The actions selected will address water quality issues related to hydromorphology, point and diffuse sources of pollution, farm nutrient management practices, characterisation and monitoring of groundwater quality, lag times in response to the implementation of measures and an economic analysis of the cost of achieving the objectives of the Water Framework Directive in the three catchments. The boreholes will reveal how water travels underground through catchments and help to understand how best to improve freshwater quality. Knowing this can make a big difference to protecting the life in our rivers and improving the quality of the water we use.

For more information, please see http://www.catchmentcare.eu/ or follow us at –

www.facebook.com/catchmentCARE
www.twitter.com/catchmentcare
www.instagram.com/catchmentcare



Irish Group

IAH Irish Group Committee Update

Barry Sexton — IAH Secretary

Charitable Status

Following a lengthy application process which included two amendments to its constitution at an EGM and an AGM the IAH Irish Group are now a registered charity. The registration was achieved through the efforts of the committee and particularly former secretary Katie Tedd.

The amended IAH constitution now includes a summary of the charitable objectives of the group "The main object for which the body is established is furthering the understanding, wise use and protection of groundwater resources throughout the world. This is achieved through the promotional and educational work that the IAH (Irish Group) carries out in Ireland. This is achieved through the hosting of technical discussion meetings, educational courses and an annual conference which highlights issues and research relating to the understanding and protection of groundwater. The IAH Irish Group also run a student bursary scheme which supports hydrogeologists who wish to advance their hydrogeological education".

Details of the registration can be found at https://www.charitiesregulator.ie/ga/faisn%C3%A9is-don-phobal/%C3%Alr-nuacht/2018/july/details-published-of-62-charities-registered-during-may-2018

New Committee Members

At the end of 2018 a number of committee members had reached the limits of their terms and stepped down. These included outgoing President Henning Moe and Conference Secretary Philip Schuler. Henning had been a great president and represented the IAH at home and abroad through his position on the board of the IGI, presenting papers at the IAH international conference in Croatia and through his work on some large-scale international groundwater supply projects, particularly in Tanzania. From the point of view of the committee members, Henning had done great job for us and had driven the rest of the committee on in his three years in office. Philip Schuler, our conference secretary, was a great loss to the committee. Through his hard work, dedication and relentless enthusiasm Philip was responsible for organising and running really great and well attended conferences over the last two years.

Donal Daly has come on board as the new IAH President. Donal is known and respected throughout the hydrogeological community in Ireland and beyond. The committee is delighted that he has agreed to take up the position of president for the next three years.

Sarah Blake of the GSI was elected as the new Conference Secretary in November 2018 and has in a very short time proven herself to be invaluable member of the committee. Sarah has in a few short weeks put together a fantastic programme for the 2019 conference in Tullamore again this year. Thanks to her efforts the conference was interesting, informative and very well attended.

IAH Irish Group Annual Conference

Sarah Blake — IAH Conference Secretary

The 39th annual conference of the IAH Irish Group was held in the usual venue at the Tullamore Court Hotel, Co. Offaly on April 30th and May 1st of this year. Nineteen speakers from a wide cross-section of the profession presented papers around the theme of "Groundwater: drought, floods and climate change", and eleven research posters were presented in rapid-fire style on the morning of the first day. The theme for this year's conference was selected to highlight that although groundwater is vulnerable to the extremes of climate change, it is also a large part of the solution, and hydrogeologists will have an important role to play in mitigation and adaptation strategies.

The talks kicked off with our first keynote speaker, the very engaging Bridget Scanlon from the University of Texas, who discussed the management of water resources in the context of climate extremes. Bridget was followed by several thought-provoking (and sometimes alarming!) presentations on climate change projections and impacts, and the poster presentations. After lunch, we heard about the impacts of drought past and present in Ireland, with an entire session dedicated to Irish Water's experience of the 2018 drought.

