Irish Groundwater Newsletter

Issue 56 ISSN 2009-8324 December 2017

In September of this year Donal Daly retired from his position as a Senior Scientific officer at the Environmental Protection Agency. Donal will be known to most readers of this Newsletter either from his time (28 years) in the Groundwater Division of the Geological Survey, or his subsequent 11 years working in the EPA. His name is inextricably bound up with the development of an awareness and understanding of groundwater as a resource in Ireland, though his final post at the EPA was concerned with the wider hydrological perspective – integrated catchment management.

However, newer readers of the Groundwater Newsletter may not be aware that Donal initiated the publication back in 1986 to disseminate information about groundwater both to practicing hydrogeologists and to the wider circle of people in Ireland with an interest in the subject. He edited the Newsletter until 2000 and then co-edited until 2005, a total of 45 issues.

Coincidentally, this Newsletter includes an article on integrated catchment management as well as contribution on peat hydrogeology, both topics of particular interest to Donal. Groundwater quality articles, covering a wide range of topics dominate this issue, whilst there are two reports of aspects of sub-Saharan Africa hydrogeology. The Hydrogeological News section included reports f matters of interest to hydrogeologists in Ireland, together with the annual list of publications that relate to hydrogeology in Ireland.

Without Donal's initiative the Newsletter may never have appeared so on behalf of the readership, the present editors would like to thank Donal and to wish him a happy and hydrogeologically active retirement.

Geological Survey Suirbhéireacht Gheolaíochta Ireland | Éireann

Monica Lee, Groundwater Section, GSI
Katie Tedd, David Drew,Sarah Blake and Melissa O Keeffe, Editors

Articles

Hydrogeology Articles

Research

Research in Hydrogeology

News

Hydrogeological News

Cover photo: Lough Mask 2004 Photo by Groundwater Section GSI.

Use of Oil Exploration Data for the Assessment of Deep Groundwater Resources in Coastal Tanzania

Henning Moe[1] and Fridtjov Ruden[2]
[1]CDM Smith, [2]Ruden AS

Development of a systematic approach to identify deep coastal aquifers

Summary

Historical oil exploration data were processed, interpreted and used to define the architecture and geometry of a deep coastal aquifer near the city of Dar es Salaam (DSM) in Tanzania. The data, consisting of seismic survey profiles and borehole logging data from oil and gas exploration wells, were obtained from the Tanzanian Petroleum Development Corporation (TPDC), under written agreement between the TPDC and the Dar es Salaam Water and Sewerage Authority (DAWASA).

The "recycling" of oil exploration data from 40 years ago made it possible to verify a conceptual hydrogeological model which places a regional, deep coastal aquifer system at the doorstep of DSM. The new groundwater resource is estimated to have a sustainable supply potential of 200,000 m^3/d or more, depending on decisions that are taken with respect to aquifer and well-

Figure 1 Location of Dar es Salaam and KAA project area (red circle)

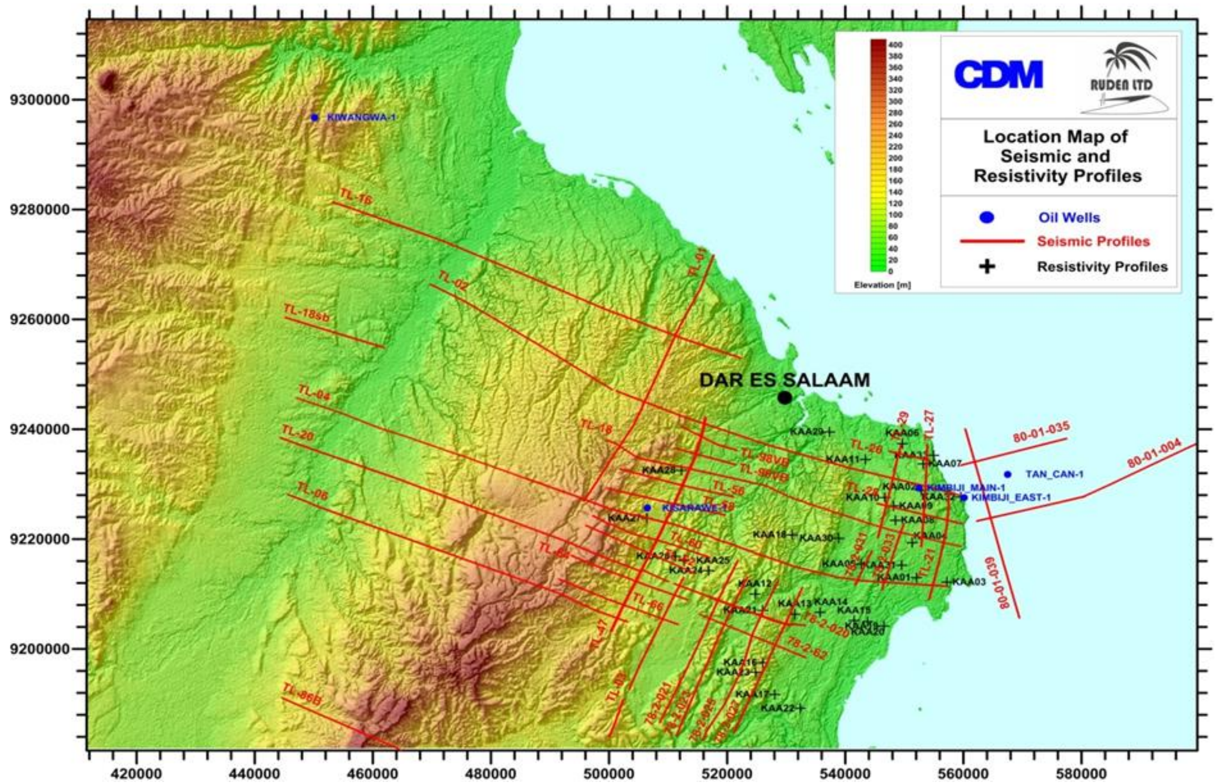


Figure 2 Oil exploration data coverage on the Kimbiji Peninsula.

field development.

Without the oil exploration data, the task of locating and verifying a new, significant source of groundwater for DSM and the surrounding region would not have been possible. In this context, the Kimbiji Aquifer Assessment (KAA) project[1] has been a pioneering endeavor. Use of oil exploration data has allowed the hydrogeologist to look much deeper than is conventionally possible with standard approaches and methods of hydrogeology, mainly because the water sector does not have the resources to investigate at similar scales or depths.

Whereas the oil sector has impressive knowledge related to oil and gas, the knowledge is rarely applied in the water industry. The oil industry is generally not concerned with the top few hundred meters of the subsurface environment. Therefore, opportunities for water exploration are missed. To change this situation, dialogue between the oil and water sectors, involving government, is needed.

Context

DSM (see Figure 1) is the largest city and economic engine of Tanzania. Recent years have brought significant and unsustainable growth to the city, and both planners and utilities are struggling to cope with the pressures on services that accompany urban growth. With an annual population growth rate of nearly 6%, DSM is an exceptionally thirsty city, and authorities are in a race to catch up with an asymptotic water demand curve.

Following the discovery of the Kimbiji Aquifer in 2005[2], initial drilling of two deep exploration boreholes on the Kimbiji peninsula yielded intriguing, if inconclusive, results. Despite limitations with the drilling equipment that was available at the time, one high-yielding and naturally artesian well was installed to 350 m depth, with groundwater of good quality. Results pointed to hydrogeological conditions which were different and more favorable for groundwater supply compared to established literature, which had characterized the area as "clay-bound sands" with limited groundwater potential. Further study was needed to ascertain the magnitude and potential scale of the related aquifer system.

The KAA project

The KAA project (2011-2017) was undertaken by the Government of Tanzania to verify the existence of a regional coastal aquifer system, to describe its hydrogeological characteristics (including water quality), and to assess its sustainable yield potential as a future source of water supply for DSM. The end objective of the KAA project was to prepare a plan that showed how the aquifer system should be developed to maximize supply whilst minimizing the potential environmental impacts that accompany large-scale groundwater abstractions.

Accordingly, a series of tasks were carried out, as follows:

- Baseline data and information were collated and analyzed on the water resources, environmental and socio-economic characteristics of the region.
- Hydrocarbon exploration data were obtained, processed and interpreted to help define the geometry and regional context of the aquifer system.
- Seven exploration boreholes were drilled to 600 m depth, supplementing two existing exploration wells. All wells were geologically and geophysically logged, as well as test-pumped and sampled for aquifer characterization purposes.
- A calibrated numerical groundwater model was developed to describe and quantify the aquifer system, and to investigate the potential or likely offshore extent of the saline groundwater interface. The model was subsequently applied to examine aquifer development alternatives and to assess potential environmental impacts associated with large-scale pumping.

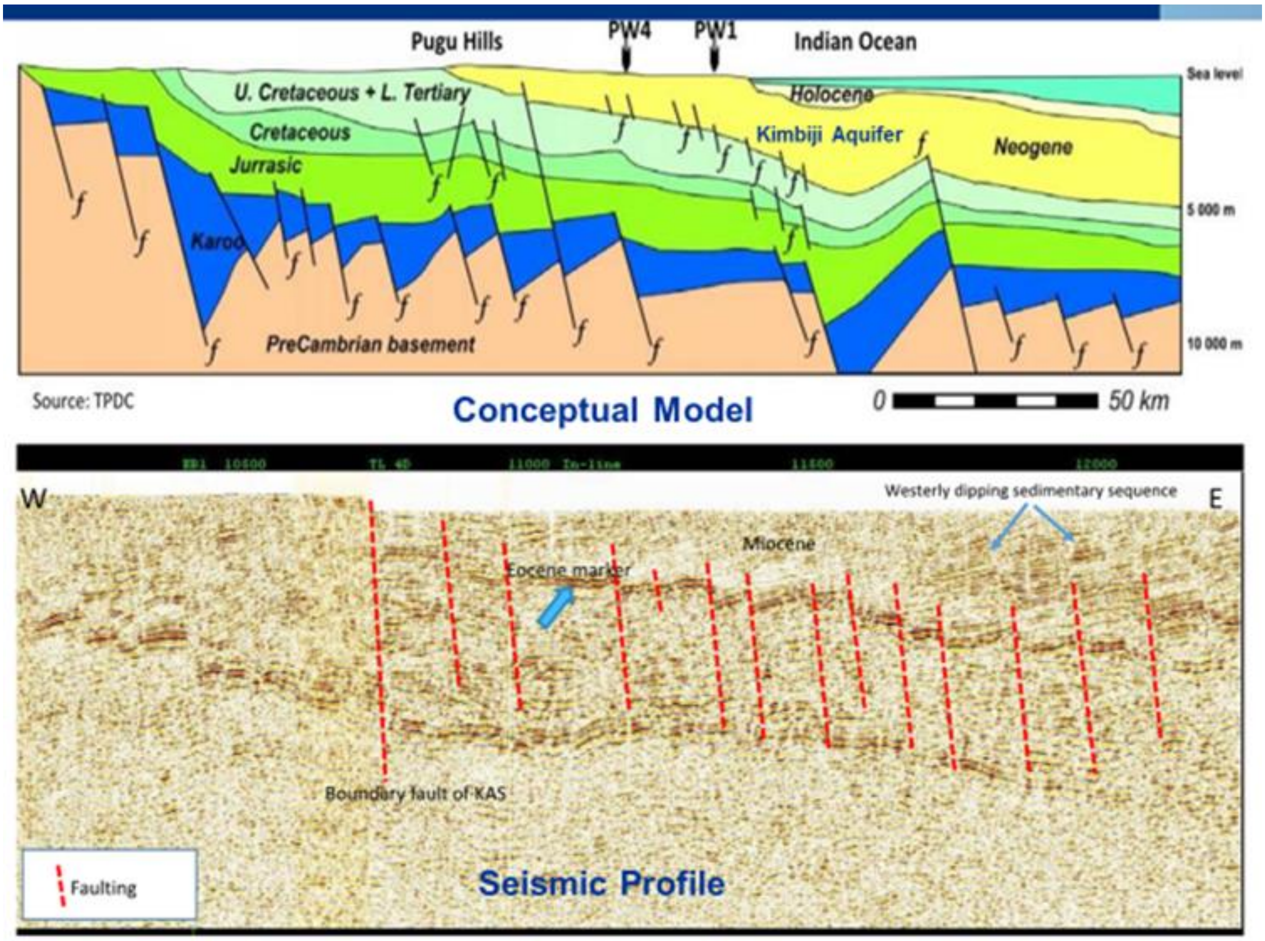
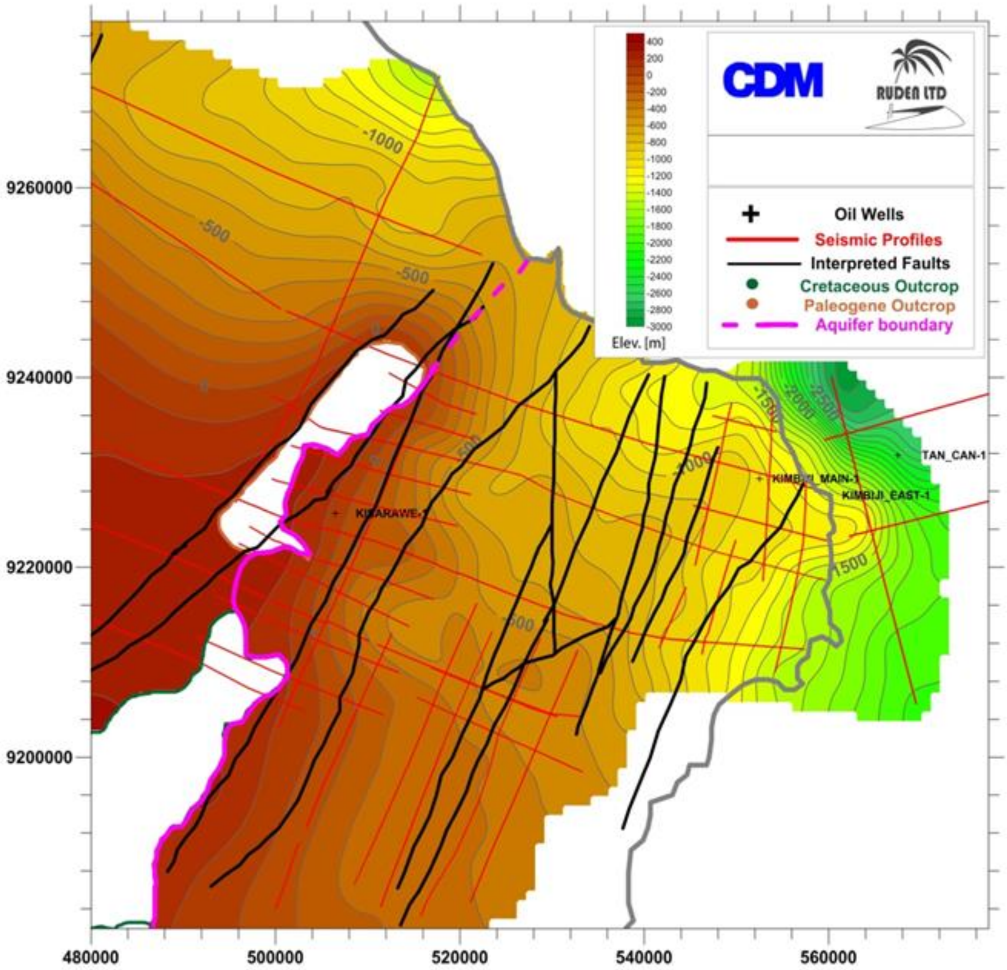


Figure 3 Conceptual geological cross-section and sample (simplified) seismic profile .



(a) Elevation Base Miocene

Figure 4 Interpreted base of Miocene (elevation in m bsl).

- Cost estimates of wellfield development alternatives were prepared, with preliminary designs.
- Cost-effectiveness and cost-benefit analyses were carried out to identify the preferred wellfield development alternative.

Sustainability was considered in terms of maintaining a continuous and reliable water supply, protecting the resource from overexploitation and environmental damage, and ensuring that the resource is properly monitored and managed for future generations.

Processing and interpretation of oil exploration data

The Kimbiji peninsula was the subject of extensive oil and gas exploration in the late 1970s and early 1980s. For the KAA project, more than 1,100 km of onshore and offshore seismic survey profiles (see Figure 2) were re-processed (and partly digitized) to 2,000 m depth to help define the geometry of the Kimbiji Aquifer system. Existing well completion reports for six gas exploration wells, including one offshore well, were also reviewed and used to establish stratigraphic control points for seismic interpretations. The well completion reports contained daily drillers' notes on conditions encountered, geological logs, borehole geophysical logs, petrographic analyses, and drill stem test results (with salinity indicators).

The Kimbiji Aquifer is defined by palaeo-deltaic sediments of (mainly) Miocene age. Guided by the borehole logs, a high-amplitude seismic reflector representing Eocene carbonates served as a marker horizon which could be traced across most of the study area. This marker was broadly used to define the base of the Kimbiji Aquifer system. As simplified in Figure 3, the stratigraphic sequence is extensively faulted (linked to the development of the East African Rift system), giving rise to a sedimentary basin which thickens towards and extends beneath the Indian Ocean. Based on the geophysical interpretations, the Kimbiji Aquifer system is approximately 100 m thick at its western boundary (faulted against older Palaeogene sediments), and more than 1,500 m thick at the coastline (see Figure 4). The gas well Tan-Can 1 (see Figure 2) provides an important control point offshore. Based on recent, published seismic surveys in offshore areas[3], the sedimentary sequence and its total thickness are further confirmed more than 100 km to the east of the Kimbiji peninsula.

Stratigraphic characteristics of the Kimbiji Aquifer System

The seismic interpretations were used to guide the selection of drilling locations for seven exploration boreholes to 600 m depth on the Kimbiji peninsula. The boreholes were drilled using the reverse circulation drilling method, (Figure 6) with bentonite mud as the drilling fluid. Use of the reverse circulation method was a deliberate decision based on prior experience with collapsing gravels during the initial drilling in 2007, and knowledge about the size of the mud pumps that would be needed for straight rotary mud drilling. Upon completion of drilling, it has been estimated that reverse circulation drilling resulted in a net 80 % reduction of fuel consumption compared to straight rotary drilling.

Borehole (geophysical) logs of each borehole show a complex palaeo-deltaic sequence of sands, gravels, clays and marls. Dozens of sub-aquifers are present in respective boreholes, which are separated by individual clays and marls (see Figure 5). The sands and gravels are individually thin, ranging from a few centimeters to a few meters (< 10 m). In combination, they form an important aquifer sequence of considerable thickness. The sands and gravels are the primary aquifers to be targeted and pumped by future production wells, and the finer sediments, including clays, provide a secondary contribution of groundwater from Hantush-type leakage.

