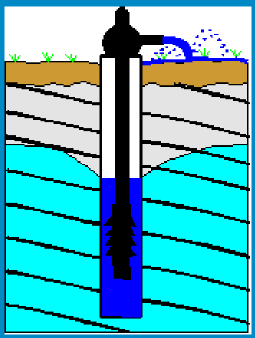

Groundwater Newsletter

Issue 50 | ISSN 0790-7753 | July 2012

Inside this issue:

50th issue!
The Future for Groundwater

Congratulations to everyone, past and present, who has contributed to the Groundwater Newsletter, over what is now 26 years and 50 issues! Groundwater Section staff take us through how the Newsletter has changed over time, but what has remained constant since the first issue in August 1986, is the continued importance of groundwater as a resource in Ireland, and the ongoing interest in sharing groundwater information that is specifically relevant to Irish practitioners.

To mark the occasion, this issue is a bumper, especially themed, edition on '*The future for Groundwater*'. To this end, several authors have provided opinion-type articles about where they think groundwater is heading, or perhaps needs to head? We have articles outlining Irish, US, Scottish and Australian regulatory and management experiences, insights from a Local Authority 'coal face' perspective, an academic view point on the future of hydrogeology education, and a piece on the future directions of IAH (International).

This edition also includes some more technical articles on potential future issues like the emerging contaminants, e.g. pharmaceuticals, industrial compounds, lifestyle and personal care products, and nanoparticles, as well as the controversial practice of fracking.

Closer to home, we take a look at the challenges that lie ahead in Ireland in understanding karst and conceptualizing Groundwater Dependent Terrestrial Ecosystems, and what we can learn from the groundwater level monitoring network and the new Tellus Border geophysical and geochemical survey data. A recent impact assessment for a new graveyard using the EA guidance is shared and a new guidance document from the EPA on Discharges to Groundwater is introduced. We hear about the use of stable isotopes in a groundwater research project and the results of a study on people's perceptions on the quality of the water from their wells. Finally, we also remember our EPA colleague Mícheál MacCárthaigh, who sadly passed away earlier this year.

We are very grateful to all our contributors for this commemorative issue, particularly our international authors, all of whom gracefully obliged us with contributions addressing our theme. Here's to the next 50 issues!

Monica Lee, Groundwater Section and Jenny Deakin, Editor

GSI Groundwater Section: 50 newsletters on …

The first Groundwater Newsletter's objective in August 1986 was to 'bring together news, developments, review and opinions on all areas of groundwater … to promote a proper appreciation of the value and importance of groundwater.' The aim was to have varied articles and a wide readership. This first edition was filled with short and snappy articles on specific water supply works, aquifer descriptions, including characteristics, water quality issues and a piece on geothermal resources. Since then there has been a continual interest in Irish aquifers, specific groundwater sources and water quality trends, contaminant issues and overseas work/development. We have been informed about technical and regulatory aspects of septic tanks and landfills; mining issues; varied aspects of karst; groundwater vulnerability and protection schemes; field and analytical techniques; and the many, many other topics that you are all familiar with.

Given its genesis in the GSI, with Donal Daly (EPA, formerly Groundwater Section, GSI) as the founder and editor for many years, the main themes often reflected the interests of the Groundwater Section. So what developments has the Groundwater Section made over this time?

Projects in the 1980s and 1990s, for example, on the Nore River Basin, in County Roscommon, compiling national datasets (wells, springs, karst features, warm springs) greatly aided our understanding of Irish hydrogeology, and the use of different techniques such as geophysics, baseflow assessments and groundwater recharge estimations. This understanding provided an excellent basis for the aquifer classification system, which is described in the 1994 article 'Guidelines On Aquifer Definition'.

Within this timeframe, the role of risk assessment and risk management are firmly grasped as the way forward in groundwater protection, as highlighted in the 1996 article 'Risk And Risk Management – A Framework For Groundwater Protection Schemes'. The use of this framework consolidated the concept of the Source-Pathway-Receptor model that underpins environmental management. The article also defined aquifers, wells and springs as important receptors and also described the groundwater vulnerability as the S-P-R Pathway. The groundwater vulnerability research of the late 1990s further supported the pathway concepts and in 1999, the Groundwater Protection Scheme Guidelines were published. In parallel, the Groundwater Section was producing County Groundwater Protection Schemes for Local Authorities, enabling them to manage risks to groundwater. Also throughout the 1990s, there was an increase in the number of articles about specific contaminants (toxic wastes, metals, nitrates, phosphates) and activity-related risks (*e.g.* from landfills, septic tanks, farms). In terms of S-P-R, the Source was sparking an interest.