On the second day we started with a stimulating talk from our second keynote speaker, Vincent Fitzsimons from SEPA, who described the impacts of flooding in Scotland. After a short session on groundwater flooding, we heard from our third and final keynote speaker, Mark Cuthbert from Cardiff University, who talked about groundwater response times, and even how groundwater may have influenced human evolution! Our final session discussed examples of groundwater systems in a changing climate at home and abroad. The conference finished with a well-attended workshop on QGIS for hydrogeologists.

The question and answer sessions on both days were lively, and our networking events provided good opportunity for mixing and further discussion. As always, we are very grateful to all of our presenters, sponsors and delegates for making the conference so interesting and worthwhile. The full conference proceedings are now available on the IAH website http://www.iah-ireland.org/annual-conference/. We look forward to seeing you next year for the 40th annual

Photo credit: Matej Blatnik.

Irish Group

The 2018 Annual Fieldtrip of the International Association of Hydrogeologists (Irish Group) to Roscommon 'Karst Hydrogeology of Mid-Roscommon'

Robbie Meehan — IAH Fieldtrip Secretary

This year the Irish group of the International Association of Hydrogeologists (IAH) held their fieldtrip on the weekend of 13th and 14th October, when over forty intrepid hydrogeologists met in County Roscommon. This county has long been known as an excellent example of a karst landscape, with many of the county's water supplies being sourced *via* karstic springs. The idea of the field trip was to examine the rich hydrogeological heritage of the region, by visiting a wide variety of sites with very different hydrogeological nuances, many of which had recently-completed or ongoing research associated with them.

On the outward journey from Geological Survey Ireland (GSI) in Dublin, the weather looked foreboding but unlike the 2017 trip, we were not treated to the appearance of a named storm (though Saturday afternoon did turn out very wet). However, at the first stop at Ballinderry Reservoir, Joe Gallagher and Noel Carroll introduced both the National Federation of Group Water Schemes (NFGWS) and the Mid-Roscommon Group Water Scheme respectively. Coran Kelly of Tobin Engineering Consultants then outlined the recent work on delineating Zones of Contribution (ZOCs) in such karstic schemes, and gave an overview of the ideology of moving from Zones of Contribution to Source Protection Zones in this terrain. Much detail was gleaned by all on the level of work, and the complexities, involved in same, in a project which is being led by the NFGWS and Groundwater Section of GSI. Through misty, murky weather was the order of the day, questions then led to focussed discussion, before the same three brought all to Ogulla Spring, one of the mid-Roscommon Spring sources, where participants could see first-hand some of the infra-

Image a) Coran Kelly discusses the some of the more challenging aspects of Zone of Contribution delineation in karst. Image b) St. Patrick watches keenly all who ponder potential contamination of drinking water at Ogulla

Image a) Koen Verbruggen and Markus Pracht discussing the regional limestone geology of Roscommon, as the core awaits.
Image b) David Drew crams them in to Oweynagat Cave.

structure and potential issues associated with such karst-influenced water supplies. A walk across heavy, waterlogged fields followed, to a deep doline feature with a swallow hole in its base. The water sinking at this site reappears at Corracreigh Spring, which is approximately 7 kilometres away. This was the final stop before lunch.

After lunch in the Rathcroghan Visitor Centre in Tulsk, Dr. David Drew, now retired but formerly of Trinity College Dublin, gave us a talk on the bus on the various types of cave present deep within the karst of County Roscommon. All participants were then led underground, in two separate groups, into Oweynagat Cave. This enlarged fissure, the home of the Morrigan witch and the birthplace of Halloween, has many interesting hydrogeological facets, which all took in as the cave gave temporary shelter to the beating rain outside. At the second stop of the afternoon following this, in the GSI 'Outlier' Core Store in Roscommon Town, Dr. Markus Pracht of Bedrock Section of GSI showed all the core from the impressive 892 m deep borehole drilled by GSI in 2016 at Castlemine Quarry, just outside Roscommon Town. Much discussion resulted here, with Koen Verbruggen and Sarah Blake also contributing to related references of regional mapping and geothermal implications of the borehole itself, respectively.