Summary of KAA project findings

The Kimbiji Aquifer has been drilled, logged, test-pumped, and sampled, and its main characteristics can be summarized as follows:

- It is a stratigraphically and structurally complex regional coastal aquifer system. It ranges in thickness from 100 m in the west to more than 1,500 m offshore. It contains significant gravel sequences at depths of more than 400 m, which are some of the more productive (and artesian) intervals encountered.
- All of the completed wells contain groundwater of potable water quality. Metals analysis indicated slightly elevated concentrations of boron in some wells, which is considered to be of natural origin. Some samples are slightly more saline than others, but all results are within drinking water guidance values.
- Future pumped groundwater will be warm, between 35 and 38 °C, as a function of the natural geothermal gradient.
- The apparent age of the deepest pumped groundwater is approximately 40,000 years, which is consistent with simulated flow velocities using a regional groundwater model.
- Individual production well yields will be influenced by how many sand and gravel units are intersected at any given location, their hydraulic properties, and how efficiently production wells can be installed. The latter is a function of the well designs and the due care and skills of installation of a capable drilling contractor.
- The limiting factor to production pumping will be the predicted drawdown in each well as a function of practical well design and the bulk hydraulic properties of the aquifer system. Numerical modelling suggests that more than 200,000 m^3/d of groundwater can be pumped within a 100-year aquifer devel-

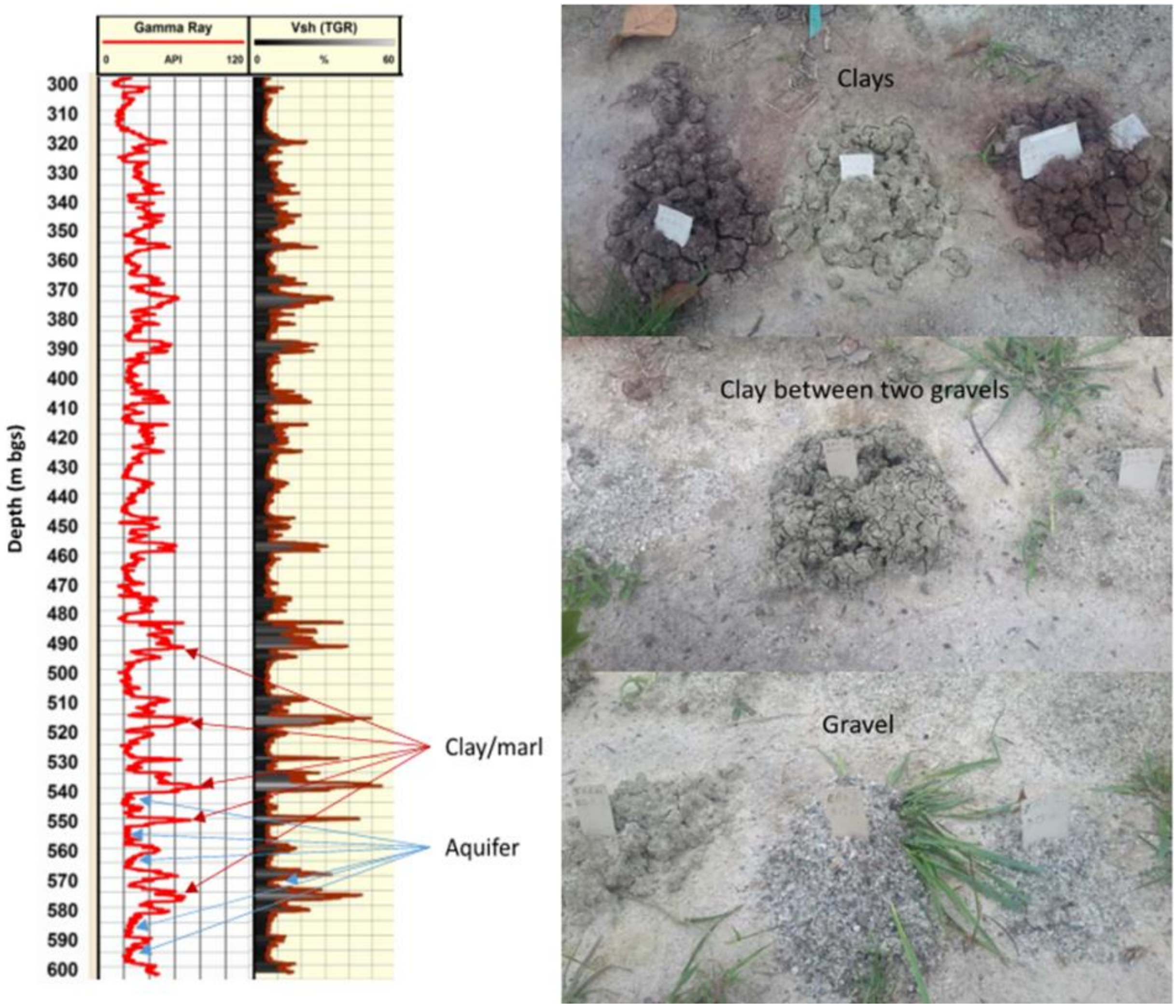


Figure 5 Example of natural gamma ray log showing sand/clay sequence .

opment context without inducing regional saline intrusion.

- The regional groundwater model was used to explore the potential offshore extent of saline groundwater. Under current measured heads and estimated flux conditions, the predicted extent is approximately 25 km offshore. By incorporating historical and published research on global sea level rises since the last glacial maximum, the predicted extent is more than 40 km offshore.
- The definition and hydrogeological understanding of the KAS would not have been possible without applying the groundwater model as an investigation tool. Hydrogeological concepts and new field data have been consolidated in the model development and its applications.
- The preferred wellfield development alternative (in terms of estimated total sustainable yield and cost of water per m^3) places deep production wells in two roughly north-south oriented lines that are perpendicular to the coastline, taking advantage of the natural east to west flow gradient and transmissivity of the aquifer system.
- Large scale production of groundwater will have environmental impacts. Lowering of groundwater levels will impact on stream flows, existing water users, and certain groundwater-dependent habitats, as predicted with the groundwater model. Land subsidence will be an unavoidable consequence of pumping from a confined aquifer system. Decision

makers will be tasked with the weighing of environmental impacts against the benefits of water supply.

Several technical questions remain, which should be addressed in subsequent phases of work, for example: a) measuring long-term responses of the aquifer system to climatic changes; b) investigating the potential contribution of groundwater from deeper, pre-Miocene formations, using chemical and isotopic fingerprinting techniques); c) measuring the aquifer response to large scale abstraction from multiple wells simultaneously (and updating the groundwater model); and d) examining the potential for precipitation of metal oxides from future and actual production wells as part of future design of an integrated water delivery system to DSM.

Conclusions

Both onshore and offshore hydrocarbon exploration data were used to interpret the architecture and geometry of the regional-scale coastal aquifer system. The verification and establishment of the KAS as a major new source of water supply to DSM would not have been possible without the data and information obtained from the TPDC.

The geological study of deep coastal reservoirs is traditionally firmly within the realm of the oil industry. The oil industry rarely considers water as a resource outside the immediate requirements related to drilling operations and production. As a rule, the oil sector ignores water as an economic commodity and rarely keeps records which are important to the water sector. An oil exploration well is an investment which is meant to provide quick returns, and oil wells are abandoned if oil/gas production falls under some threshold. Groundwater is consequently of little interest.

Oil exploration data should be used as a matter of routine in regional groundwater studies where such data exist. A model of cooperation that bridges the oil and water sectors would benefit both sectors. The upper/shallow part of seismic profiles is typically of limited interest to the oil sector, and although shallow seismic data are normally acquired, they are not necessarily processed. However, in the water context, this upper/shallow section represents the target zone. As such, the oil sector could set limits on data sharing by only releasing data or interpretations from the first 1-2 km depth, which is of little consequence to their work. In return, the oil sector would contribute towards improved, broader natural resources understanding. The oil sector could also benefit from the more economic drilling technology that is available in the water sector, specifically reverse circulation drilling.

The concepts of deep coastal aquifers are of course not new[4]. However, no one to date has explored or explained a systematic approach towards identifying potential deep coastal aquifers, and no one has, to our knowledge, suggested the beneficial cooperation with the oil industry in a hydrogeological context.

Interest and awareness regarding deep groundwater is fueled by an increasing global water shortage. The Kimbiji experience and recent discovery of deep groundwater in Namibia[5] suggest that discoveries of deep and fresh groundwater resources can yet be made around the world. From a geological point of view, there are good reasons to believe that other Kimbiji Aquifers may exist up and down the coast, and even interior, of Africa. The region is currently the subject of intense oil and gas exploration, but the data are protected by proprietary law.

Figure 6 Reverse circulation drilling.

Articles

Footnotes and references

[1]Funded by the Government of Norway and implemented by the Dar es Salaam Water and Sewerage Authority (DAWASA; responsible for water and wastewater services in DSM and part of the Ministry of Water and Irrigation).

[2]The discovery of the Kimbiji Aquifer was made as part of a Future Water Source Options review for the city of DSM. See: Ruden, F. (2007). The Discovery of a Regional Neogene Aquifer in Coastal Tanzania. Published in: Coastal Aquifers: Challenges and Solutions, Vol 1, pp. 363-372. Instituto Geológico y Minero de España, Madrid 2007, ISBN 978-84-7840-712-5.

[3]Davis, K. (2013). Deepwater Depositional Systems of Northern Tanzania. Presentation at the 13th International Conference: Africa: A World of Opportunities. Houston, Texas. September 2014

[4]Kohout et al. (1977). Fresh ground water stored in aquifers under the continental shelf: implications from a deep test, Nantucket Island, Massachusetts. Journal of the American Water Resources Association 13 (2), 373-386.

[4]Barlow, P. (2003). Groundwater in freshwater-saltwater environments of the Atlantic coast. USGS open report, Circular 1262, https://pubs.usgs.gov/circ/2003/circ1262/;

[5]See: https://www.theguardian.com/global-development/2017/aug/07/how-an-ancient-well-is-bringing-northern-namibia-water-until-funds-dry-up

A Hidden Crisis: Functionality of Handpumped Boreholes

Paul Wilson[1,2], Alan MacDonald[2], and Helen Bonsor[2]

[1]Geological Survey of Northern Ireland, [2]British Geological Survey

Unravelling current failures for future success in rural groundwater supply.

Introduction

A Hidden Crisis is one of five UPGro (Unlocking the Potential of Groundwater for the Poor) 'Consortium' research projects funded by the Natural Environment Research Council (NERC), Economic and Social Research Council (ESRC) and UKaid. Recent emphasis on improving access to improved water supplies in regions such as Sub-Saharan Africa has obscured a hidden crisis of failure (Bonsor et al. 2015). Estimates of how many handpumped boreholes (HPBs) are not functioning at any given moment range from 20% to 50%, therefore it is difficult to determine if the scale of failure is unreasonable and what the underlying causes of this failure really are. The aim of the project is to use interdisciplinary approaches to understand, diagnose and ultimately anticipate and mitigate the complex and multi-faceted underlying causes of rapid failure of rural African handpumped boreholes. This paper will detail some of the challenges that have been faced during the implementation of phase 1, providing particular focus on the thorny topic of defining functionality.

Defining functionality

Before assessing the functionality of 600 HPBs in Ethiopia, Uganda and Malawi, functionality first needed to be defined.

A literature review of water point (a system that delivers a water supply such as a HPB, hand-pumped shallow well, spring or tapstand) functionality found that there was no common approach to how functionality was defined and this likely contributed to the high degree of functionality variance found during studies.

An effort was made to derive a definition that would be used for the purposes of the project and could go some way towards a common approach. The definitions in the box on page 12 are the result of the findings from the literature review and extensive discussions between the project partners.

Survey design

The first phase of work was a rapid survey of 600 HPBs in Ethiopia, Uganda and Malawi. A simultaneous survey would also be performed to assess the functionality of the HPBs management arrangements. These surveys aimed to collect sufficient data so that an assessment could be made to identify the most relevant data for determining the functionality of an HPB and to derive a more robust estimate of HPB functionality. Random sampling of HPBs was an essential part of the value of this survey.

The design criteria for any borehole supply are that it delivers a certain quantity of water that meets a certain standard of water quality. Therefore, since the definition of functionality compares a HPB against a set of standard design criteria, the rapid surveys in phase 1 needed to assess if a HPB delivered a certain quantity of water and whether this water met certain water quality standards.

Quantity

What is the standard design quantity of water a HPB is normally expected to deliver? A figure of 600 litres per hour was settled upon following a literature study. This relates to the minimum standard expected of the widely used India Mark II and Afridev handpumps (Erpf, 2007; Erpf, 2008) and is also relevant to the anticipated demand that a HPB should meet.

A consistent and easily deployed test was needed to assess a HPB against these criteria. If a HPB was unable to deliver the required 600 litres per hour, then the cause would be due either to a low inflow rate to the borehole resulting in a rapid rate of drawdown below the pump chamber, or a mechanical issue with the handpump. A period of pumping would therefore be required but measuring drawdown without dismantling or altering a handpump is not easy.

The following test was derived from the discharge test that is the accepted inspection test applied to India Mark II and Afridev handpumps (Erpf, 2007; Erpf, 2008). It is therefore referred to as the modified discharge test (see explanatory box on page 12).

During a pilot study in Malawi, the test was found to be easy to deploy. A metronome set on the pump head maintained a rhythm of 40 beats per minute. Two operators would take it in turns to pump for five minutes so that one did

Figure 1 High demand water point ©NERC.

HPB functionality

"An assessment of how a handpump equipped borehole compares to standard design criteria for quantity [*and quality] at a given moment in time."

National functionality of HPBs

"An assessment of the proportion of HPBs within an explicit population that meet their design criteria for quantity [*and quality] at a given moment in time".

HPB performance

"An assessment of how successfully a hand pumped equipped borehole functions over time."

**Inclusion of water quality assessment is dependent on purpose of survey.*

not get excessively tired causing the pumping rate or stroke length to reduce. A third person would conduct the test and write down results whilst a fourth person counted the strokes using a manual tally counter. A fifth team member would change buckets at the handpump spout.

Quality

The inclusion of water quality in a water point functionality assessment is a controversial one. The misuse of such data could result in an HPB being removed from service, which could in turn result in users returning to unimproved water sources. Despite this, sufficient water quality is an important deliverable for any new capital works scheme.

For this survey, water quality was included so that the nuanced arrangements of factors that contribute to HPB functionality could be assessed. However, for practical purposes, undertaking a comprehensive suite of drinking water parameters would not be feasible, therefore key indicator parameters were identified. Partners agreed that the survey results would be compared against national drinking water standards for the three countries being studied.

Figure 2 In-field alkalinity titration, Ethiopia 2016 ©NERC

A streamlined approach to collecting water quality data was used at each HPB. Samples were collected to be analysed for a suite of major and minor ions. Conductivity, temperature, pH, turbidity, alkalinity and total iron were all measured in situ. A sample was collected for testing for thermo-tolerant coliforms (TTC). TTC samples were tested each day using a portable incubator unit.

Observations and questionnaire

As well as conducting the quantity and quality assessments, the local researchers were trained to carry out some visual observations of each HPB and conduct a short questionnaire with a user of the HPB. This questionnaire took place at the same time as a separate questionnaire was put to those involved with the management of the HPB. It mainly focused on gathering data on the performance of the HPB over time.

Results and future plans

The final results from the rapid survey are still coming in with analysis ongoing. The aim is to use the data to develop a tiered approach to defining functionality and a more robust and statistically sound figure of functionality and performance of HPB.

A second phase of surveying is planned to further survey a subset of 50 HPBs by undertaking intrusive investigations. The purpose of this study will be to identify the underlying causes of failure, following on from the work carried out during the catalyst project.

A third line of study is already ongoing looking at temporal factors in HPB failure. This is using groundwater level loggers and rain gauges to investigate HPB usage.

Measuring water levels – without a dipper!

The challenge of appraising the rate of drawdown in a borehole that is being pumped by a handpump is a difficult and complex one. Both the India Mark II and Afridev handpumps that are used widely across Africa do not permit easy access to the borehole to measure water levels without dismantling or altering the handpump stand.

A team from the University of Oxford have undertaken a proof of concept project where they inserted a water level logger inside a handpump and attached the logging accelerometer to the pump handle. Using machine learning, they were able to use the data from the accelerometer to identify pumping trends that corresponded to groundwater levels (Thomson et al., 2015). This worked well in this specific single HPB but would require the same process of machine learning for each new HPB.

The volume of a handpump cylinder is constant, therefore as it is pumped, each full stroke delivers the same volume of water. Therefore if a handpump is pumped at a constant rate, the flow rate will not be affected by declining head. To maintain the same pumping rate will require an increase in power delivered to the handpump by the user. Monitoring the relative power increase over a period of pumping should in theory translate to a declining head.

To further study this, two identical India Mark II

Modified Discharge Test

1. Pump at a rate of 40 strokes per minute and count the number of strokes until a constant flow is delivered then stop pumping
2. Commence pumping again at the same rate, counting the strokes with a tally counter, recording the cumulative total every minute. Collect the water discharging in 10 litre buckets and record the time that each bucket fills.
3. Continue the test for a period of 30 minutes unless the time to fill a bucket is consistently longer than 1 minute for more than 5 minutes.

Figure 3 Modified discharge test in operation, Malawi 2015 ©NERC

Figure 4 India Mark II handpump installed at Mount Stewart ©NERC.

handpumps were installed in two boreholes at Mount Stewart, Co. Down that were previously used for the Lo-Pro studies by Queen's University. One was installed in a borehole drilled through Sherwood Sandstone (low rate of drawdown) and greywacke (high rate of drawdown). These are going to be used to test prototype devices that will log strain on the pump handle during a period of pumping. Access has been provided to allow water level measurement at the same time so that the strain measurements can be related to the groundwater levels and thus derive a method for translating relative strain change to rate of drawdown.

Further information

Visit the A Hidden Crisis website

Further updates in future groundwater newsletter articles.

References

Bonsor H.C., Oates N., Chilton P.J., Carter R.C., Casey V., MacDonald A.M., Calow R., Alowo R., Wilson P., Tumutungire M., Bennie M. (2015) "A Hidden Crisis: strengthening the evidence base on the sustainability of rural groundwater supplies - results from a pilot study in Uganda." British Geological Survey (BGS)report reference: OR/15/019. UPGRO Catalyst Grant reference: NE/L001969/1

Erpf, K. (2007) "Installation and Maintenance Manual for the Afridev Handpump." SKAT – RWSN. Revision 2.

Erpf, K. (2008) "Installation and Maintenance Manual for the India Mark II Handpump." SKAT – RWSN.

Thomson P., Greef H., Colchester F., Clifton D., Hope R. (2015) "Distributed Monitoring of Shallow Aquifer Level using Community Handpumps." Briefing Note – August 2015. Smith School of Enterprise and the Environment.

Figure 5 Water point management survey, Ethiopia 2016 ©NERC.

Is Your Well Water Safe to Drink?

Derval Delaney
Environmental Protection Agency

Resources for homeowners to protect and improve the quality of well water.

Up to 30% of private wells in Ireland are contaminated by *E.coli* arising from animal or human waste. This amounts to 50,000 private wells. *E. coli* cause a wide range of illnesses, from mild diarrhoea to severe abdominal pain and bloody diarrhoea.

Ireland has the highest rate of VTEC - a form of *E. Coli* – cases in Europe. VTEC causes a serious type of gastroenteritis. In some persons, particularly children and the elderly, the infection can cause a complication called haemolytic uraemic syndrome (HUS), leading to kidney failure.