Articles in the Noughties reflected further understanding and development of the same topics: 'Number Games with Recharge'; 'Microgravity in Karst Areas'; 'Geothermal Heating of County Council Offices, Tullamore'. We were informed about guidance documents (*e.g.* EPA's Code of Practice for OSWWTs) and legislation, especially the EU Water Framework Directive (WFD). The Section's work was now focusing on characterising groundwater for the purposes of the WFD. This involved producing a *national* aquifer map[1], from which the Groundwater Bodies were derived. These were further developed by the River Basin District consultants with additional data and then eventually used as the assessment, reporting

[1]Prior to this, aquifer maps were being produced on a county basis as part of the Groundwater Protection Schemes.

THE GSI GROUNDWATER NEWSLETTER

NUACHTÁN SCREAMHUISCE SGÉ

- *Exploration*
- *Management*
- *Pollution*
- *News from abroad*
- *Development*
- *Quality*
- *Reviews*
- *Opinion Forum*

- *Taiscéalaíocht*
- *Bainistíocht*
- *Truailliú*
- *Nuacht idir Náisiúnta*
- *Forbairt*
- *Cáilíocht*
- *Athbreithniú*
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Edited by: Donal Daly

No. 1 August 1986

INTRODUCING THE GSI GROUNDWATER NEWSLETTER

Work on groundwater development and management has expanded significantly in the last 10 years and there are now many scientists and engineers in the public, private and educational sectors involved with groundwater projects or interested in groundwater. Due to this expansion and the interdisciplinary nature of groundwater work, there is an increasing need for an improved means of communication and for a forum where news and views can be exchanged.

This **GSI Groundwater Newsletter** is the first of a series which aims to bring together news, developments, reviews and opinions on all aspects of groundwater - exploration, development, management, water quality, pollution and energy - and to promote a proper appreciation of the value and importance of groundwater.

The **Newsletter** will be circulated free-of-charge to engineers in local authorities; engineering consultants specialising on water supply projects; hydrogeological consultants; certain semi-state bodies and Government Departments; Departments of Geology, Geography and Engineering in third-level colleges; and technical libraries. If you wish to be deleted from the circulation list or if you know of other people who would like to receive the **Newsletter** please contact the Geological Survey.

The **Newsletter** will consist of 3-6 double-sided A4 sheets and will be published 4 times every year. We hope that items included in the **Newsletter** will be contributed mainly by engineers and scientists from outside the Geological Survey. In particular we welcome contributions from engineers - we are pleased that the first item in this issue is from two engineers. All items should be short (maximum 200 words, but preferably 100-150 words) and informative. So please contribute to the dialogue and communication by providing us with details on groundwater in your area of interest.

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and management unit for groundwater under the WFD.

So if we jump forward to the present day, how have these areas since developed in the Groundwater Section? An allocation of National Development Plan funding has enabled us to expedite the Groundwater Protection Scheme Programme. Specifically, consultants have been taken on to map the groundwater vulnerability for those counties that had not been mapped – c.50% of the country. This map (including its component maps) is not only being used to compile County Groundwater Protection Scheme for Local Authority use (focusing on resource rather than source protection), but is also part of the suite of maps used for national risk assessments *e.g.* WFD assessments. By the end of this year we will have our first national, standardised groundwater vulnerability map.

Groundwater Section's work in source protection zone (SPZ) delineation has adapted over the years from being a significant part of the county GWPS projects, to being part of the review process on the EPA's SPZ delineation project[2], and over the last year, managing SPZ delineation for public water supplies in response to direct requests from Local Authorities to either the GSI or EPA. In addition to this, a pilot project delineating zones of contribution for group water schemes was instigated in 2010. Working closely with the National Federation of Group Water Schemes (NFGWS), one of the aims of the project is to engage with the personnel from the schemes to provide better information and enable better understanding and use of water supplies and the protection maps. The Groundwater Section plans to build on this work in the coming years by working with Local Authorities to help them to meet their needs and expanding the group water scheme project in collaboration with the NFGWS to produce zones of contribution for all groundwater schemes.