The group stayed overnight at Hannons Hotel in Roscommon Town, where the colloquium dinner was attended by the majority of the participants.

On the Sunday, the weather was much calmer and brighter, with crisp air and blue skies. The Sunday morning focussed on some of the waterbodies south of Roscommon Town. Initially, Ted McCormack outlined the Groundwater Flood (GW Flood) project of Groundwater Section, GSI, at Correal Turlough. Here, local historian James Moran also gave insights into the history of the flooding of the feature and its' effect on the local community. Following this, at the nearby, roadside, Castlestrange Group Water Scheme, Gerry Baker of Arup Consulting Engineers gave an account of the Zone of Contribution delineation process for a small, karstic borehole supply, which led to much debate and

ideas about group scheme rationalisation and the general day-to-day issues with small-scale water supplies. Rebecca Bradford, James McAteer, Ted McCormack and Shane Carey then brought all to Castleplunkett Turlough, where the GW Flood team outlined varied topics such as the hydrogeology of the turlough, LIDAR mapping of karst, drone imagery and thermal mapping, and the telemetric monitoring of such turloughs. This stop ended with Rebecca taking a drone thermal image of all participants from a significant elevation!

Following lunch at the Rathcroghan Centre again, a final stop on the homeward trip back to Dublin was had at Lough Funshinagh, where the GW Flood team again discussed the unusual aspects of flooding in and around the lake, and proposed potential 'solutions', and the associated issues, with same.

The IAH would like to thank all the contributors to this year's field trip. Thanks also to all landowners of the Rathcroghan and wider region for giving us permission to visit their lands, and thanks also to McCaffrey coaches, and the bus driver Noel, for allowing us to get from place to place safely and dryly.

Image a) A Group Scheme discussion on a Sunday morning sidewalk at Castlestrange.

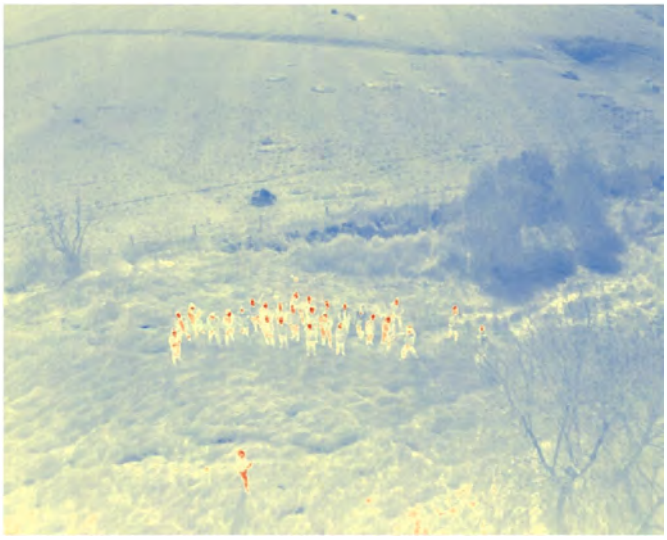


Image b and c) Thermal images of fieldtrip participants taken by GSI drone at Castleplunkett Turplough

IAH—News on the International Front

Bruce Misstear — IAH Secretary General

In this issue I will report on four IAH activities: international liaison, new IAH education webpages, IAH awards and congresses.