Figures indicate that there is an increasing trend in the number VTEC cases in Ireland. In 2011 there were almost 300 cases but that more than doubled to 730 cases in 2015. Most VTEC cases in Ireland so far have affected children (60%) many of whom have been hospitalised. Twenty-two individuals developed HUS in 2015. Some people are left with lifelong problems, which can, on rare occasions prove

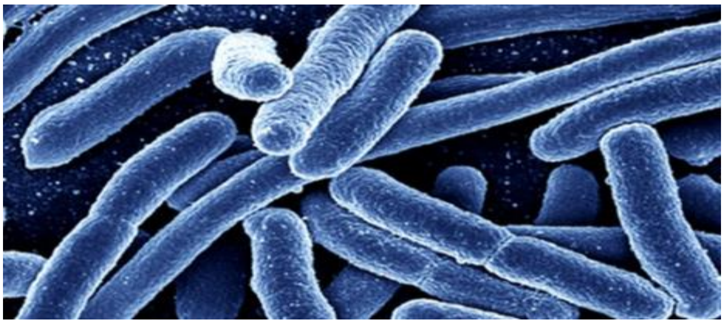


Figure 1 Microscopic image of *E.Coli* (Source: www.bbc.com)

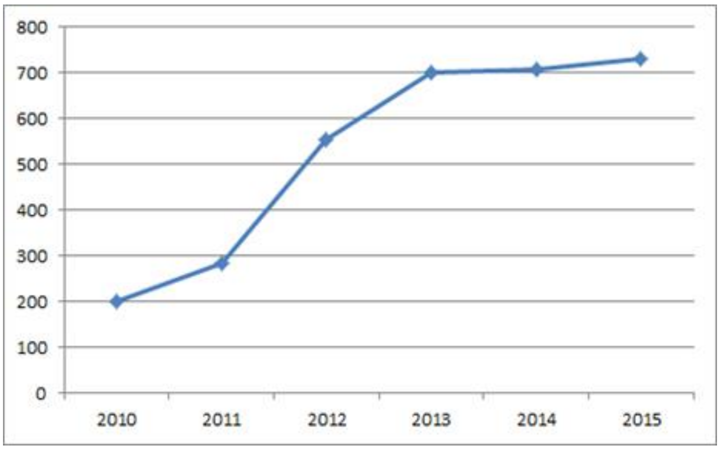


Figure 2 Number of VTEC cases per year as reported by the Health Protection Surveillance Centre (HPSC).

Figure 3 Poorly constructed wellhead with surface water entering top of the borehole (source: EPA).

Figure 4 An example of a sealed and protected well-head/borehole (source: EPA).

fatal. During 2015 one death was attributed to VTEC infection.

Animals, particularly cattle, are the main source of VTEC and infection is spread from direct animal contact or through contaminated food and water. The cases in Ireland are predominantly associated with rural families and private domestic wells; however, visitors from urban areas have also been affected.

What is not generally known is that there is a greater risk of illness associated with private well supplies. **People treated for VTEC are four times more likely to have consumed untreated water from private wells.** These wells are generally poorly located and constructed and do not have any form of treatment unlike the public and group water schemes. **By taking simple steps to protect your well this disease is preventable.**

You may have been using your well for years and have had no health problems as you may have built up immunity to the contamination. However, friends, family and children may become ill as a result of consuming your well water.

Many well owners do not seem to be aware of the risks posed to their health from private well water. Little consideration has been given to the proper location or construction of private domestic wells. Most wells do not have any form of treatment nor are they regularly tested.

Poorly constructed wells run the risk of surface water ingress either directly over the top of the borehole casing and into the groundwater (if the wellhead is below ground or flush with the ground or in an area liable to flooding) or down the side of the casing (if it has not been properly grouted and sealed after drilling). In such cases, surface water contaminants such as VTEC and the parasite *Cryptosporidium* can travel directly into the water source putting consumers at risk of illness.

In 2007, the Institute of Geologists in Ireland (IGI) published "*Water Well Guidelines*", which provide guidance on drilling wells for private water supplies and sets out best practice on water well construction. Also, the EPA's "*Advice Note No. 14: Borehole Construction and Wellhead Protection*" (available here) sets out the best practice for the design, construction and protection of a drinking water supply borehole.

The purpose of the Advice Note is to inform and instruct all to apply the IGI Guidelines when assessing the construction of existing drinking water supply boreholes, and also apply the Guidelines when commissioning the construction of new drinking water supply boreholes.

What can you do to improve your well water?

In summary, you should carry out a few simple steps to assess if your well is at risk of contamination and take action to protect your and your family's health:

1. Assess the location, construction and protection of your well. You can do this by using an assessment tool developed by the EPA which is available at www.epa.ie. The web application 'Protect your Well' asks a series of questions with multiple choice answers and takes 5-10 minutes to complete. Once completed, it will provide you with advice specific to your well, depending on the answers you provide.

2. Test your well water at least once a year for microbiological (*E. coli*) contamination, preferably after heavy rain, when the risk is highest. If you are concerned, boil your water while you wait for the results to come back. If the results of testing confirm that contamination is present, seek advice from your Local Authority and HSE Environmental Health Officer and take steps to protect your well (e.g. fence off around the well to prevent animal access, ensure slurry is not spread within 25 m of your well).

3. Seal your wellhead to prevent any contaminated surface water from flowing down over the top of the well and prevent shallow groundwater from entering the well by properly lining and grouting the well; and by ensuring that the groundwater itself is not contaminated by nearby pollution sources.

Consider treating your well water if these measures are insufficient to prevent contamination (e.g., in karst limestone areas where groundwater is heavily influenced by surface water). Permanent treatment including disinfection as a minimum should be installed, or consider connecting to a group or public water scheme.

The EPA and HSE want to help well owners learn how to protect their well and reduce the risk to their family's health. A lot of relevant information is now available on the EPA's new private wells webpage www.protectyourwell.ie. The information includes a short animation (in English and Irish) to explain the risks to well water quality and the simple things that can be done to reduce the risks, the '*Protect your Well*' assessment app and an infographic leaflet.

For further information visit:

- Your local authority website;
- www.protectyourwell.ie;
- 'Protect your well' app on erc.epa.ie/water/wells;
- FAQ's on Private Wells: http://www.epa.ie/water/dw/hhinfo/faqpwells/;
- List of testing laboratories at: http://www.epa.ie/water/dw/hhinfo/
- Drinking Water Parameters https://www.epa.ie/pubs/advice/drinkingwater/2015_04_21_ParametersStandaloneDoc.pdf
- "Have you checked your well water supply?" Leaflet at: http://www.epa.ie/pubs/advice/drinkingwater/SS%20Wells%20Web.pdf
- Your Local Authority and/or your local HSE Environmental Health Officer can provide further advice if you are concerned about your well water supply.

Uisce Aille – Lisdoonvarna Integrated Catchment Management Project

Tiernan Henry[1], Gesche Kindermann[2], Grainne Barron[1], Eamon Doyle[3]
[1]Earth & Ocean Sciences, NUI Galway; [2]Applied Ecology Unit, NUI Galway; [3]Burren & Cliffs of Moher UNESCO Geopark

A look at the award-winning local engagement project in Co. Clare.

Formally, maps are graphic representations that facilitate a spatial understanding of things, concepts, conditions, processes, or events in the human world (Harley & Woodward, 1987), which means that they are creative interpretations of space. Less formally, maps appeal to our memory, our creativity and our dreams. In practice, maps reflect choices; the 16th century cartographer Ortelius wrote that maps show some things, which means not showing other things; hence we have geology maps, or habitat maps, or road maps. Maps haven't just allowed us to reproduce the world, they have allowed us to construct it. Wallace Pratt (1944) famously wrote that "gold is where you find it, according to an old adage, but judging from the record of our experience, oil must be sought first of all in our minds", in other words we must be able to represent the ground that holds the oil: we must be able to map it. And this is true of water too: if we want to manage our water resources we must consider mapping them and this means understanding catchments.

A catchment (or watershed) is a landscape unit that includes all ecological, social and economic processes taking place within its boundaries. Integrated Catchment Management (ICM) is an approach that aims to organise and manage all of the processes within a catchment through sustainable policy and action (Rolston et al, 2016). The Water Framework Directive (WFD) is the catalyst for the catchment-based approach in the protection, preservation and improvement of water environments, encouraging local community engagement (DEFRA, 2013). ICM is strongly rooted in balancing economic, social and environmental considerations and this ethos is reflected in recent work on the state of the WFD and on ideas of social geology. Both Daly et al (2016) and Voulvoulis et al (2017) stress the importance of meaningful and sustained stakeholder engagement in the success of the next phase of the WFD and Stewart and Gill (2017) argue convincingly for the inclusion of ideas of sustainability into both geoscience education and practice. Daly et al (2016) stress that the success of the WFD requires a paradigm shift in approach and thinking, and that stakeholder engagement, and retention of that engagement, is key to this. They see ICM as a new type of reflexive governance – open, experimental and learning oriented – that, while building on the past, provides an organising framework, allowing us to view catchments in their full four-dimensional reality (including time) at a scale that allows sovereignty of all stakeholders through true citizen engagement.

Local engagement can only be fully realised when a community can see their experience and knowledge reflected in stewardship and shared

Figure 1 Uisce Aille students presenting to UNESCO Geopark staff.

ownership of their catchment. Managing catchments effectively requires us to take on board and integrate a huge range of information. And what better way to encourage awareness, pride, and participation than through training future local stakeholders, giving them with the skills that allow them to become knowledge generators, in de Loë et al's (2016) phrase, rather than just knowledge recipients? One project aiming to do just that is the Uisce Aille project in the Burren Co. Clare.

The project was conceived by Dr Tiernan Henry and Dr Gesche Kindermann from NUI Galway and was developed in discussion with Dr Eamon Doyle and Carol Gleeson from the Burren and Cliffs of Moher UNESCO Geopark. The team had already been working with John Sims from Mary Immaculate School in Lisdoonvarna and he and the other teachers agreed to host the project, working with the transition year (TY) class. The Burren and Cliffs of Moher UNESCO Geopark provided funding through the EU GeoparkLIFE programme to allow the recruitment of a research MSc student (Grainne Barron) who would devise and run the programme in the school. Grainne started working with the students in September 2016 and the students named the programme Uisce Aille. Over the following months she led the TY group in exploring and mapping the natural and built environment of the Aille River catchment. The river rises on the sandstone and shale of the Gull Island Formation on the slopes of Slieve Elva, flowing through and over the limestone of the Slievenaglasha Formation and the Clare Shale Formation before discharging to the sea at Doolin.

This programme focused the students on their place; they studied and investigated their own home ground - the river runs through Lisdoonvarna, and the students all live in the catchment. In effect, they completed a desk study of their local area as defined by the river catchment.

The aims of the project were to give the students the skills and means to make maps of the catchment (their catchment), and to co-develop a transferable toolkit with the students that would allow other TY groups in other schools to make similar maps of their catchments. Student engagement is at the heart of Science Foundation Ireland's (SFI) education and public engagement programme (www.sfi.ie/discover-science-engineering-dse/), a programme that aims to "catalyse, inspire and guide". The Uisce Aille project is built on the idea of a partnership approach that engaged with students in a positive, inspiring and empowering way – at its core is the notion that the work was directed by the students and the outcomes are real and have real value.

Grainne is based in NUI Galway and she ran weekly classes with the TY students from mid-September 2016 to the end of February 2017. She led the students on a catchment walk as well as visiting reaches of the Aille to give them hands-on field experience in river surveying, including kick sampling, flow characteristics, identification of habitats and invasive species etc. (Figure 2). Critically, and importantly, she trained the students in the use of QGIS, an Open Source Geographical Information System mapping software package. This allowed the students to access and download a wealth of freely available online environmental information and data (from GSI, EPA, Teagasc, Met Éireann, etc.). Combining local knowledge, outdoor field and surveying skills with the use of GIS, the students built up their map. Accessing and collecting data was important, but just as important was connecting the students with locally-based experts who gave their time and shared their knowledge and insight: the input of Dr Eamon Doyle (Geopark geologist), Tracy Duffy of Clare County Council Environment section and the staff of the Burren Outdoor Education Centre was invaluable to the project.

From a pedagogical perspective, this approach transforms learning possibilities for the students, allowing them to take control of their own learning (Earl & Forbes, 2011). This type of approach reinforces concepts, increases student confidence and supports a multi-stranded, resource-based pedagogy (Lancellotti et al., 2016; Turner, 2015). This method, which is

Figure 2 Uisce Aille students in the field.

student led, involves group work, and its link to the environment has been shown to have a positive emotional impact on students (Boyle et al, 2007). This type of partnership working empowers students, allowing them to develop a clearer sense that they belong to a larger learning community and it engages them in the work (Moore-Cherry et al, 2016). This has clear constructive implications in the wider context too, when considering the broader community in the catchment.

The map created by the students is populated with different datasets such as soils, geology, land use, aquifers, water resources and also with important cultural and heritage sites identified as important by the students. The finished map and accompanying poster were presented by the students to an international meeting of 100 European Geopark managers in Lisdoonvarna in March 2017 (Figures 1 and 3). The students also presented their project to their peers at an assembly of all the students of Mary Immaculate School in May 2017.

The students and their teachers entered the project in the ECO-UNESCO Young Environmentalist Award (YEA) and in April this year they were announced as Joint Winners in the Senior Water Section (Figure 4).

The Uisce Aille programme is a pilot scheme in developing a transferrable toolkit that other schools can use to channel students' energy into positive action, empowering them to characterise and map their local water resources. The ICM toolkit fits within the current Leaving Certificate Geography, Biology and IT curriculum, while the place-based nature of the programme grounds the students' learning in their own landscape, community and shared history, thereby enhancing the experience. The toolkit will be designed to enable educators and TY students to refine the mapping process to suit any location in Ireland, whether urban or rural.

Grainne presented a poster of the work at the Irish Geological Research Meeting (IGRM) in TCD in February 2017 and at the Environ Conference in Athlone in April 2017, and she was one of the invited speakers at the International Association of Hydrogeologists (Irish Group) (IAH) meeting in Tullamore in April 2017. She also talked about the project at the annual NUI Galway GIS research seminar in June 2017 and at The Magical Waters of the Burren talk hosted by the Waters and Communities Office together with the Burren Nature Sanctuary in July 2017. She is currently working on completing the toolkit, and over the coming months she'll be interviewing the students to get their feedback and reflections on the programme.

One key finding of WFD reviews and of the review of the WFD process in Ireland is that the ultimate success of the directive requires that the ICM process be inclusive and meaningful. The success of the Uisce Aille project is encouraging and it provides an additional means to engage with stakeholders. The approach is also sustainable in that it aims to embed the programme in a secondary school allowing teachers and students to engage with the process and allowing the students to work from within their own catchments and to share their findings with their own community. The Uisce Aille project fits with the aims and ethos of the Water Framework Directive: it is participatory, it is educational, and, for the students, it is emancipatory. It is based in and of the community, and the outcomes are replicable and transferable.

On a final note, projects like this can only work if they are locally supported. In this case the community support was always forthcoming and we would like to acknowledge and thank anyone who contributed time, information and support to the success of the Uisce Aille project.

References:

Boyle, A., Maguire, S., Martin, A., Milsom, C., Nash, R., Rawlinson, S., Turner, A., Wurthmann, S. & Conchie, S. 2007. Fieldwork is Good: The Student Perception and the Affective Domain. Journal of Geography in Higher Education, 31, 2, pp 299-317.

Daly, D., Archbold, M. & Deakin, J. 2016. Progress and challenges in managing our catchments effectively. Biology and Environment: Proceedings of the Royal Irish Academy, 116B, pp 157-166.

de Loë, R. C., Murray, D. & Brisbois, M. C. 2016. Perspectives of natural resource sector firms on collaborative approaches to governance for water. Journal of Cleaner Production, 135, pp 1117-1128.

DEFRA. 2013. Catchment Based Approach: Improving the quality of our water environment. A policy framework to encourage the wider adoption of an integrated Catchment Based Approach to improving the quality of our water environment. Department of Food, Environment and Rural Affairs, UK Government Publications.

Earl, K. & Forbes, D. 2011. Transforming learning though ICT: swimming with dolphins. In: McGee, C. & Fraser, D. (Eds). The Professional Practice of Teaching, 4th Ed. Cengage, Melbourne.

Harley, J.B. & Woodward, D. 1987. A History of Cartography, Volume 1, University of Chicago Press.

Lancellotti, M., Thomas, S. & Kohli, C. 2016. Online video modules for improvement in student learning. Journal of Education for Business, 91, 1, pp 19-22.

Moore-Cherry, N., Healy, R., Nicholson, D.T. & Andrews, W. 2016. Inclusive partnership: enhancing student engagement in geography. Journal of Geography in Higher Education, 40, 1, pp 84-103.

Pratt, W. 1944. Oil in the Earth. University of Kansas Press, US.

Rolston, A., Jennings, E. & Linnane, S. 2016. Towards Integrated Water Management (TIMe) Synthesis Report 2014-W-DS-20, EPA Research Report. Environmental Protection Agency, Wexford.

Stewart, I.S. & Gill, J.C. 2017. Social geology – integrating sustainability concepts into Earth Sciences. Proceedings of the Geologist's Association, 128, pp 165-172.

Turner, Y. 2015. Last orders for the lecture theatre? Exploring blended learning approaches and accessibility for full-time international students. The International Journal of Management Education, 13, pp 163-169.

Voulvoulis, N., Arpon, C.D. & Giakoumis, T. 2017. The EU Water Framework Directive: From great expectations to problems with implementation. Science of the Total Environment, 575, pp 358-366.

Figure 3 Uisce Aille students at YEA Awards 2017, Mansion House Dublin.

Figure 4 Uisce Aille maps.

Water and blanket bogs – a fertile research area

***Raymond Flynn*[1]*, Fergus Campbell*[1] *and Joshua Deery*[1]**
[1]*Queen's University, Belfast*

Quantification of Blanket Bog Ecosystem Services (QUBBES): project update

Blanket bogs and blanket peat occupy a neglected position in Irish hydrology and hydrogeology. Even though blanket peat covers vast areas of upland across the country, and extends right down to the coast in the west, its hydrological and hydrogeological properties remain poorly characterised. From an economic perspective, this may not be all that surprising. After all many areas containing blanket bog are sparsely populated and display little conventional economic value. In fact for hundreds of years people have been trying to think of ways to develop these areas; one only has to think back to the Bog Commissioners who investigated the possibility of using peatlands to grow linen at the time of the Napoleonic wars. Fast forward to the 21st Century and the view that blanket bogs require development remains a persistent theme for many.

However, this view is changing. Recent years have witnessed a growing recognition that blanket bogs may also provide valuable ecosystem services. These include regulating stream flow and water quality, while maintaining ecosystems in many high status water bodies. Quantifying these services proves essential for assessing blanket bog natural capital. The EPA-funded project "Quantification of Blanket Bog Ecosystem Services (QUBBES)", started in August 2016, aims to provide information that will assist in more confidently assigning financial benefit to these services. Understanding how water behaves in these habitats, both in supporting aquatic and terrestrial biodiversity, while maintaining stream flow and good water quality, is central to project research.

Field-based and desk-based activities undertaken in 2017 by project researchers have combined peatland ecohydrological expertise with more conventional hydrological methods to understand the condition of blanket bogs and how ecological and hydrological regimes interact. At the same time investigators have been busy trying to determine costs associated with changes in hydrological impacts associated

Figure 1 Streams discharging from blanket bog catchments have acted as sources of high quality drinking water. However removal of elevated levels of dissolved organic carbon incur significant treatment costs. More critically degradation of peatland increases these costs. Using figures provided by Yorkshire Water to IUCN, an increase of 100 Hazen Units in Water Colour can result in treatment costs going up by £17.85/ML or roughly €20ML, or approximately €1.5Million/year for a plant supplying 200 ML/day.

with peatland alteration/development and the associated changes in water quality.

Results to date have proved "interesting", to put it mildly. Organic matter levels in water can vary dramatically between intervals of healthy peat-accumulating vegetation, where high water tables limit peat decomposition rates, and more damaged areas, where periodic ingress of oxygen into peat mass accelerates decomposition and may lead to elevated levels of DOC in receiving waters. These increases in organic matter content result in significantly higher water treatment costs and provide a strong economic incentive for water companies to initiate or expand peatland-friendly catchment management programmes (Figure 1).

Results of hydrological and hydrogeological monitoring at three relatively intact sites have proved similarly interesting. On the one hand rainfall/runoff monitoring and associated modelling has helped to dispel the myth that blanket bogs act as sponges that buffer the impacts of flooding further downstream; if anything, results from two test sites monitored during summer 2017 have shown streams to be extremely responsive to rainfall. On the other hand, recession analysis has shown stream discharge during drier periods to be more stable than anticipated, while hydrochemical data suggest that much of this baseflow is derived from subsoil and/or bedrock units underlying the peat –yet again highlighting how much more we need to appreciate groundwater in Ireland.

If the first few months of field work are anything to go by, further interesting discoveries await the project team. If you would like to know more about QUBBES, please follow us at @qubbes on Twitter, or at the project web page www.qub.ac.uk/schools/NBE/Research/ResearchCentres/qubbes/

Research

Arsenic Contamination in Drinking Water in Ireland: A Spatial Analysis of Occurrence and Potential Risk

Tiernan Henry[1,2] and Liam Morrison[1,3]

[1]NUI Galway, [2]iCRAG, [3]Ryan Institute, NUI Galway

*A summary of a recently published article by McGrory et al. (2017)**

**McGrory, E., Brown, C., Bargary, N., Hunter Williams, N., Mannix, A., Zhang, C., Henry, T., Daly, E., Nicholas, S., Petrunic, B.M., Lee, M. & Morrison, L. 2017. Science of the Total Environment, 579, pp 1863-1875.*

Groundwater reflects the ground in which it flows and is stored, and unpicking its chemistry allows us to look back into the catchment and into the bedrock aquifer to make reasoned inferences about its journey to wells, springs, rivers,lakes or the sea. Dissolved mass or particulate matter is found in all groundwater, but excess levels of particular elements or compounds can lead to contamination of the resource and this can lead to harmful impacts on human or animal end-users.

Dissolved arsenic (As) is a recognised carcinogen and toxicant and is sometimes found in groundwater, occasionally in amounts higher than the drinking limit.. Concentrations in groundwater are typically higher than in surface water because of the longer residence time, greater solid to solution ratios and subsurface redox conditions; reflecting the makeup of the system through which the water moves (Garelick et al 2009).

Much work has been completed in Asia and in north and south America where elevated arsenic levels are frequently associated with groundwater found in unconsolidated Quaternary sediments, where these sediments host the high-arsenic water but are not the source of the arsenic (Blake & Peters, 2015 and references therein). In Europe, by contrast, the distribution of high-arsenic groundwater is found across many lithologies and geological settings. In a global compendium of arsenic contamination of groundwater, Murcott (2012) suggests that the primary source of arsenic in Irish groundwater is likely anthropogenic in origin (specifically related to burning coal), although he acknowledges that mineralisation associated with zinc and lead deposits may also be a source. The adoption of the Water Framework Directive (WFD) coupled with a good monitoring and analytical infrastructure means that there is greater availability of reliable data. In Ireland, the EPA has been systematically collecting water chemistry data since the early 1990s during which time analytical methods and detection limits have improved.

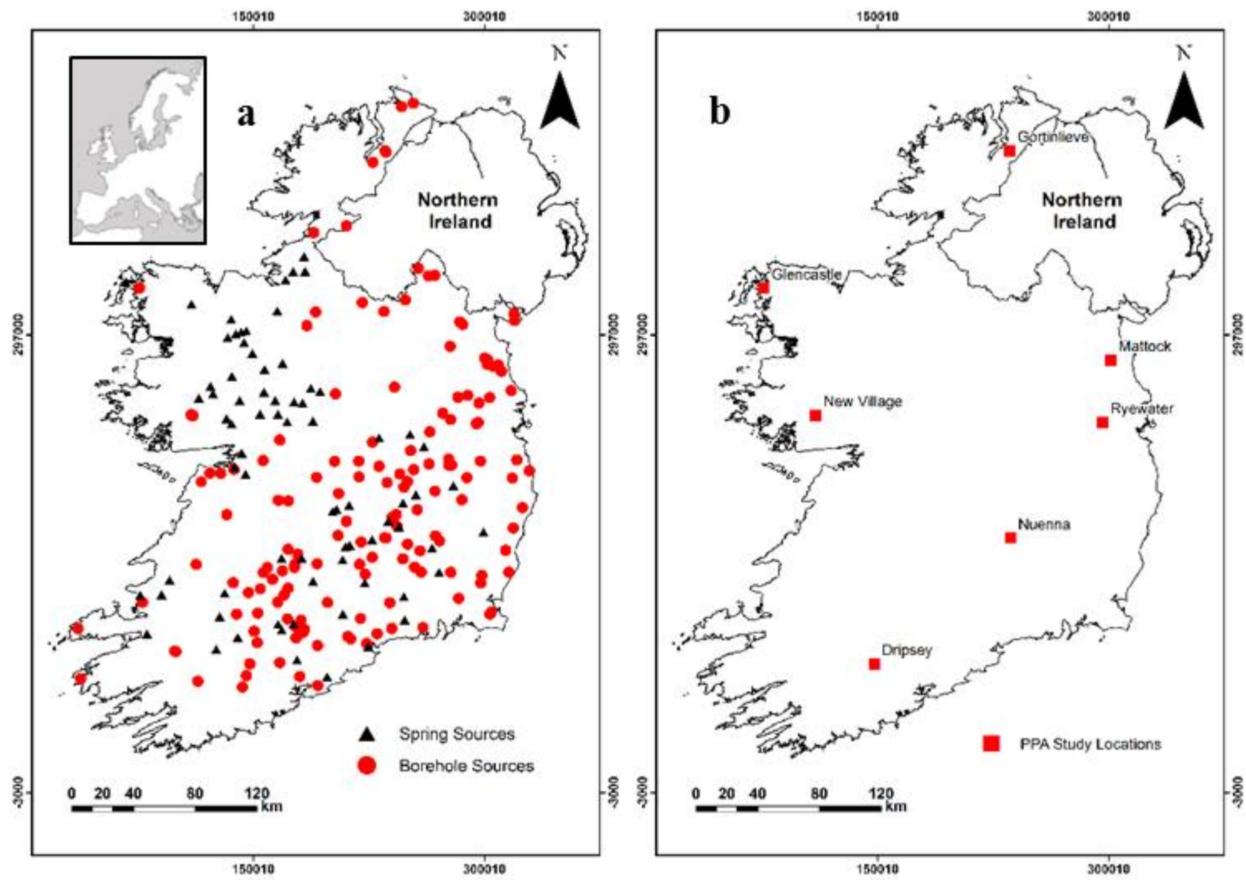
Across north America, China and parts of Asia, assessments, including geostatistical studies, of the spatial distribution of arsenic in groundwater have been undertaken (e.g., Gong et al., 2014; Yang et al., 2014), but no similar studies have been completed in any EU member state. The paper we published in Science of the Total Environment was the first national geostatistical assessment of geogenic arsenic contamination of groundwater in the EU. The aims of the work were:

1. To develop a combined statistical and geostatistical method for the most appropriate interpretation of a left-censored dataset (data below detection limit by unknown amount) at a national scale;
2. To explore if statistically significant differences existed in arsenic distribution in groundwater across geological and hydrogeological classifications; and,
3. To identify potential arsenic clusters in groundwater using spatial mapping techniques.

No new data were collected as part of this work; rather existing data sets were accessed and collated. A national collaboration was established between local government, the GSI, the EPA, and the HSE and various data sets obtained from these sources were used in this work. It is important to point out that these were the only data used in this study: no exploration data, data from the historic or active mine sites across Ireland, or other research data were accessed or used. Data from "small supplies" were not included in the statistical and spatial statistical analyses.

The EPA routinely assesses water quality in almost 300 wells across the Republic reflecting different usage patterns, different hydrogeological settings and different geological settings. For this study the data from 1993-2012 was accessed and a total of 8270 measurements of arsenic in groundwater were obtained (EPA-TOTAL). Of these data, almost 89 percent were from productive aquifers (EPA-NPPA). Interval mapping of arsenic concentrations was generated using five classes: ((0,1], (1,7.5], (7.5,10], (10,100], and (100,234]). At each of the monitoring wells there were between one and 41 arsenic measurements. A large number of these were reported as below detection limit (DL) so, to reduce complexity, only the maximum recorded value at each well was included. As a check, the analysis was repeated using the median value resulting in very similar results. Non-detect (left censored data) are common in datasets of this type (spanning a 20-year period) especially as techniques and methods improved. A number of approaches have been and are widely used to utilise non-detect data (Helsel, 2012); in this case an empirical distributive function (EDF) was used which offers more precision.

The HSE provided additional arsenic data from three regions (Mayo, Leitrim and Sligo, covering 2001-2007), while data from Donegal, Cork, Galway, Kilkenny, Longford, Louth, Meath,



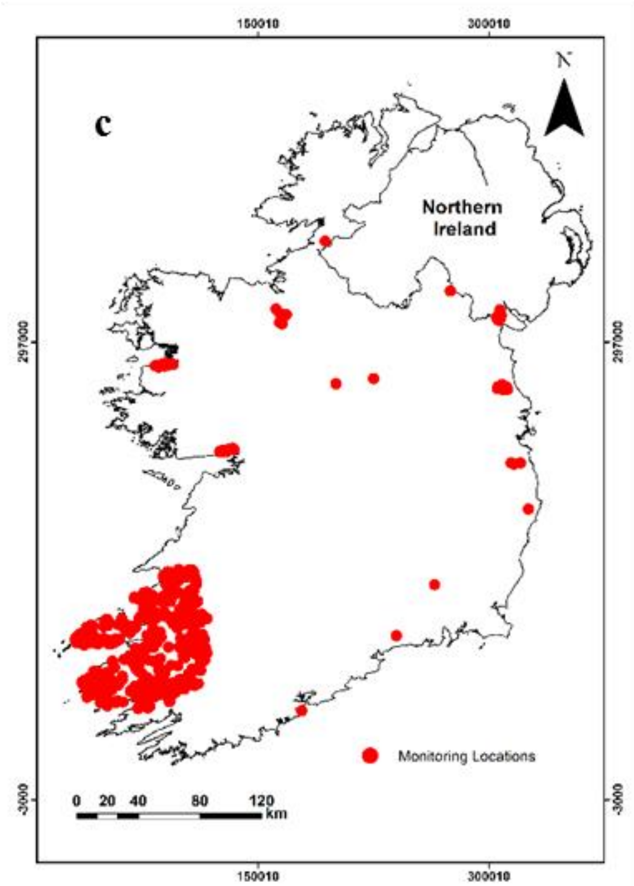


Figure 1 Geographic distribution of the Irish EPA (a) 287 mixed groundwater monitoring locations, (b) seven clustered PPA study sites, and (c) Spatial distribution of the monitoring locations of the HSE and local government.

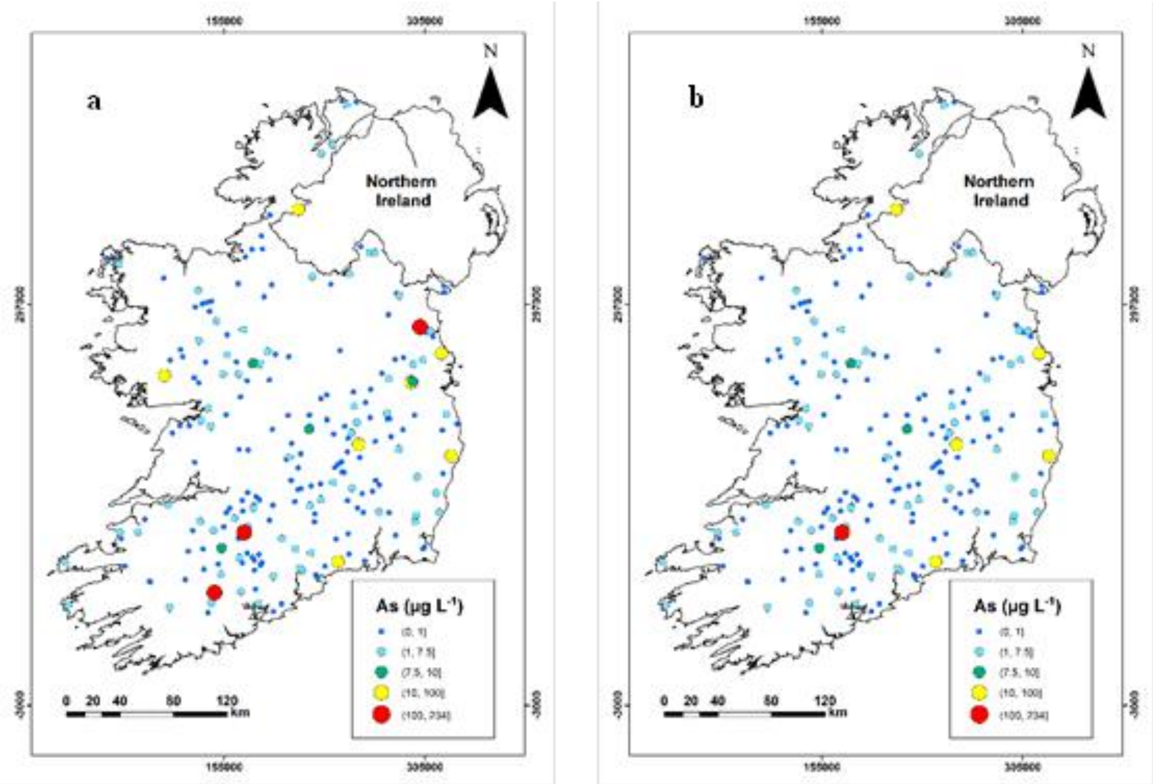


Figure 2 Spatial distribution of the Irish EPA arsenic data with five geochemical classifications of (a) EPA-Total data and (b) EPA-NPPA data. Geochemical classifications are based on the following arsenic concentration ranges (µg L-1); (0, 1] (blue), (1, 7.5] (teal), (7.5, 10] (green), (10, 100] (yellow) and (100, 234] (red).

Monaghan, Waterford and Wicklow covering 2001-2011 was obtained from local authorities. Kerry provided an extensive data set of 1494 arsenic measurements (Figure 1).

The National Generalised Bedrock and the Groundwater Vulnerability maps were accessed from the GSI, and the simplified rock unit groups were reduced from 27 to 11 classes. This generalised grouping was then coupled with the vulnerability classes to create a basic geology map, over which the arsenic data could be draped. Inverse distance weighting (IDW) and local indicator of spatial association (LISA) methods were then used to spatially interpret and present the data.

Interval maps for both EPA-TOTAL and EPA-NPPA data are shown in Figure 2a and 2b. Of the TOTAL number of sites, only 25 have values above the GTV of 7.5mg/l (~9%); of the NPPA sites, only nine (9) have values above the GTV (~4%). Looking at the number of analyses (8270 and 7334, respectively) only 2% and 1.6% were above the GTV. Given these low returns the relationships between bedrock type and arsenic abundance must be carefully considered. Low storativity, high transmissivity aquifers (Rk and Rkc) typically had low arsenic values, which is to be expected given the (relatively) short residence time of the water in the bedrock. Aquifers classed as poorly or locally productive generally had higher arsenic values. Groundwater sourced from the Sandstone grouping typically exhibited higher arsenic levels. The spatial data interpretation outputs are presented in Figure 3. The LISA hotspot analysis produces clusters categorised as high-high (high values in high value areas), and low-low (low values in low value areas). The IDW maps suggest a wider spread of contamination in the northeast and along the south and southwest coasts. These interpolated values must be treated with extreme caution, based, as they are, on small sample numbers.

The LISA analyses and IDW interpolation indicate that groundwater in the west of Ireland contains lower levels of arsenic, and that the majority of potentially contaminated locations in the west are springs. The south and east of Ireland showed higher overall levels of arsenic, and the majority of these locations are boreholes (Figure 3). This interpretation and assessment of the contaminative potential based on IDW and LISA analyses of arsenic contamination agree with European-wide and national soil assessments (Salminen et al 2005; Fay et al 2007) that identified higher concentrations of arsenic in the east and south of Ireland with lower concentrations in the west.

There are anomalous data within the HSE data sets not included in this analysis. The single largest recorded value was from a borehole monitored by Kerry County Council. For the 1993-2012 period arsenic concentrations in groundwater recovered from this monitoring point ranged from <1 to 21,020 mg/l.

While the elevated values were associated with a broad grouping of Sandstones, this is extremely generalised and does not take complex geology into account. A recent survey of Dublin soil found that median arsenic values for Silurian metasedimentary rocks were elevated at 24.7 mg/kg due to arsenopyrite mineralisation (Glennon et al 2014). Studies in the US have also identified metasedimentary bedrock aquifers as sources of elevated arsenic in groundwater (Ayotte et al 2003 and 2006; Ryan et al 2013 and2015; O'Shea et al 2015). Wilkinson and Hitzman (2015) note that the Lower Carboniferous carbonates of the Irish Midlands host significant accumulations of base metals, covering an area of more than 30,000km^2 and a volume of more than 130,000km^3 Arsenopyrite is one of the common sulphides or ore minerals associated with these deposits (Banks et al 2002). These deposits are structurally controlled by deep seated faults that penetrate the Silurian metasediments to the underlying Precambrian basement (Blake et al 2016). These faults, that facilitated the flow of mineralising fluids, frequently facilitate groundwater movement (Henry, 2014).

There are numerous examples where the EPA monitoring network does not identity arsenic contamination in regions with known issues, such as the southern shore of Clew Bay. Although no EPA monitoring points are present within this locality, regional data from private sources have recorded arsenic concentrations from less than 5 to 193 μg/l. In this area gold mineralisation hosted in mesothermal quartz shear-veins occurs in a sequence of Silurian and Ordovician metasedimentary rocks (Aherne et al 1992).

This study has demonstrated that while there is a good spatial distribution in the EPA monitoring network it was unable to fully delineate areas of potential contamination that have been noted as part of regional or local studies. Broadly similar conclusions have been reached in the US (Focazio et al 2000) in that regional data revealed additional insight in contrast to the available national datasets. In Ireland, upgrading of the EPA network to include details of well depth, depth to bedrock, water makes, weathering, faulting and fracturing of the rock, and other site-specific data, and lower yielding wells (e.g. private sources) could help reconcile the differences between regional and national data in order to generate more insight into elevated arsenic concentrations in groundwater. Daly (2009) suggests that this may be difficult to achieve, given the technical difficultly in sampling poorly productive aquifers and capturing heterogeneity in rock types at a national level. Some of these difficulties may be overcome within the context of the 3-D Ireland project underway in iCRAG, where large, complex data sets representing heterogeneous systems are being successfully modelled.