International liaison

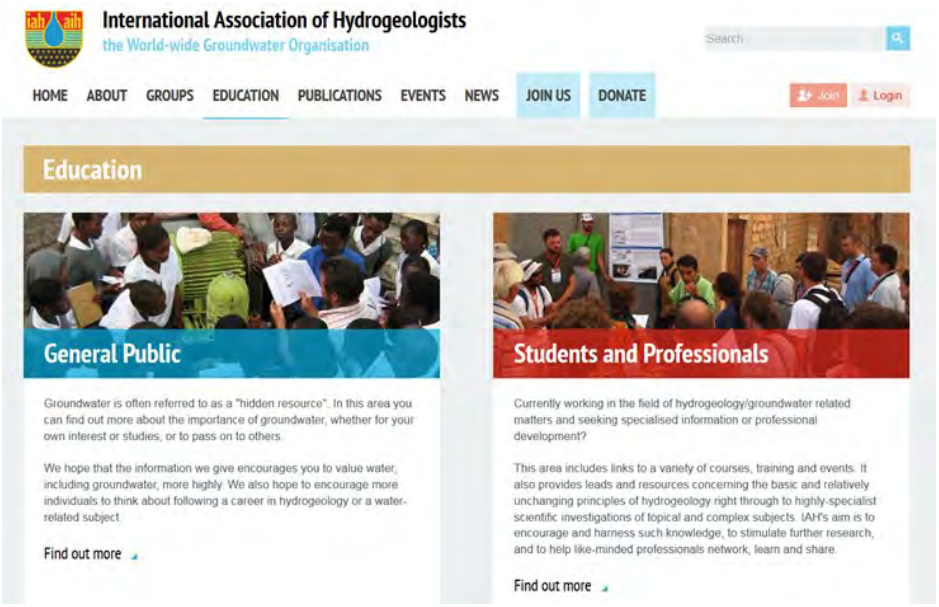
My role as Secretary General includes many outreach activities between IAH and other organisations involved in water science, policy and management, with the overall aim of trying to inform and influence global water policy. Clearly this is a very broad aim, and we must therefore focus our activities (and limited financial resources) on trying to influence specific policies concerned with international water development. The key policy framework that is underpinning water resource planning between now and 2030 is the Sustainable Development Goals, especially Goal 6 relating to water and sanitation. One response to this by IAH has been the preparation of a Strategic Overview paper that flags some of the main issues concerned with SDG Goal 6 and groundwater (this and the other Strategic Overview papers are available at https://iah.org/education/professionals/strategic-overview-series).

A second activity is participating in various activities by UN Water, and its partner organisations, relating to the SDGs. At present, I am collaborating in a GEMS/Water project (managed by its Capacity Development Centre based at University College Cork, and led by Debbie Chapman) that is developing a methodology for assessing SDG indicator 6.3.2 – the proportion of bodies of water with good ambient water quality. As readers of this Newsletter will appreciate, there are major challenges involved in trying to develop targets and criteria for determining if groundwater bodies are of "good ambient quality", especially since the methodology will have to be applied globally, taking account of the wide variations in data availability.

In August 2018, I attended the UN Water partners meeting in Stockholm (held just before the main annual Stockholm World Water Week events). The two-day meeting mainly involved various updates from UN agencies on past or future meetings and reports. Importantly for IAH, attendance at this meeting led to an invitation from UN Environment for IAH to participate in a new World Water Quality Assessment (WWQA). This project will run in parallel to - and feed into - projects concerned with SDG targets and indicators, such as the GEMS/Water project mentioned above. The analytical brief for the WWQA project has a strong surface water focus (http://www.wwqa-documentation.info/analytical-brief.html), but the involvement of IAH should help in promoting a greater groundwater component, and I was able to join the project inception meeting in Geneva at the end of November 2018.

I should add here that IAH is not alone in engaging with international agencies to increase the global awareness about groundwater and its role in integrated water management and socio-economic development. For example, IAH collaborate on certain activities with igrac (International Groundwater Resources Assessment Centre), and we are a core member of GRIPP (Groundwater Solutions Initiative for Policy and Practice), which organised a special session on groundwater-based natural infrastructure during World Water Week in Stockholm in August).

These are just a few examples of our recent activities aimed at increasing the profile of groundwater in international policies and reports.