This study is the starting point for further work and while there were significant limitations to the use of the outputs, these can be overcome. In this study the bedrock geology was reduced to 11 broad groupings (by comparison, for example, recent work on arsenic contamination in groundwater in Cornwall identified nine separate lithologies), and no structural data, topographic or three-dimensional data was taken into account. No-flow boundaries were not accounted for within this context. By necessity, the data was draped over the geology, rather than integrated with the geology. An appropriate next step would be to fully integrate these data. The only data used in this work was sourced from the EPA, HSE and local authorities. There are numerous other data sets that could be added for in the future, including data from the historic mine database, and data from the closed and operational mines, as well as those data available from exploration companies. Integrating these complex data sets would provide a much more robust, more reliable and more useable series of maps.

Furthermore, the harmonization of data and the creation of a central digital data repository, which would help with the holistic assessment of arsenic concentration in groundwater over time and for identifying impacted areas, has already started in the Geological Survey Ireland. One of the projects within the Groundwater 3D Mapping Programme, which started in 2015, has been building a national hydrochemistry database, compiling existing data and collecting additional data from all available sources to populate the database with. This study provides the preliminary steps towards the creation of a national database on arsenic in groundwater within Ireland, which is also feeding into the national hydrochemistry database.

Arsenic is not persistently elevated in groundwater throughout Ireland, but the presence of regional hotspots of contamination warrant further detailed investigations. Statistical analysis using EDFs and score tests to appropriately handle non-detect data with multiple detection limits suggest certain lithologies, and their structure, present a greater risk of elevated concentrations of arsenic in groundwater. The identification of potentially at-risk regions is beneficial prior to the commencement of groundwater source development programmes. If there is a potential high concentration of arsenic, then arsenic removal technologies could be used as remediation. While the full extent of the potential for elevated arsenic in groundwater sources within Ireland is unknown, incorporating all of the various data sets available (from the EPA, HSE, local authorities, GSI, exploration and mining companies, and researchers and consultants) into one database will enable this type of further investigation and situation-specific actions..

References

Aherne, S., Reynolds, N.A. & Burke, D.J. 1992. Gold mineralisation in the Silurian and Ordovician of south Mayo. In: Bowden, A.A., Earls, G., O'Connor, P.G. & Pyne, J.F. (Eds). The Irish Minerals Industry 1980-1990. Irish Association for Economic Geology, Dublin, pp 39-48.

Ayotte, J.D., Montgomery, D.L., Flanagan, S.M. & Robinson, K.W. 2003. Arsenic in groundwater in eastern New England: occurrence, controls, and human health implications. Environmental Science and Technology, 37, pp 2075-2083.

Ayotte, J.D., Nolan, B.T., Nuckols, J.R., Cantor, K.P., Robinson Jr., G.R., Baris, D., Hayes, L., Karagas, M., Bress, W., Silverman, D.T. & Lubin, J.H. 2006. Modelling the probability of arsenic in groundwater in New England as a tool for exposure assessment. Environmental Science and Technology, 40, pp 3578-3585.

Banks, D.A., Boyce, A.J. & Samson, I.M. 2002. Constraints on the origins of fluids forming Irish Zn-Pb-Ba deposits: evidence from the composition of fluid inclusions. Economic Geology, 97, pp 471-480.

Blake, S., Henry, T., Murray, J., Flood, R., Muller, M.R., Jones, A.G. & Rath, V. 2016. Compositional multivariate statistical analysis of thermal groundwater provenance: a hydrochemical case study from Ireland. Applied Geochemistry, 75, pp 171-188.

Daly, D. 2009. Groundwater – the 'hidden' resource. Biology and Environment: Proceedings of the Royal Irish Academy, 109B, pp 221-2326.

Fay, D., Kramers, G., Zhang, C., McGrath, D. & Grennan, E. 2007. Soil Geochemical Atlas of Ireland. Teagasc & Environmental Protection Agency, Dublin.

Focazio, M.J., Welch, A.H., Watkins, S.A., Helsel, D.R. & Horn, M.A. 2000. A retrospective analysis on the occurrence of arsenic in ground-water resources of the United States and limitations in drinking-water-supply characterizations: Water Resources Investigations Report 99-4279. United States Geological Survey, Virginia.

Garelick, H., Jones, H., Dybowska, A. & Valsami-Jones, E. 2009. Arsenic pollution sources. Reviews of Environmental Contamination, 197, pp17-60.

Glennon, M.M., Harris, P., Ottesen, R.T., Scanlon, R.P. & O'Connor, P.J. 2014. The Dublin SURGE project: geochemical baseline for

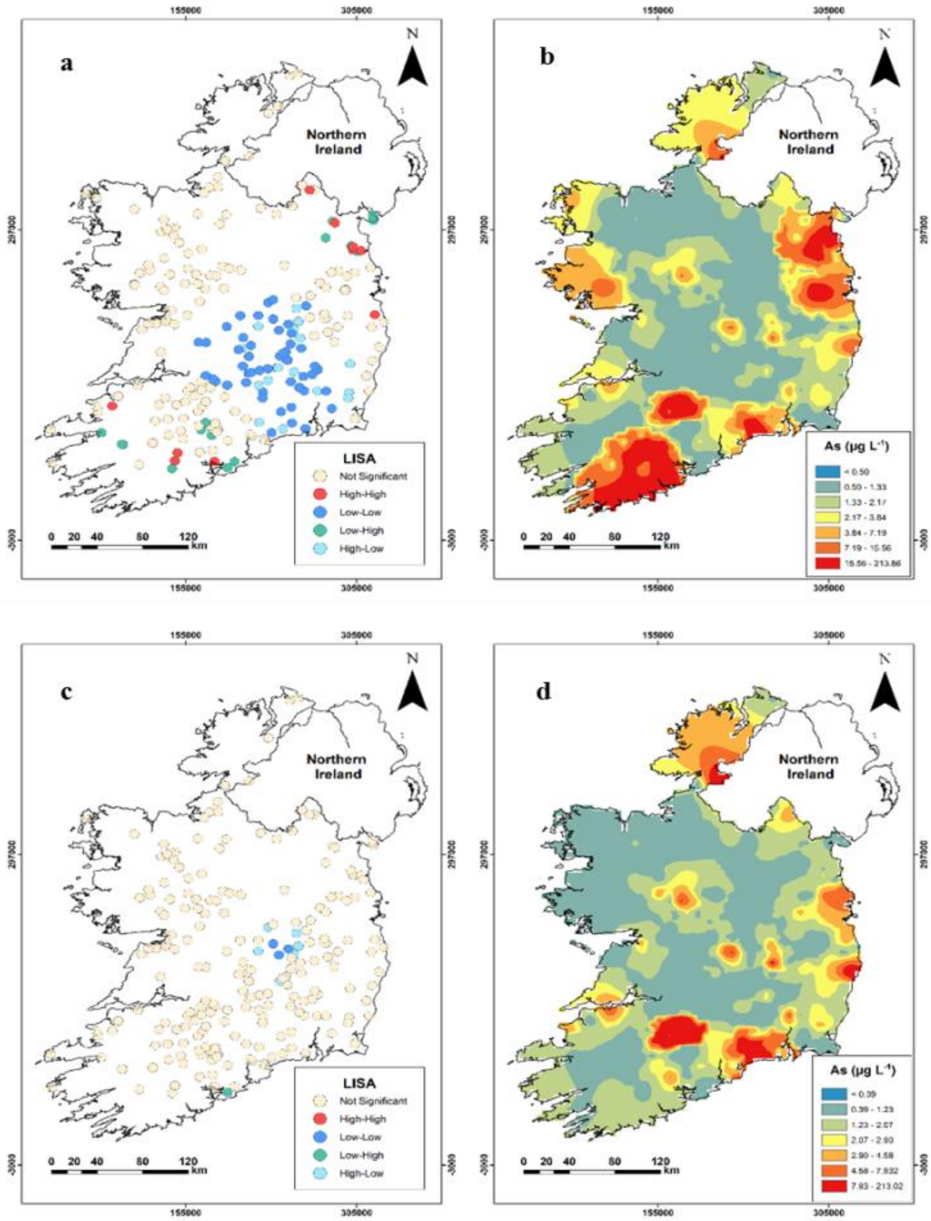


Figure 3 Geostatistical analysis of arsenic data using (a) LISA hot-spot analysis (EPA-Total), (b) IDW interpolation (EPA-Total), (c) LISA hot-spot analysis (EPA-NPPA), and (d) IDW interpolation (EPA-NPPA). The range used for the LISA maps are not significant (pale cream), high (red), low-low (blue), low-high (green) and high-low (light blue).

heavy metals in topsoils and spatial correlation with historical industry in Dublin, Ireland. Environmental Geochemistry & Health, 36, pp 235-254.

Gong, G., Mattevada, S. & O'Bryant, S.E. 2014. Comparison of the accuracy of kriging and IDW interpolations in estimating groundwater arsenic concentrations in Texas. Environmental Research, 130, pp 59-69.

Helsel, D. 2012. Plotting censored data. In: Helsel, D. (Ed). Statistics for Censored Environmental Data using Minitab and R, 2nd Ed. Wiley, NJ. pp 44-61.

Henry, T. 2014. An Integrated Approach to Characterising the Hydrogeology of the Tynagh Mine Catchment, County Galway, Ireland. Ph.D. thesis, National University of Ireland Galway (unpublished).

Murcott, S. 2012. Arsenic Contamination in the World: An International Sourcebook. IWA Publishing, London.

O'Shea, B., Stransky, M., Leitheiser, S., Brock, P., Marvinney, R.G. & Zheng, Y. 2015. Heterogeneous arsenic enrichment in meta-sedimentary rocks in central Maine, United States. Science of the Total Environment, 505, pp 1308-1319.

Ryan, P.C., Kim, J.J., Mango, H., Hattori, K. & Thompson, A. 2013. Arsenic in fractured bedrock slate aquifer system, New England, USA: influence of bedrock geochemistry, groundwater flow paths, redox and ion exchange. Applied Geochemistry, 39, pp 181-192.

Ryan, P.C., West, D.P., Hattori, K., Studwell, S., Allen, D.N. & Kim, J. 2015. The influence of metamorphic grade on arsenic in metasedimentary bedrock aquifers: a case study from western New England, USA. Science of the Total Environment, 505, pp 1320-1330.

Salminen,R., Batista,M.J., Bidovec, M., Demetriades, A., DeVivo, B., DeVos, W., Duris, M., Gilucis, A., Gregorauskiene, V., Halamic, J., Heitzmann, P., Lima, A., Jorden, G., Klaver, G., Klein, P., Lis, J., Locutura, J., Marsina, K., Mazreku, A., O'Connor,P.J., Olsson, S.Å., Ottesen, R.-T., Petersell, V., .Plant, J.A., Reeder, S., Salpeteur, I., Sandström, H., Siewers, U., Steenfelt, A. & Tarvainen, T. 2005. Geochemical Atlas of Europe. Part I – Background, Information, Methodology and Maps, Geological Survey of Finland, Espoo.

Wilkinson, J.J., & Hitzman, M.W. 2014. The Irish Zn-Pb orefield: the view from 2014. In: Archibald, S.M. & Piercey, S.J. (Eds.). Current Perspectives on Zinc Deposits, Irish Association for Economic Geology, Dublin, pp 59-72

Assessing and Developing Natural Background Levels for Chemical Parameters in Irish Groundwater

K. Tedd[5], C. Coxon[1], B. Misstear[2], M. Craig[3], A. Mannix[3], D. Daly[4] and N. Hunter-Williams[5]

[1]Centre for the Environment / Department of Geology, Trinity College Dublin; [2]Department of Civil, Structural and Environmental Engineering, Trinity College Dublin; [3]Hydrometric and Groundwater Section, Environmental Protection Agency; [4]Catchment Science & Management Unit, Environmental Protection Agency; and [5]Groundwater Section, Geological Survey of Ireland.

A summary of a recently published EPA research report on Natural Background Levels (NBLs)

Introduction

This article summarises an EPA research report which established natural background levels for 40 parameters. This EPA research report updates an O'Callaghan, Moran and Associates 2007 report which established natural background levels for 22 parameters in Ireland.

The natural background levels established in this report are the range in concentration of chemical parameters in Irish groundwater arising from natural processes. Knowledge of natural background levels is an essential prerequisite for understanding pollution and imposing regulatory limits (Edmunds et al, 2003). In Ireland, the condition of groundwater is assessed via the Water Framework Directive (WFD, 2000/60/EC) which stipulates that good chemical and quantitative status must be achieved in order to protect human health and associated dependent ecosystems. Article 17 of the WFD stresses the need for member states to identify significant and sustained upward trends of contaminant concentrations and to determine starting points for reversing these trends. The Groundwater Directive (GWD, 2006/118/EC) emphasises the importance of natural background levels when establishing threshold values for groundwater pollutants. Indeed, the GWD recognises that the upper limits of natural background levels may exceed environmental quality or drinking water standards, as these are usually based on ecotoxicological or human health grounds. This may have important implications for regulators as remediation to environmental quality or drinking water standards is unlikely to be possible where natural groundwater concentrations exceed the relevant drinking water standards and thus a good understanding of hydrogeological processes is important.

Methodology

Determining natural background levels is not straightforward due to the ubiquitous nature of anthropogenic influences on groundwater chemistry. Humans have had a long-term impact on the environment including: land use changes spanning several thousand years; alteration of rainfall chemistry from burning fossil fuels; diffuse pollution from agricultural activities and urban point source pollutions (Figure 1). The presence of purely anthropogenic substances (e.g. pesticides) indicates an obvious departure from "natural" groundwater chemistry but for most parameters, which have both natural and anthropogenic sources, the distinction is more difficult (Shand et al, 2007). There are, however, a limited number of ways to determine natural background levels. Kelly and Panno (2008) describe the options as (i) temporal where groundwater data prior to human activity are reviewed; (ii) spatial where current groundwater data from areas unaffected by human activities are collected; or (iii) a

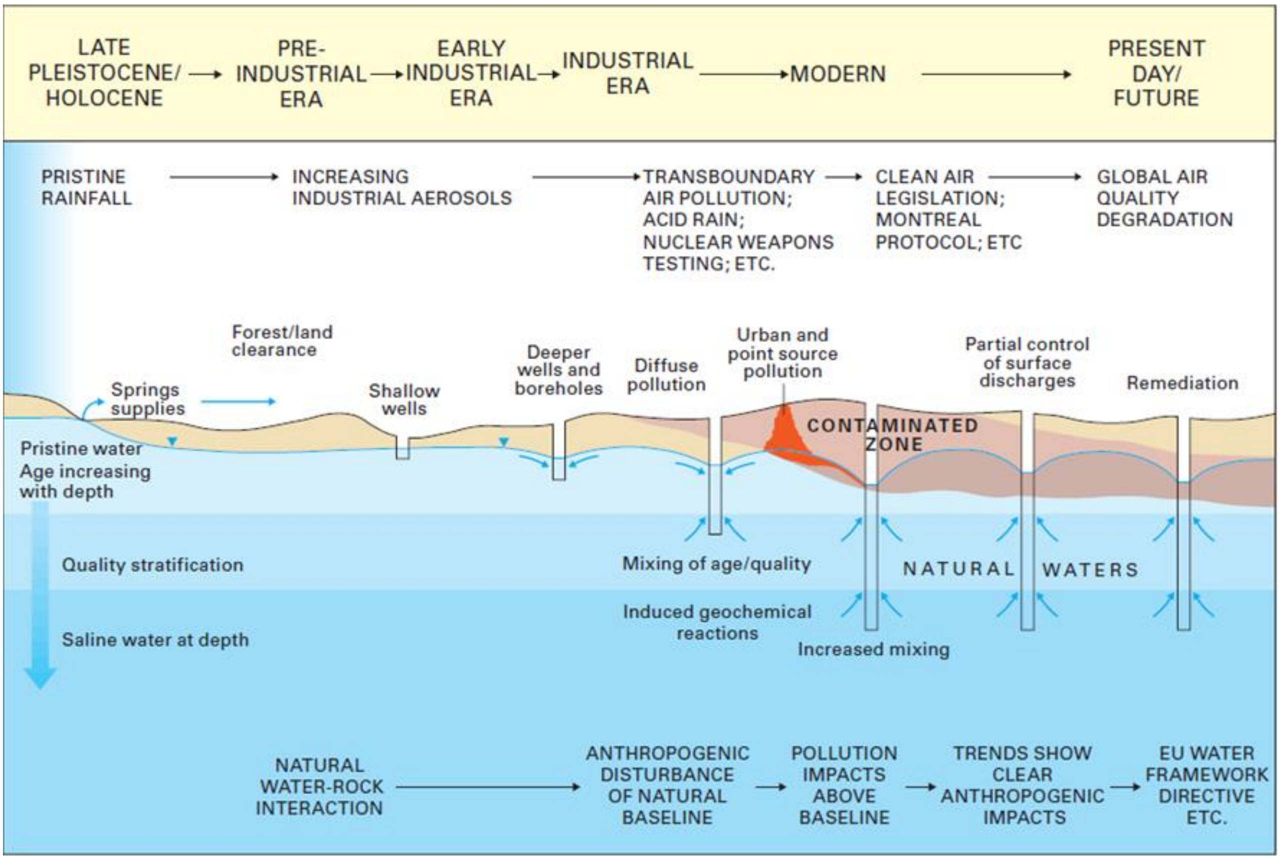


Figure 1 Conceptual figure highlighting temporal changes from pristine conditions to the modern day (after Shand et al., 2007).

combination.

Tedd et al (2017) evaluated the EPA's national groundwater monitoring database and used descriptive statistics to establish or update natural background levels for 40 parameters. As in the EU BRIDGE project (Müller et. al., 2006), Tedd et al (2017) used preselected datasets to establish natural background levels. The 40 parameters were divided into groups based on their likely susceptibility to anthropogenic activities. For example, the concentration of groundwater nitrate, phosphorus and chloride are likely to be affected by widespread rural anthropogenic activities. While the groundwater concentration of other parameters such as radon, barium and arsenic at the sampling points in the national groundwater quality monitoring programme are unlikely to be affected by anthropogenic activity. (Groundwater near industrial sites may have elevated levels of trace metals and metalloids, but such sites are not included in this monitoring network).

Likewise, the *monitoring points* were grouped using pathway and pressure datasets (e.g. soils, subsoils, geology, groundwater recharge, land use categories, livestock units and fertiliser application rates) to predict whether their zones of contributions (defined as the area surrounding a pumping well that encompasses all areas or features that supply groundwater recharge to the well (U.S. EPA, 1987) or as the catchment to a spring) were likely to contain anthropogenic sources. A subset of the EPA's monitoring network (approximately 10% of the network) was used to establish the natural background levels for the parameters susceptible to anthropogenic activities[1]. This reflects the extensive nature of anthropogenic activities in Ireland and their potential to alter groundwater chemistry. Natural background levels for the other parameters[2] used 97% of the EPA's 223 groundwater monitoring points. Data for establishing radon's natural background level came from a reduced dataset comprising a survey of the EPA groundwater monitoring points between 2007 and 2011 (RPII, 2013).

The chemistry of groundwater is affected by numerous interacting processes which are often difficult to distinguish and quantify. However, the ultimate source of most dissolved ions is the mineral assemblages in sediments and rocks near the land surface (Hem, 1985). Therefore, in order to best reflect the groundwater chemistry, and to report the natural background level results, the monitoring points were also divided into six lithological groups based on the Geological Survey of Ireland's rock unit groups (GSI, 2005) comprising: (i) sand and gravel; (ii) impure limestone; (iii) pure limestone; (iv) non-calcareous sedimentary; (v) igneous and (vi) metamorphic.

Results and conclusions

The upper (and lower where appropriate) limits of natural background levels established for the 40 parameters in Irish groundwater are presented in Table 1.

The most likely hydrogeological / hydrochemical controlling processes for each parameter were considered and the natural background levels were defined accordingly. For example, the natural background levels for:

1. Parameters that are influenced by lithology (i.e. Table 1a) were defined for each simplified lithological group;
2. Parameters that are influenced by the degree of confinement (i.e. Table 1d) were defined for unconfined conditions with a note on the likely impact of confined conditions;
3. Parameters that showed little spatial variation (i.e. Table 1e), sometimes because of a high percentage of sample with concentrations less than the limit of detection, were defined nationally; and
4. Parameters which appear show other controls (i.e. Table 1b and 1c) were defined appropriately.

Natural background levels for parameters that are susceptible to anthropogenic activities were established using less than 10% of the monitoring network. This reflects the extensive nature of anthropogenic activities in Ireland and hence the potential alteration of groundwater chemistry. This is a small number of monitoring points to perform this type of analysis and therefore statistical confidence in the natural background levels established for these parameters is low. However, the methodology follows best practice and has made best use of the available data, and results are comparable to natural background levels established in other countries or regions (Edmunds et al, 2003, Shand et al, 2007).

Most parameters show a large variation in natural groundwater chemistry with concentrations varying over a number of orders of magnitude. This variation reflects the complex interactions between rainfall input, soils, subsoils and aquifers. Where anomalous, naturally high concentrations were identifiable from the data (e.g. barium) or from literature (e.g. arsenic, fluoride, lead and uranium) details have been included. However, the list of anomalies included is not exhaustive. In addition, the natural background levels were established at national or regional scale and therefore average out the spatial variability of parameters which include topography, vegetation, recharge rates, aquifer type, well depths, and proximity to natural sources of the parameter of interest. Therefore, when applying the results at different scales, particularly local scale studies, caution should be exercised and an emphasis should be placed on understanding the local hydrogeological and hydrochemical setting and its relevance nationally.

(a) Lithological groups							
Parameter	**Unit**	**1. Sand and gravel**	**2. Impure limestones**	**3. Pure limestones**	**4. Non-calcareous sedimentary**	**5. Igneous**	**6. Metamorphic**
pH	pH units	*7.5*	*8.3*	7.9	7.1	*7.5*	*7.7*
Electrical conductivity	µS/cm	*583*	*554*	601	392	*60*	*546*
Turbidity	NTU	*1.7*	*3.1*	5.8	1.7	*1.9*	*4.7*
Calcium	mg/l Ca	*111*	*113*	117	64	*8.2*	*114*
Alkalinity	m/l $CaCO_3$	*350*	*290*	322	216	*43*	*310*
Silica	mg/l SiO_2	*13*	*17*	10	14	*19*	*16*
Aluminium	µg/l Al	15	19	26	16	131	19
Barium	µg/l Ba	586	195	179	427	179	114
Chromium	µg/l Cr	11	11	11	9.0	4.3	8.0
Radon	Bq/l	33	28	35	141	268	164
Strontium	µg/l Sr	651	2900	575	320	498	772
Total hardness	mg/l $CaCO_3$	*310*	*294*	328	212	*42*	*303*
Uranium	µg/l U	5.0	3.1	2.8	3.8	1.0	2.6
Zinc	µg/l Zn	*16*	*30*	31	67	*17*	*37*
(b) Groundwater vulnerability							
Parameter	**Unit**		**Extreme X**	**Extreme**	**High**	**Moderate**	**Low**
Dissolved oxygen (mg/l O_2)	mg/l O_2	Lower limit	4.4	0.8	3.9	0.7	*0.5*
		Upper limit	12	11	12	8.1	*5.9*
(c) Flow regime							
	Unit		**Parameter**	**Inter-granular**	**Karstified**	**Poorly productive**	**Productive fissured**
Total phosphorus (µg/l P)	µg/l P		Upper limit	13	26	16	-

(d) Influence of unconfined and confined aquifers			
Parameter	**Unit**	**Unconfined**	**Confined**
Sodium	mg/l Na	13	*105*
Magnesium	mg/l Mg	17	*42*
Potassium	mg/l K	2.1	*5.9*
Sulphate	mg/l SO_4	13	*223*
Fluoride	mg/l F	0.2	*2.6*
Nitrate	mg/l NO_3	8.7	*1.5*
Ammonium	mg/l N	0.1	*0.4*
Boron	µg/l B	15	*573*
Iron	µg/l Fe	268	*762*
Manganese	µg/l Mn	23	*176*
Nickel	µg/l Ni	2.1	*4.7*
(e) National parameters			
Parameter	**Unit**		**All pre-selected data**
Chloride	mg/l Cl		21
Molybdate reactive phosphorus	µg/l P		17
Antimony	µg/l Sb		0.5
Arsenic	µg/l As		2.0
Copper	µg/l Cu		16
Lead	µg/l Pb		2.9
Nitrite	mg/l NO_2		<0.05
Beryllium	µg/l Be		<1
Cadmium	µg/l Cd		<0.4
Cobalt	µg/l Co		<1
Mercury	µg/l Hg		<0.05
Molybdenum	µg/l Mo		<1

Table 1 The upper (and lower where appropriate) limits of natural background levels established for parameters defined (a) by lithological group; (b) by groundwater vulnerability categories; (c) by flow regime categories; (d) nationally for unconfined conditions; and (e) nationally for all pre-selected data. Values which are shown in blue italics are included for information only. They have been calculated using data from two or fewer monitoring points and are therefore not defined as natural background levels.

The natural background levels established by this report may be used as a basis for updating Threshold Values for groundwater pollutants as well as a standard against which future pollution events may be assessed.

Footnotes and references

[1]nitrate, ammonium, nitrite, molybdate reactive phosphorus, total phosphorus, alkalinity, boron, cadmium, calcium, chloride, electrical conductivity, copper, dissolved oxygen, fluoride, iron, magnesium, manganese, molybdenum, nickel, pH, potassium, sodium, sulphate, total hardness, turbidity and zinc.

[2]aluminium, antimony, barium, beryllium, chromium, cobalt, lead, mercury, silica, strontium and uranium.

Department of Environment and Local Government/ Environmental Protection Agency/Geological Survey of Ireland, 1999. Groundwater protection schemes. Department of Environment and Local Government, Environmental Protection Agency and Geological Survey of Ireland.

Directive 2000/60/EC Water Framework Directive (WFD). Directive of the European Parliament and the Council of 23 October 2000. Establishing a Framework for Community Action in the Field of Water Policy, OJ L327, 22 Dec 2000. P 1-73.

Directive 2006/118/EC Groundwater Daughter Directive (GWDD). Directive of the European Parliament and of the Council of 12 December 2006 on the Protection of Groundwater against Pollution and Deterioration, OJ L372, 27 December 2006. P 19 -31.

Edmunds, W.M., Shand, P., Hart, P. and Ward, R.S. (2003) The natural (baseline) quality of groundwater: a UK pilot study. The Science of the Total Environment 310 25-35.

Geological Survey of Ireland. Grouped rock units map. Scale 1:100,000; 2005. Available from http://spatial.dcenr.gov.ie/imf/imf.jsp?site=Groundwater.

Government of Ireland. 2014. Statutory instrument No 122 of 2014. European Union (Drinking Water) regulations. The Stationery Office, Dublin, Ireland.

Hem, J.D. (1985) Study and interpretation of the chemical characteristics of natural water. Third edition. US Geological Survey water supply paper 2254.

Kelly, W.R. and Panno, S.V. 2008. Some considerations in applying background concentrations to ground water studies. Ground Water; 46: 6: 790-792.

Müller, D.; Blum, A.; Hart, A.: Hookey, J.; Kunkel, R.; Scheidleder, A.; Tomlin, C.; Wendland, F. (2006). Final proposal for a methodology to set up groundwater threshold values in Europe, BRIDGE research project, Background cRiteria for the IDentification of Groundwater thrEsholds, co-funded by the European Commission within the Sixth Framework Programme, D18 report, UBA-A Umweltbundesamt GmbH

OCM (O'Callaghan Moran & Associates), 2007. Establishing natural background levels for groundwater in Ireland. The South Eastern River Basin District Project Team, OCM, Cork.

Radiological Protection Institute of Ireland, 2013. Radioactivity levels in groundwater sources in Ireland. Radiological Protection Institute of Ireland, Dublin, Ireland, 76pp.

Shand, P., Edmunds, W.M., Lawrence, A.R., Smedley, P.L. and Burke, S. 2007. The natural (baseline) quality of groundwater in England and Wales. British Geological Survey Research Report No. RR/07/06. 72 pp.

Tedd, K., Coxon, C, Misstear, B, Daly, D, Craig, M, Mannix, A and Hunter-Williams, N, 2017. Assessing and Developing natural background levels for chemical parameters in Irish groundwater. EPA research report number 183. EPA research programme 2014-2020. Environmental Protection Agency, Dublin. Available from http://www.epa.ie/pubs/reports/research/water/EPA%20RR%20183%20Essentra_web.pdf

United States Environmental Protection Agency. 1987. Guidelines for delineation of wellhead protection areas. Office of groundwater protection. Available online: hrrp://nepis.epa.gov

Water Tracing Using a GGUN-FL30 Flow-Through Field Fluorometer for Sampling and Analysis

David Drew[1] and Natalie Duncan[2]
[1]ex-TCD, [2]Geological Survey Ireland

Investigation of the pros and cons of using a portable fluorometer for dye-tracing experiments

Research

Introduction

Water tracing is now a widely used method for determining underground flow routes, particularly in karst terrains of Ireland. Tracing experiments are becoming increasingly sophisticated in terms of the reliability of the results obtained and in terms of ancillary data obtained from the tracings. Almost all tracings nowadays employ fluorescent dyes which include: sodium fluorescein, a green dye (the cheapest and often the most reliable), rhodamine WT (red); and optical brighteners (Tinopal for example). Sampling for the tracers is often via water samples taken from possible re-appearance sites for the traced water and/or the use of activated charcoal to concentrate dye from flowing water (rhodamine and fluorescein) with subsequent analysis using a laboratory spectrofluorometer such as the instrument owned by Geological Survey Ireland (GSI). For optical brighteners the tracer is concentrated from flowing water on to cotton rather than charcoal with subsequent analysis for the dye using UV light. If a spectrofluorometer is used then tracer concentrations can be quantified from water samples. Aqueous and eluted concentrations of fluorescein and rhodamine can be detected at low concentrations, if optimal field and laboratory practices are adhered to with detection limits displayed in Table 1.

However, there are drawbacks to these meth-

Figure 1 Deploying the GGUN-FL30 field fluorometer at Polecats Spring, Co. Roscommon

ods of water tracing:

- Neither charcoal bags nor cotton are wholly reliable as fluorocaptors, particularly the latter in regard to optical brighteners where ambiguous visual results are not uncommon.
- The fluorocaptors mentioned above are typically used where regular access to sampling sites is difficult for whatever reason and therefore they provide only registration tracings (Yes/No) at a sampling point.
- If the samples for analysis are from water samples then the resolution in the tracer breakthrough curves is limited by sampling frequency and duration which in turn are determined by personnel, logistical and budgetary considerations.
- It can take up to several days to obtain results from the laboratory.

The Instrument

Portable field fluorometers, used for automatic and continuous sampling, are increasingly being used for groundwater tracing tests. GSI has acquired three fluorometers and has applied them to characterising groundwater flows in karstic terrains in 2016.

The advantages of this sampling option are:

- Minimal labour, with time spent on site only for set-up and removal,, quality control sampling, and data download and changing batteries (if required);
- High definition data: this reduces aliasing, graphs can be interpreted with more confidence (peak concentrations, time of travel, dye recovery calculations)

Dye	Detection Limit (ppb)	
	Elutant	Water
Fluorescein LT	0.025	0.002
Rhodamine WT	0.17	0.006
Tinopal	n/a	0.07

Table 1 Detection limits for three tracer dyes in water and in an elutant.

Class	Name	Detection limit with the GGUN
I	Pyranine	Fair
I	Uranine (Na fluorescein)	Very good
I	Eosine	Fair
II	Amidorhodamine G	Fair
II	Rhodamine WT	Good
II	Sulforhodamine B	Good
III	Tinopal (CBS-X or -CL)	Very good
III	Amino G acid	Good
III	Photine	Fair
IV	Duasyne yellow T	Very good
V	Sodium naphtionate	Fair

Table 2 Tracer classes and detection limits for various dyes, using the GGUN-FL30 field fluorometer (source: abillia.com).

- Lower possibility of missing dye breakthrough;
- Results are available immediately after download and checked on site.

The Geological Survey uses the GGUN-FL30 flow-through field fluorometer, manufactured by Albillia Sàrl (www.albillia.com). It comprises a submersible probe (optical cell) that can sit on a stream/river bed and a waterproof data logger that can sit on the stream/river bank or the nearest shelter (Figure 1). Water flows naturally through the flow-through cell of the probe and is analysed for temperature, conductivity, turbidity, and up to three dye types concurrently. The advantage of simultaneously measuring turbidity is that the software automatically corrects the resulting dye concentrations for turbidity interference.

The relative sensitivity to different dyes is similar to that of laboratory spectro-photometers, but the detection limits of these dyes are higher for the field fluorometer. The detection limit (in clear water) is 0.02 ppb for fluorescein and 0.14 to 0.2 ppb for the other tracers (Schnegg, 2002). The fluorometer can detect up to three different tracers selected from five classes (I to V) but tracers from the same class cannot be separated (with the exception of fluorescein-eosine)For example, Fluorescein (Class I), Rhodamine WT (Class II) and Tinopal (Class III) can be used concurrently within a dye tracing experiment. An overview of these classes and detection limits is displayed in Table 2.

The GGUN-FL30 flow-through field fluorometer has an option of 8 sampling rates, from 2 second intervals up to 15 minute intervals and, depending on the sampling rate, can display results in real-time, also saving the data for processing later. Furthermore, it is possible to download data remotely through a GPRS connection. The fluorometer comes with two 12V batteries, each lasting approximately two weeks when using the 2 minute sampling interval. Also provided is a software package that handles data processing and reading, as well as calibration and programming.

An Example

An illustration of the quality of data provided by the different sampling and analysis strategies described above is provided by the results of a series of three water tracings (and repeat tracings) carried out between November 2016 and April 2017 on the karst drainage system near Crossmolina, Co. Mayo.

South of Crossmolina the River Deel loses water at several discrete locations via sinks, the loss ranging from 100% to less than 1% of river flow depending on discharge of the river but total losses are within the range 800-1200 l/s. The sinking water re-emerges from two connected springs at Mullenmore, 2300-1200m to the northeast. Discharge from the springs varies only in the medium term and all of the water from the sinks flows to the springs so it provides a good location to evaluate strategies of fluorometric tracing. The springs are additionally fed by an isolated sink, with a small discharge, some 4500m to the southwest.

1. Low resolution

- Tracer injection at the isolated sink mentioned above, 4500m from the springs
- 5 litres fluorescein, charcoal bag detectors, sampling 4 and 11 days after tracer injection
- Positive trace, time 4-11 days,
- Flow velocity less than 100m/h
- Form of breakthrough curve – unknown
- Time base for tracer at the springs – unknown

2. Medium resolution (Table 3)

- Tracer injection at river sink 1200m from the springs
- 5 litres fluorescein
- Manual sampling from the springs commencing 7 hours after tracer input at 5-6 hour intervals for 80 hours then a final sample at 100 hours
- Analysis for tracer using a laboratory spectrofluorometer (Figure 2)
- Positive trace, time less than 7hrs
- Flow velocity 170-184 m/h
- Time base accurate to within 7 hour

3. High resolution (Figure 3)

- Tracer injection in same sink as for medium resolution, 1200m from the springs

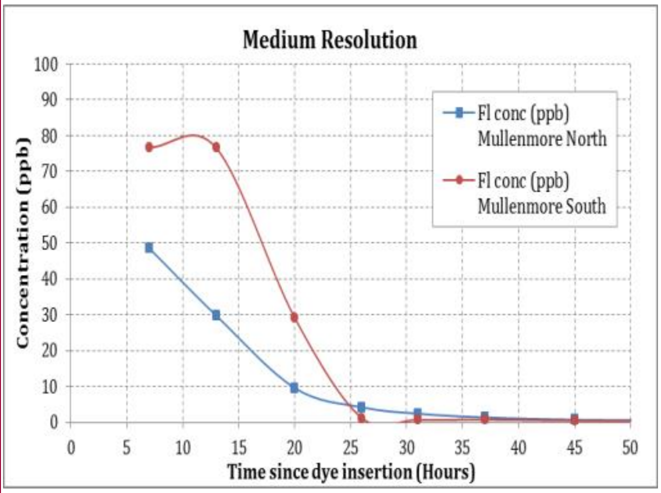
Location	% of tracer recovered
Mullenmore N	11.21
Mullenmore S	41.60
TOTAL	**52.81**

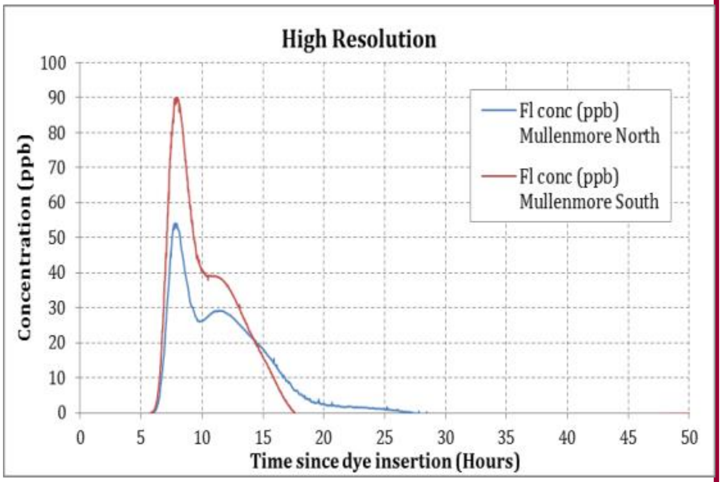
Table 3 Dye recovery from the medium resolution experiment.

Location	% of tracer recovered
Mullenmore N	13.42
Mullenmore S	31.86
TOTAL	**45.28**

Table 4 Dye recovery from the high resolution experiment.

Research





Figures 2 (left) and 3 (right) Breakthrough curves for fluorescein derived from manual sampling at the two Mullenmore springs.