IAH education webpages

I chaired a working group that reviewed IAH's role in educational activities, and made various recommendations on how we might enhance our role through training courses, webinars, educational materials and so forth. Many of the recommendations are reliant on improving the IAH website to include dedicated educational webpages, and I am pleased to report that new education webpages went live in December 2018. Entry to these webpages is organised according to the interests of the readers, with separate pages and links for the general public and for hydrogeology students/professionals: https://education.iah.org/education/general-public. The general public pages, for example, include introductory information about groundwater and what hydrogeologists actually do – and there are links to numerous videos, classroom materials and general information about groundwater. The "professionals" pages also include links to videos and other resources, along with information about training courses and degrees in hydrogeology, mentoring opportunities, etc.

IAH congresses

The 45th IAH congress was held in South Korea from 9th to 14th September 2018. The congress venue was in Daejeon, a city with a population of over a million, and a couple of hours' bus ride south of Seoul international airport. The congress was very well organised, with good talks, interesting excursions and en-

Traditional Korean dancers at the opening ceremony of the 45th IAH congress in Daejeon

Boat ride to the Baengnyong karst cave system, one of the mid-week congress excursions

joyable entertainments (see photos).

The 2019 IAH congress will be in Malaga Spain, between the 22nd and 27th September. Malaga is well connected to Ireland by regular flights, and there are lots of accommodation options available. The congress will offer Irish hydrogeologists a good opportunity to talk about some of the interesting groundwater work in Ireland, so I would encourage readers to participate in the congress, initially by submitting an abstract – the abstract deadline is the end of March 2019 – see http://www.iah2019.org/.

IAH awards

The IAH makes four awards each year: the Presidents' award, the Applied Hydrogeology award, the Distinguished Associate award and Honorary Membership (https://iah.org/about/awards). This year there was Irish interest, with the Presidents' award going to the well-known Irish hydrogeologist Bridget Scanlon. To quote from part of the award citation "Bridget graduated from Trinity College in Dublin in 1980 in geology and earned her Master's degree at the University of Alabama. She received her doctorate from the University of Kentucky, focusing on karst hydrogeology in Kentucky's Inner Bluegrass region. She has conducted research at the Bureau of Economic Geology at the Jackson School of Geosciences (University of Texas at Austin) for the past 30 years, where she leads the Sustainable Water Resources Program. Her research has covered a wide range of topics. Her early research concentrated on groundwater recharge in semi-arid regions, using monitoring, chemical and isotopic tracers, and numerical modelling. She has examined the impacts of climate change and land use change on groundwater, sources and mitigation of natural and anthropogenic contamination, and sustainable groundwater development using managed aquifer recharge. Dr Scanlon is an excellent ambassador for IAH and for groundwater. She is a very worthy recipient of the 2018 Presidents' Award". (By the way, the apostrophe in Presidents' award comes after the s because this award is chosen by the current and the two previous IAH Presidents).

Unfortunately, Bridget couldn't make it to the congress in Korea (where the awards were announced), so she received the award later from Jack Sharp, a previous recipient.

Jack Sharp (2012 Presidential Awardee) presents Bridget Scanlon the 2018 Presidential Award in Austin, Texas

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. For 2019, the full annual membership fee is €88 if you wish to receive a paper copy of Hydrogeology Journal as part of your membership, or €78 if you receive the journal online. Students can join for as little as €20 (with the online journal option).

Recent Literature Relevant to Irish Hydrogeology

This section of the newsletter contains a bibliography of recent literature relevant to Irish hydrogeology compiled by the editors. If you are involved in, or aware of, any papers which may be relevant for this section of the newsletter please contact the editors at groundwaternewsletter@gsi.ie.

Groundwater quality

Arsenic in Groundwater in South West Ireland: Occurrence, Controls, and Hydrochemistry.