- 5 litres fluorescein
- Tracer analysis using data from portable fluorometer commencing before tracer input at 30 second intervals for 150 hours.
- Flow velocity 180 m/h
- Time base 20 hours
- Subsidiary tracer peaks identifiable

Table 4 shows the percentage of dye recovered from the springs.

All three tracings involved using 5 litres of fluorescein and all three tracings gave a positive result. However, the increase in accurate subsidiary data is marked as the sampling interval is shortened and the sampling duration increased. The secondary tracer peaks apparent only in the third tracing obviously relate to the character of the aquifer and require interpretation (not the province of this article). High resolution breakthrough curves combined with discharge data for the springs makes it possible to estimate dye recovery percentage and hence provide an indication of whether all the sinking water goes to a particular outlet, though this was not an issue in the case of the Deel tracings. As far as the authors' are aware the tracer recovery data presented in this article are a 'first' in Ireland. The recovery amounts (c.50%) are perhaps surprisingly low considering the short distances and durations involved. This casts doubt on the presumption that tracer recovery percentages would be a guide as to the validity of negative results from sites: in the tracings described above it might be inferred from the results that a considerable proportion of the traced water emerges from somewhere other than the Mullenmore springs, but this is known not to be the case. Clearly, more research into this aspect is needed. The use of a portable fluorometer is demonstrably valuable in obtaining high-quality data from a tracing. However, the method is not without its drawbacks:

- The need to have an instrument in place at every possible outlet if, unlike the Deel situation, the destination(s) of the tracer are uncertain.
- The instrument is expensive and must be secured during tracing experiments.
- Maintenance and repair of the instruments have proven to be time consuming.
- The field instrument is less sensitive than its laboratory counterpart in terms of the tracer dilutions it can detect.

Reference

Schnegg, Pierre-André (2002) An inexpensive field fluorometer for hydrogeological tracer tests with three tracers and turbidity measurement. Groundwater and Human Development 1484-1488.

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

GSI Quaternary Sediments map dataset now available in Groundwater Data Viewer

The Geological Survey Quaternary Geology mapping programme released a compiled National Quaternary Sediments and Geomorphology map dataset in 2013. The Quaternary Sediments map is a more up-to-date, complete and standardised map dataset than the previously available Teagasc subsoils map dataset (2006). When assessing information on subsoils at national, regional or local scales, the Quaternary Sediments map should now be consulted.

The 2013 compilation project consisted of the merging of all available Quaternary data and resolving data conflicts in order to creating a single Quaternary Geology map dataset. To give appropriate context within which to resolve data conflicts in the National Quaternary Sediments map, the National Quaternary Geomorphology map was also developed at this time. The National Quaternary Geomorphology map describes landforms which are the result of ice acting on the landscape during the Quaternary Period, and give unparalleled insight into ice-dynamics and the resultant sediment assemblages.

The three principal map datasets in the compilation exercise included:

- Geological Survey Quaternary datasets
- EPA /Teagasc Subsoils dataset
- Geological Survey Groundwater Permeability Mapping dataset

Additional Geological Survey datasets which were consulted as part of the project, to help resolve issues where conflicts in interpretation arose between the three aforementioned datasets, include Aggregate Potential Mapping (APM), groundwater point datasets, the geotechnical borehole database, and the exploration open file database. As well as this, academic papers from the Quaternary Geology body of literature were assessed and, where relevant, landscape features and sediments were captured from these sources.

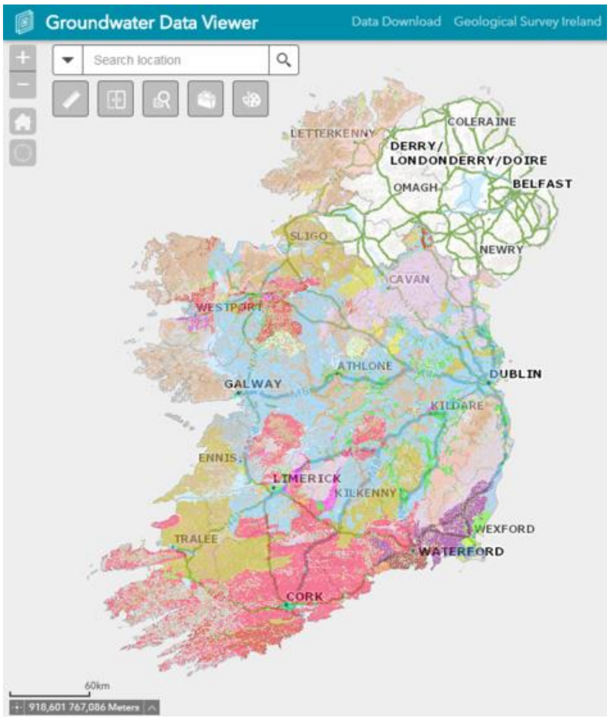
Data collection to improve confidence in the Quaternary Sediments map dataset has always been an ongoing activity in Geological Survey Ireland. Data for this purpose has, from 2014 onwards, been collected using a systematic data collection methodology as part of a new map dataset augmentation procedure, described in individual reports available from the Geological Survey. The results of both the 2013 compilation project and compilation updates to the National Quaternary Sediment and Geomorphology map datasets from 2014 to 2016 field mapping campaigns, are freely available to view, link to using WMS, or download by using the Quaternary tab at the following link: Geological Survey Ireland Spatial Resources Viewer.

The significant improvements available in the Quaternary Sediment map datasets compiled in 2013, and since, include the removal of much of the 'Made' ground class to show underlying geology, improvements in sand and gravel coverage arising from field mapping carried out in the National Groundwater Protection Scheme between 2008 and 2012, improvements in the mapping of peat units, especially in upland areas, and better information on the petrography of tills, as a result of improvements in the Geological Survey bedrock map in the early 2000's.

The Quaternary Sediments map dataset for Ireland is also available for interrogation as a layer in the Groundwater Data Viewer on the new Geological Survey Ireland website.

Michael Sheehy and Robbie Meehan

Geological Survey Ireland



Quaternary Sediments layer in the Groundwater Data Viewer (available through the GSI website).

GSI makes new appointments

Geological Survey Ireland, Department of Communications, Climate Action and the Environment, recently completed a series of external competitions for new posts, through the government Public Appointments Service (PAS). We are delighted to announce the appointment of Katie Tedd (editor of this publication!) to the role of Senior Geologist in the Groundwater Programme.

Katie comes to GSI with 12 years of hydrogeological experience, after finishing her MSc in Hydrogeology (University of Birmingham), and MSc and BA in Natural Sciences (University of Cambridge). Having worked in consultancy and for water companies in the UK, and as a research fellow with Trinity College Dublin and the Irish Environmental Protection Agency, Katie brings with her expertise in hydrogeological investigation and modelling, groundwater resource management and hydrochemistry. Katie will be able to 'hit the ground running' as she has been working as an independent hydrogeologist with the GSI's Groundwater Section and already has links with our key stakeholders. Katie currently manages the groundwater levels/flow regimes and water quality databases in order to give us national insights into our groundwater and is producing user friendly information for our stakeholders. Within her new role, Katie will be able to more fully drive these, and other, areas. When she's not busy hydrogeologizing, you may find Katie chasing after her chickens, or busy in her role as Brown Owl to a pack of Dublin Girl Guides!

In addition to Katie, we are also delighted to welcome the following new staff members:

- Mairéad Glennon, Geologist, Tellus Programme;
- Sean Cullen, Principal Geologist and Project Manager, INFOMAR;
- Jim Hodgson, Senior Geologist and Project Manager, Tellus Programme;
- Xavier Monteys, Senior Geologist, Marine Programme/INFOMAR;
- Grainne O'Shea, Information Manager; and
- Cathal Jordan, Information Officer.

We very much look forward to incorporating their skills and experience into our existing and future projects.

Monica Lee

Geological Survey Ireland

New Economic Review of the Geoscience Sector

Minister of State for Natural Resources, Seán Kyne, T.D., recently launched a Sectoral Economic Review of the Irish Geoscience Sector, by Indecon International Economic Consultants, at the opening of Geoscience 2017, the annual conference of Geological Survey Ireland (GSI), on November 7th in Dublin Castle.

The review puts a value of €3.28 Bn on the overall Economic Impact of the sectoral outputs for 2016, across the areas of Geotourism & Geoheritage, Groundwater, Extractive Industries, Geoscience Research and Geohazards. Full-time employment (FTE) figures calculated for the same year, across the same subsectors, comes to 15,110 directly employed, with a further 9,628 Indirect and Induced, giving a total of 24,739.

Minister Kyne said, "I greatly welcome this new report which gives us firm figures on the value of the Geoscience Sector to Ireland. It is a sector that may be sometimes overlooked and yet is

Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

The Irish Geoscience Sector What is it worth?

Overall Impact Direct €1.5Bn Indirect €1.8B
Total c.€3.27Bn

Employment Direct 15,100, Indirect 9,600
Total 24,700

Economic Impacts

Overall Economic Impacts - Output 2016 (€ Million)

	Geotourism/ Geoheritage	Groundwater	Extractive Industry	Geoscience Research	Natural Hazard	TOTAL
Direct	370.7	35.2	939.9	30.9	414	1790.7
Indirect & Induced	290.3	29.5	716.3	21.5	429.6	1487.2
Overall Economic Impact	660.9	64.7	1656.2	52.5	843.6	3277.9

clearly very significant. In terms of employment, it is worth noting that these are generally high-end professional jobs and that much of the activity, being linked to Geotourism and Natural Resources, is located throughout the country and not concentrated in our cities."

Koen Verbruggen, Director of GSI, added, "This report is very encouraging and will be vital in planning a new strategy for GSI. The figures show a healthy economic recovery in the Geoscience Sector, but also a significant growth in areas such as Geotourism and Research, and the need to plan and prepare for Natural Hazards such as have occurred lately with flooding and landslides. The analysis of the impact of GSI-backed initiatives such as INFOMAR and the Geoscience Ireland business cluster is also a strong validation of our current programmes."

The new report was compiled from CSO figures and other sources and is available for download from the new GSI website.

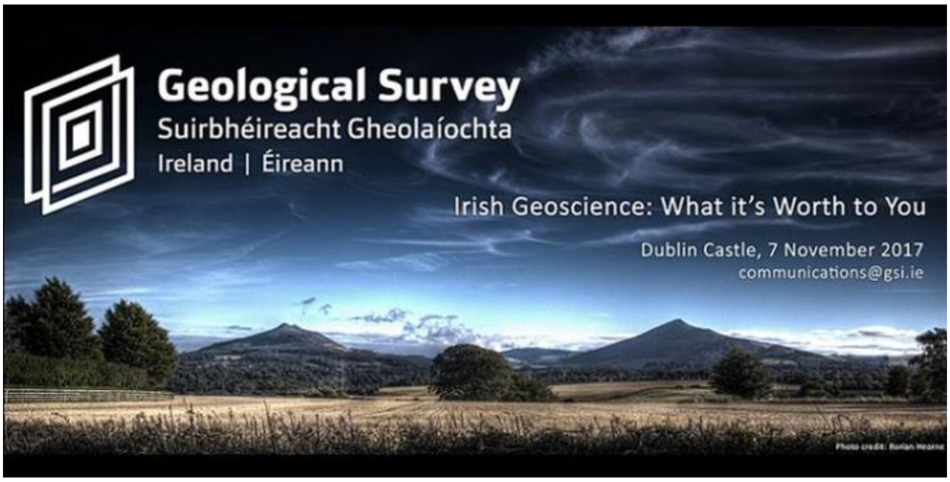
GSI hosts Geoscience 2017 conference

This year's annual GSI conference was again held in Dublin Castle on Tuesday November 7th, with the overall theme of "Irish Geoscience: What It's Worth to You". The conference coincided with the release of a new economic review of the Irish geoscience sector (see previous news item), and with the official launch of the new GSI website by Minister Seán Kyne, T.D.

Representatives from GSI and further afield presented updates on the economic value of several of our programmes, including Geotourism, Geological Mapping, Tellus, Research, our Marine Programme and the Geoscience Ireland business cluster. Monica Lee (GSI) and Jenny Deakin (EPA) provided a brief yet interesting overview of the value of GSI's Groundwater Mapping Programme, and how it feeds into Catchment Science work and research in the EPA.

There were two topical panel discussions during the day. The first was on the effects of Brexit on Geoscience, and questions were fielded by Marie Cowan (GSNI), Katie Daughen (British Irish Chamber of Commerce) and Ray Bowe (IDA Ireland). The second was on competing interests in the future of geoscience, and the speakers were John Walsh (iCRAG), Deirdre Lewis (SLR Consulting) and Elaine Nevin (Eco UNESCO).

Posters from various GSI-funded academic research projects were on view throughout the day, bringing together a diverse group of researchers from fields such as economics and social sciences, to computational geophysics! After a wrap-up session focusing on future challenges ahead for geoscience (including an entertaining talk by Balz Kamber, TCD), the conference concluded with a reception and optional tours to visit a Viking excavation and the Chapel Royal within Dublin Castle. Bring on Geoscience 2018!



Irish Group

IAH Irish Group Meet Delgation of Chinese Water Engineers

A group representing the IAH Irish Group met with a delegation of Chinese Water Engineers and Hydrogeologists from the Henan Province Water Resources Department in Dublin on the 19th of October 2017. The Chinese delegation were visiting Ireland as part of a tour of a number of European Countries to develop an understanding of the European approach to a number of hydrogeological topics and assess the potential for co-operation between the IAH and the Henan Province Water Resources Department. The main objectives for the delegation were to explore:

- Irish experiences in developing IAH membership and the promotion of all hydrogeology;
- Current and future groundwater and surface water technologies;
- Sustainable development and protection of groundwater resources
- Potential opportunities for cooperation between the IAH and Henan Provence Water Resources Department, including the exchange of experiences and technologies.

The IAH delegation included Henning Moe (IAH President), Barry Sexton (IAH Secretary), David Ball (Former IAH President), Philip Schuler (IAH Conference Secretary & iCRAG), Conor Quinlan (EPA) and Dunzhu Li (TCD).

The Chinese Delegation included Ms. Dai Yanping, Deputy Director General of Water Resources Department of Henan Province, Mr. Wei Zhenfeng, Division Chief of Rural Water Resources Division of Water Resources Department of Henan Province, Mr.Lei Cunwei, President of Henan Provincial Water Conservancy Research Institute, Mr. Hui Dazhong, Senior Lecturer/ Vice-President of Henan Vocational College of Water Conservancy and Environment, Mr. Shi Xianying, Director General of Yubei Water Resources and Engineering Bureau and Mr. Xu Yongzheng, Deputy Director General of Xinyang Water Resources Bureau.

Henning Moe welcomed the group and gave them an overview of the IAH Irish Group and introduced all members of the delegation. Conor Quinlan gave a summary of the management and protection of Irish surface and groundwater resources including details of EPA monitoring strategies and infrastructure. David Ball drew on his many years working as a hydrogeologist in Ireland to highlight the issues to consider when developing and protecting groundwater sources in Ireland. Philip Schuler delivered a summary of current Irish groundwater research activity through the prism of iCRAG. Monica Lee of the GSI provided some very helpful slides for the presentations.

Despite none of the delegation speaking English, they asked questions through their interpreter and they asked questions and expressed their appreciation for the effort made by the IAH in facilitating their visit and giving them an overview of Irish Hydrogeology.

Barry Sexton

IAH Secretary

IAH (Irish Group) Conceptual Site Model Competition 2018

The IAH (Irish Group) committee are pleased to announce that we are, once again, inviting all members to enter a competition for hydrogeological Conceptual Site Model (CSM) graphics, in advance of the 2018 IAH (Irish Group) Annual Conference.

The CSM is a key tool that hydrogeologists use to develop our own understanding of a site and also to communicate the issues and outcomes

News

with our clients, the public, etc. The aim of the competition is to showcase the variety of CSMs that have been produced as well as to demonstrate to our members the best in field in terms of quality.

The submissions should meet the following criteria:

- Be Conceptual – i.e., these are graphics as opposed to technical drawings.
- Be of a Site – should relate to a location rather than the concept of a process such as a flow diagram.
- Be a Model – a model is a useful representation of a system and therefore has some understanding to communicate in relation to the hydrogeology.
- Names can be changed or removed to protect the identity of the site.
- A brief explanation should accompany the CSM (max. 500 words), including:

→project background (contaminated land, resource evaluation, water supply development etc.) and

→specific site issue(s) to solve;

→overview of information used to develop the model (Geological Survey of Ireland maps, site walkover, site investigations);

→particular challenges in developing the model;

→how the model assisted in developing an understanding of the site/area;

→outcome of project.

- A3 Landscape, jpeg file.
- One person per entry.

In addition, the CSMs will be assessed in terms of the following:*

- Clarity of Design - is it easy to read the CSM as an image?
- Skill in Design - design decisions made regarding tones, colours, weight of line, position of text and font clarity.
- Visual Appeal - does it attract the eye and encourage the viewer to look at it in detail?

Entries (graphic CSM model) and accompanying summary to be submitted to educationandpublicity@iah-ireland.org by Monday 2nd March 2018.

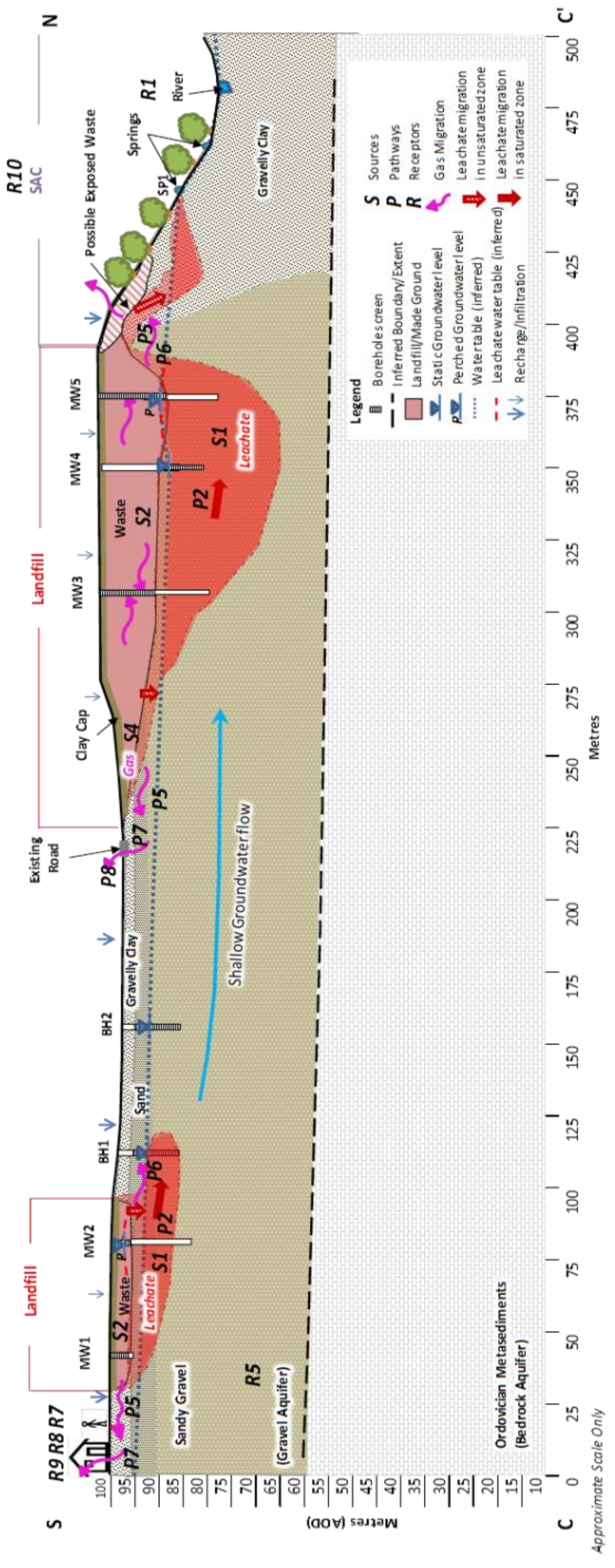
The winner will be invited to attend the two-day conference free of charge (including accommodation on the first night of the conference).

The competition entrants will be informed of the winner by 16th March 2018. Selected competition entries will be showcased for the duration of the conference. The winner of the competition will give a brief presentation (c. 5 minutes) on their CSM entry.

**Thanks to David Ball who made these suggestions and who assisted in assessing the 2017 CSM competition entries.*

Orla O'Connell

IAH Education & Publicity Secretary



2017 CSM Competition Winning Entry "Historic Unregulated Landfill" from Janka Nitsche, RPS Aquaterra.

IAH—News on the International Front

Bruce Misstear — IAH Secretary General

For this issue I will report on the recent IAH congress in Dubrovnik.

44th IAH Congress, Dubrovnik Croatia, 25th to 29th September 2017

The 44th IAH congress was held in the lovely Dubrovnik Palace hotel, which occupies a stunning location near Lapad, about 5 km northwest of the old city. There were more than 500 delegates from more than 60 countries, including a very good presence from Ireland. After some short training courses - and a (9-hour!) Council meeting - on the Sunday, the opening ceremony was held on the Monday morning. As well as the usual speeches there was some music from a cello and piano duo – including the theme from Game of Thrones, part of which is filmed in and around Dubrovnik. The congress then proceeded with a mix of plenary and parallel sessions of oral presentations, and a poster programme.

As is normally the case with IAH congresses, there was a wide range of topics covered by the technical programme including:

- Groundwater heritage
- Sustainable management of groundwater resources
- Groundwater modelling
- Groundwater monitoring
- Groundwater in karst systems
- Coastal and island hydrogeology
- Groundwater and dependent ecosystems
- Mineral waters and human health

Dubrovnik lies within a classic karst area (the city gets its water supply from a very large lime-

Our guide explaining aspects of the geology of Mljet in front of a map of the island

stone spring), so there were plenty of options for enthusiasts to visit karst sites during the mid-week field excursions (see photos).

An IAH congress provides an opportunity for members of our Commissions and Networks to get together, and in Dubrovnik there were meetings of the Karst Commission, the Burdon Groundwater Network for International Development, the Commission on Groundwater and Energy, the Managed Aquifer Recharge Commission, the Coastal Aquifers Network, the Urban Groundwater Network and the Commission on Mineral and Thermal Waters. The Early Career Hydrogeologists Network held its AGM and, as has become customary, also organised a social event that combined a hydrogeology-based challenge with much conviviality and dancing. IAH Commissions and Networks are open to all members, so please check the website for more information: https://iah.org/groups/commissions-networks. Joining a Commission or Network is a great way to make new contacts.

Apart from the technical programme and the Commission and Network meetings, there was a meeting of representatives of National Chapters, which provided a useful forum for Chapter members to share experiences, activities and to raise any problems with the Secretariat and Executive. Finally, as a registered charitable company in the UK, IAH is obliged to hold a General Assembly each year, at which year-end accounts are presented, accountants approved, etc. The General Assembly also gives the Executive an opportunity to update members on IAH activities and progress over the past year, such as membership numbers, publications, events, etc.

Informal feedback has been very positive, with many people commenting on how well the congress was organised - and observing that the standard of the presentations was generally very good. People also enjoyed the location and the social events too. So, well done to Tamara Marković, Kristijan Posavec and their colleagues on the organising committee.

The next congress will be in Daejon, Korea, between 9th and 14th September 2018. A call for abstracts will be issued next month (with an abstract deadline in March). It would be great to have another strong participation from Ireland.

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 2018, the full annual membership fee will be €86 if you wish to receive a paper copy of Hydrogeology Journal as part of your membership, or €76 if you receive the journal online. Students can join for as little as €20 (with the online journal option).

Bruce Misstear, Secretary General

International Association of Hydrogeologists

Blatsko polje on the island of Mljet

Irish Group

IAH (Irish Group) Annual Field Trip 2017

Holistic Hydrogeology of the South Irish Midlands

Robbie Meehan — IAH Fieldtrip Secretary

This year the IAH fieldtrip was held on the weekend of the 21st and 22nd October, when almost fifty intrepid hydrogeologists met in Counties Offaly and Laois. The Irish Midlands have long been known as a sacred landscape with long-famed historical sites such as Clonmacnoise, Croghan Hill and Durrow underpinning this reputation. The theme of this field trip was to examine the rich hydrogeological heritage of the region, by visiting a wide variety of sites with very different hydrogeological influences.

On the outward journey from Dublin, Storm Brian raged in the southwest of the country, so intensely that some participants had to postpone travelling until the storm had calmed somewhat. Driving through Westmeath was like driving through a very long car wash, so heavy was the battering the bus got from the rain. However, at Clonmacnoise, despite still-driving rain and high winds, Damien Doherty of Tobin Consultants representing Geological Survey Ireland introduced the recently-delineated sand and gravel aquifer body that centres on Clonmacnoise. The wet weather led to a focussed discussion! Then John Feehan brought us on foot from a roadside stop at Creevagh to view one of the strange phenomena that are the mushroom rocks of the Midlands. A short walk meant that the dust was shaken off after the long journey earlier, and all were ready for lunch.

After lunch in Gussie's of Ballycumber, Ray Flynn took us to the first of two stops related to Clara

John Feehan explains the theories behind mushroom stone formation.

Yes, it really was that wet.

Damien Doherty Shows the extent of the Clonmacnoise sand and gravel aquifer.

Hydrogeologist (n): a scientist expert at scrutinising groundwater.

Bog; the first being a kettle hole adjacent to an esker. At the second bog-related stop, Paul Johnston, Ray Flynn and John Cody of the Bog Restoration project led a superb presentation and ensuing discussion about bog reclamation, and the historical studies that have taken place on Clara Bog over the last thirty years. The final stop of the day was a visit to Ireland's only three-dimensional on-site wastewater treatment demonstration facility, at Molloy Environmental Systems in Tullamore. Following an introduction to the principles of wastewater treatment for single houses from Laurence Gill, John Molloy and Michael Cahill showed the various facets of the demonstration facility itself.

The group stayed overnight at the Maldron Hotel in Portlaoise, where the dinner was attended by the majority of the participants.

On Sunday, the weather was much calmer, though still somewhat wet. Sunday morning focussed on the Cullahill Group Water Scheme Zone of Contribution, with visits to the pumphouse and the spring source itself. Historically the scheme has had ongoing issues with elevated nitrates, and Jimmy Walsh, Roisin Dowd Smith, Taly Hunter Williams and Catherine Coxon discussed the studies that have been completed on the ZOC in the last few years. Discussion was intense at these stops, which meant that all were very ready for a burger at Junction 14 on the trip back to Dublin!

Many thanks to all the contributors to this year's field trip. Thanks also to all landowners for giving us permission to visit their lands, and to McCaffrey coaches, and the bus driver Hassan, for literally allowing us to weather the storm.

Thanks to Malcolm Doak for providing the accompanying photographs.

ECHN—Early Career Hydrogeologists Network

Racquel Sousa — President of IAH (Portuguese Group) and ECHN Co-chair

The Early Career Hydrogeologists Network (ECHN) of the International Association of Hydrogeologists (IAH) is specially dedicated to support young hydrogeologist professionals. It was created in 2010 during the 38th IAH meeting hold in Krakow, Poland. An early career is considered all of those in the first 10 years of their career irrespective of their age. At the present, the ECHN consists of a Chair, two Co-Chairs, a task team and an advisory team, constituted by former Chairs and Co-Chairs, from several different countries.

The ECHN has developed and grown rapidly being a very active network within the working groups of IAH. The network aims:

- To promote information sharing possibilities for early career hydrogeologists.
- To provide support networks for members to discuss and develop ideas or schemes, through web-based forums, meetings, etc.
- To preserve hydrogeological competence and experience via productive exchanges between junior and senior hydrogeologists sessions.
- To enhance the social and professional networking opportunities of early career hydrogeologists, e.g. by specific events at conferences.
- To strengthen the status of early career hydrogeologists within IAH by networking at conferences, congresses and within its National Chapters, Commissions and Networks.

The ECHN organizes many activities, in particular at the IAH annual congress. During the congress, the ECHN organizes - with the joint effort of ECHN, IAH Council and Executive Congress Organizers - activities and events aimed at early careers, creating a very special dynamic during these events. Events include:

- Pre-Congress Short Courses on scientific writing and presentations;

ECHN steering committee (clockwise from top left): Carlos Maldaner (Canada/Brazil), Raquel Sousa (Portugal), Rui Hugman (Portugal), Gaathier Mahed (S. Africa), Kelley Swana (S. Africa), Sebnem Arslan (Turkey), Stefania Stevenazzi (Italy), and Tirza Contreras (Honduras).

- Award for the best ECHN presentation and poster during IAH Congresses;
- Joint/cheap accommodation for ECHs – details of low cost hotel and hostels for students and ECHs are provided by the conference organizers;
- ECHs have the opportunity to become Technical Session (Co-)Chairs;
- ECHN Annual Meeting & Social Event are organized during the IAH Congresses to create a friendly and casual environment for socializing and networking;
- Special attention to ECH delegates and their work – ECHs are identified by the ECHN logo on the poster or presentations. The logo is generally available for download on the conference website.

For several years the ECHN has run the 'Coolest Paper of the Year' Award, which aims to highlight the most inspiring and meaningful papers on hydrogeology from the perspective of young groundwater professionals. It looks to energize the early career hydrogeology community and encourage the discussion of recently published papers. The definition of 'cool' has been deliberatively left open to interpretation to inspire a wide range of nominations and voting.

ECHN social function during Acqua 2015 (top) and Morocco in 2014 (bottom).

The ECHN Steering Committee is always open for new members who would like to be more hands on involved with the network. If you are interested in contributing just send us an email! We encourage everyone to join the IAH and be part of the ECHN network. For updates and news follow us on LinkedIn (only for IAH members), Facebook or Twitter. More information about the ECHN can be found at www.echn.iah.org.

Coolest Paper Award 2013 – Delivering the award during the 41st IAH Congress in Marrakech, Morocco.

ECHN meeting with early career hydrogeologists attending Acqua 2015.

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 contamination of drinking water in Ireland: a broad geostatistical analysis of occurrence and risk.

McGrory, E.R., Brown, C., Bargary, N., Hunter Williams, N., Mannix, A., Chaosheng Zhang, Henry, T., Nicholas, S., Petrunic, B.M., Daly, E., Lee, M., Mulcahy, M. & Morrison, L. (2017). Science of the Total Environment, 579, pp1863-1875.

http://dx.doi.org/10.1016/

Evaluation of levels of antibiotic resistance in groundwater-derived E. coli isolates in the Midwest of Ireland and elucidation of potential predictors of resistance.

O'Dwyer, J., Hynds, P., Pot, M., Adley, C.C., Ryan, M.P. (2017). Hydrogeology Journal, 25 (4), pp939-951.

https://link.springer.com/article/10.1007%2Fs10040-017-1546-8

Hydrogeological characteristics influencing the occurrence of pesticides and pesticide metabolites in groundwater across the Republic of Ireland.

McManus, S.L., Coxon, C.E., Mellander, P.E., Danaher, M., Richards, K.G. (2017). Science of the Total Environment, 601-602, pp594-602.

https://doi.org/10.1016/j.scitotenv.2017.05.082

Logistic regression model for detecting radon prone areas in Ireland.

Elío, J., Crowley, Q., Scanlon, R., Hodgson, J., Long, S. (2017). Science of the Total Environment, 599-600, pp1317-1329.

https://doi.org/10.1016/j.scitotenv.2017.05.071

Groundwater nitrate reduction versus dissolved gas production: A tale of two catchments

McAleer, E.B., Coxon, C.E., Richards, K.G., Jahangir, M.M.R., Grant, J., Mellander, Per.E. (2017). Science of the Total Environment, 586, pp372-389.

https://doi.org/10.1016/j.scitotenv.2016.11.083

In situ denitrification and DNRA rates in groundwater beneath an integrated constructed wetland

Jahangir, M.M.R., Fenton, O., Müller, C., Harrington, R., Johnston, P., Richards, K.G. (2017). Water Research, 111, 254–264.

https://doi.org/10.1016/j.watres.2017.01.015

Lithium in the Natural Waters of the South East of Ireland

Kavanagh, L., Keohane, J., ,Cleary, J., Garcia Cabellos, G., Lloyd, A. (2017). Proceedings from the 3rd International Symposium on Environment and Health, International Journal of Environmental Research and Public Health, 14 (6), pp561.

10.3390/ijerph14060561

Waterborne outbreak of cryptosporidiosis in the South East of Ireland: weighing up the evidence

Mahon, M., Doyle, S. (2017). Irish Journal of Medical Science, 186 (4), pp989-994.

https://doi.org/10.1007/s11845-016-1552-1

An overview of dissolved organic carbon in groundwater and implications for drinking water safety

Regan, S., Hynds, P., Flynn, R. (2017). Hydrogeology Journal, 25(4), pp959-967.

https://doi.org/10.1007/s10040-017-1583-3

Assessing and Developing Natural Background Levels for Chemical Parameters in Irish Groundwater

Tedd, K., Coxon, C., Misstear, B., Daly, D., Craig, M., Mannix, A., Hunter Williams, T. (2017). EPA Research Report No. 183, 183pp.

http://www.epa.ie/pubs/reports/research/water/EPA%20RR%20183%20Essentra_web.pdf

Karst

Characterisation of karst hydrogeology in Western Ireland using geophysical and hydraulic modelling techniques

McCormack, T., O'Connell, Y., Daly, E., Gill, L., Henry, T., Perriquet, M. (2017). Journal of Hydrology Regional Studies, 10, pp1–17.

http://dx.doi.org/10.1016/j.ejrh.2016.12.083

Groundwater flood risk mapping and management: examples from a lowland karst catchment in Ireland

Naughton, O., Johnston, P.M., McCormack, T., Gill, L.W. (2017). Journal of Flood Risk Management, 10, pp53-64.

http://dx.doi.org/10.1111/jfr3.12145

The World Karst Aquifer Mapping project: concept, mapping procedure and map of Europe

Chen, Z., Auler, A.S., Bakalowicz, M., Drew, D., Griger, F., Hartmann, J., Jiang, G., Moosdorf, N., Richts, A., Stevanovic, Z., Veni, G., Goldscheider, N. (2017). Hydrogeology Journal, 25 (3), 99771-785.

http://dx.doi.org/10.1016/

Integrated assessment of agricultural nutrient pressures and legacies in karst landscapes

Fenton, O., Mellander, P-E., Daly, K., Wall, D.P., Jahangir, M.M.R., Jordan, P., Hennessey, D., Huebsch, M., Blum, P., Vero, S., Richards, K.G. (2017). Agriculture, Ecosystems & Environment, 239, pp246–256.

https://doi.org/10.1016/j.agee.2017.01.014

Stable isotopes

Geospatial drivers of the groundwater δ18O isoscape in a temperate maritime climate (Republic of Ireland)

Regan, S., Goodhue, R., Naughton, O., Hynds, P. (2017). Journal of Hydrology, 554, pp173–186.

https://doi.org/10.1016/j.jhydrol.2017.09.017

Combining stable isotopes with contamination indicators: A method for improved investigation of nitrate sources and dynamics in aquifers with mixed nitrogen inputs

Minet, E.P., Goodhue, R., Meier-Augenstein, W., Kalin, R.M., Fenton, O., Richards, K.G., Coxon, C.E. (2017). Water Research, 124, pp85–96.

https://doi.org/10.1016/j.watres.2017.07.041

Groundwater flow

Effect of volcanic dykes on coastal groundwater flow and saltwater intrusion: A field-scale multiphysics approach and parameter evaluation

Comte, J-C., Wilson, C., Ofterdinger, U., Gonzalez-Quiros, A. (2017). Water Resources Research, 53, pp2171–2198.

https://doi.org/10.1002/2016WR019480

Environmental Flow Assessment for Irish Rivers.

Webster, K.E., Tedd, K., Coxon, C., Donohue, I., (2017). EPA Research Report No. 203, 92pp.

http://www.epa.ie/pubs/reports/research/water/EPA%20RR%20203%20final%20web-3.pdf

Previous issues available at www.gsi.ie

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

Edited by:
Katie Tedd and David Drew
groundwaternewsletter@gsi.ie

Published by the:
Geological Survey of Ireland
Beggars Bush Buildings
Haddington Road
Dublin 4

Foilsithe ag an:
Suirbhéireachta Gheolaíochta Éireann
Tor an Bhacaigh
Bothar Hadington
Baile Átha Cliath 4

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

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

2018

11-12 Jan 2018	**Irish Geoscience Early Career Symposium (iGEO2018)** https://igeo2018.wordpress.com/
9 Jan 2018	**IAH (Irish Group) TDM** – GSI http://www.iah-ireland.org/upcoming-events/
10-13 Jan 2018	**BT young Scientist and Technology Exhibition** RDS, Ballsbridge http://www.btyoungscientist.com
22-24 Feb 2018	Irish Geological Research Meeting (IGRM)-UCC http://www.icrag-centre.org/news-and-media/conferences-and-events/irishgeologicalresearchmeeting.html
TBC Mar 2018	**IAH (Irish Group) Burdon Lecture** - GSI Burdon lecture on development issues Speaker TBC http://www.iah-ireland.org/upcoming-events/
22 Mar 2018	**World Water Day** http://www.worldwaterday.org/
18-19 April 2018	**The SEAI Energy show** RDS, Ballsbridge http://www.seai.ie/energyshow/
25-26 April 2018	**GeolSoc Hydrogeological Group Conference** The Hydrogeology of the Chalk https://www.geolsoc.org.uk/HG-Hydrogeology-of-the-Chalk
24-25 Apr 2018	**IAH (Irish Group) Annual conference** http://www.iah-ireland.org/annual-conference/
4-8 Jun 2018	**International Groundwater Vulnerability Conference** New Approaches to Groundwater Vulnerability University of Silesia, Ustron, Poland. http://www.vulnerability.us.edu.pl/
17-22 Jun 2018	25th Salt Water Intrusion Meeting (SWIM2018) Gdansk, Poland http://swim2018.syskonf.pl/
TBC June	**EPA National Water Event** https://www.epa.ie/newsandevents/events/

The editors welcome feedback on the contents of this issue and the changes to the newsletter, as well as suggestions for contributions to the next issue. Please contact: Groundwaternewsletter@gsi.ie