McGrory, E., Holian, E., Alvarez-Iglesias, A., Bargary, N., McGillicuddy, E.J., Henry, T., Daly, E. and Morrison, L. (2018). Frontiers in Environmental Science, 6, 154.

https://doi.org/10.3389/fenvs.2018.00154

Surface water flooding, groundwater contamination, and enteric disease in developed countries: A scoping review of connections and consequences

Andrade, L., O'Dwyer, J., O'Neill, E. and Hynds, P.D. (2018). Environmental Pollution 236, 540-549.

https://doi.org/10.1016/j.envpol.2018.01.104

Development of a hierarchical model for predicting microbiological contamination of private groundwater supplies in a geologically heterogeneous region.

O'Dwyer, J., Hynds, P.D., Byrne, K.A., Ryan, M.P., Adley, C.C. (2018). Environmental Pollution 237, 329-338.

https://doi.org/10.1016/j.envpol.2018.02.052

The Impact of On-site Domestic Wastewater Effluent on Rivers and Wells

Gill, L., O'Flaherty, V., Misstear, B., Brophy, L., Fennell, C., Dubber, D., O'Connell, D., Kilroy, K., Barrett, M., Johnston, P., Pilla F. and Geary P. (2018). EPA research report 251

http://www.epa.ie/pubs/reports/research/water/Research_Report_251.pdf

Karst

Karst of Ireland: Landscape Hydrogeology Methods. Drew, D. (2018). Published by Geological Survey Ireland.

https://www.gsi.ie/en-ie/publications/Pages/Karst-of-Ireland-Landscape-Hydrogeology-Methods.aspx

Groundwater flood hazards and mechanisms in lowland karst terrains

Naughton, O., McCormack, T., Gill, L. and Johnston, P. (2017) Geological Society, London, Special Publications, 466, 397-410.

https://doi.org/10.1144/SP466.9

Submarine and intertidal groundwater discharge through a complex multi-level karst conduit aquifer

Schuler, P., Duran, L., McCormack, T. and Gill, L. (2018). Hydrogeology Journal, 26, 8, 2629–2647.

https://doi.org/10.1007/s10040-018-1821-3

The Hydrogeology of the Gort Lowlands

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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

2019

17-21 Jun 2019 **27th International Karstological School** "Classical Karst" - Postonjna

24-26 Jun 2019 **GeoPython 2019** conference, Basel/Muttenz, Switzerland
http://2019.geopython.net/

4 Jul 2019 **Geothermal Association of Ireland's** Annual General Meeting, Geological Survey of Ireland, 17:30

25-31 Jul 2019 **20th INQUA Congress** Dublin
http://www.inqua2019.org/

17-19 Sep 2019 **88th National Ploughing Championships** - Fenagh, Co.Carlow
https://www.npa.ie/2018/10/2019-national-ploughing-championships-to-take-place-in-ballintrane-fenagh-co-carlow/

22-27 Sep 2019 **IAH 46th Congress** –University of Malaga, Malaga, Spain
http://www.iah2019.org/

1 Oct 2019 **IAH Irish Group Technical Discussion Meetings-**TBC
www.iah-ireland.org or @iah_ireland for further information
Email tdm@iah-ireland.org to be added to TDM mailing list

19-20 Oct 2019 **IAH Irish group** fieldtrip, Clare
Contact Robbie Meehan fieldtrip@iah-ireland.org for more information

TBC Nov 2019 **Geoscience Conference** - Dublin Castle
https://www.gsi.ie/en-ie/events-and-news/annual-events/Pages/Geoscience-Conference.aspx

TBC Nov 2019 **National Hydrology Conference, Midlands (venue to be confirmed)**
http://hydrologyireland.ie/

5 Nov 2019 **IAH Irish Group Technical Discussion Meetings**
The hydrogeology of Irish wells, Brucve Misstear (TCD)

3 Dec 2019 **IAH Irish Group Technical Discussion Meetings-**TBC
www.iah-ireland.org or @iah_ireland for further information
Email tdm@iah-ireland.org to be added to TDM mailing list