The EPA is the responsible authority and driver for the Water Framework Directive work. Further to the initial spate of groundwater characterisation work, the GSI's Groundwater Section currently manages the re-delineation of the Groundwater Bodies (GWBs) on behalf of the EPA for the next planning cycle (2015). GWBs have been drafted and are due to be finalised mid 2012. For future planning cycles, the Groundwater Section will input to further characterisation as required by the EPA.

Geothermal resources are noted in the first edition of the newsletter and a number of times in the 1990s. Over the last two years there has been a renewed interest in the geothermal resources in the Groundwater Section. This has culminated in securing NDP funding for a shallow geothermal resources project, which is looking at providing best practice guidance for installations, starting up a database of geothermal installations and eventually to improve the existing geothermal resource/ suitability maps. The long term aim is to provide better information to aid sustainable use of the resource and therefore support the growth of this industry. The current project is one baby step towards this end. The Section is also peripherally involved with looking at deep geothermal energy, the exploration of which is main theme of the Geothermal Bill that is currently being drafted, and which is also the focus of the SFI funded IRETHERM project.

The comparison of 'then' and 'now' has been interesting in highlighting how far we have come in terms of understanding Irish hydrogeology and collating data to produce maps that convey that information. The groundwater maps raise awareness of groundwater and provide a basis that helps our colleagues (hydrogeological or otherwise) to understand and take account of groundwater. It was also interesting to see warm spring in the first edition, especially as shallow geothermal resources are currently of interest in the Groundwater Section and deep geothermal resources are of interest to our parent department (DCENR).

Although involved in many varied projects, the Groundwater Section has worked towards, and on, resource and source identification and protection as a central theme for a number of decades. The current and future achievements are due to the vision, collaboration and hard work of the many former and current members of the section, whether employed as permanent staff, project hydrogeologists or consultants – too numerous to name individually, but we know who we are! The changing way in which we have to operate – the use of consultants – is a recognised sign of the times. However, the continued focus, interest and funding for this area highlight its importance.

Monica Lee, Taly Hunter Williams and Caoimhe Hickey
Groundwater Section
Geological Survey of Ireland

[2]EPA procured a consultant consortium to delineate source protection zones or zones of contribution around WFD groundwater monitoring points.

Water/Groundwater – Challenges and Questions for the Future
A Personal View

Introduction

Looking to and trying to anticipate the future is an effort best left, it could be argued, to those of the highest intellectual ability (people like the present day equivalents of the great Greek philosophers come to mind); yet, if 'ordinary' people don't try, there is a danger that those of us living in Western democracies will not adapt to our changing world in a way that is appropriate to leave a world in which our children and their children will be happy in terms of having adequate supplies of water, food, energy and jobs. This is my reason for raising certain issues and questions in this article; they are written to provoke thought and not offense! Perhaps the biggest threat facing humankind is the likely impact of climate change; however, this issue is not dealt with here.

Barriers to Anticipating the Future

Dark Knowledge

Whenever I think of what the future 'will bring', I worry about the truth in Donald Rumsfeld's[1] 'knowns', 'known unknowns' and 'unknown unknowns' observations. My interpretation of this is that there is 'knowledge we need to know, but don't know, <u>and</u> …….. don't know that we need to know'. While this may be a frightening concept, it should temper our vision of the future rather than stop us from considering it.

Remembering and Learning from the Lessons of History

Two quotations[2] illustrate the challenge:

"That people do not learn very much from the lessons of history is the most important of all the lessons of history." **Aldous Huxley**

"What experience and history teach is this - that people and governments never have learned anything from history, or acted on principles deduced from it." **G. W. F. Hegel**

While hopefully these quotations are too extreme, they indicate our propensity to be optimistic and our inability to analyse mistakes and learn from them. In late 1929 after seven years of unprecedented growth in the US, Herbert Hoover, the then President, initiated a study entitled 'Recent Social Trends' in anticipation of continued prosperity; four weeks later the crash occurred. While there isn't necessarily a direct analogy here to the recent Irish and world economic problems, reading about the Great Depression generates eerie echoes. So, let us be 'wise people' in the context of the quote from another famous leader, Winston Churchill, *"All people make mistakes, but only wise people learn from their mistakes".*

Complacency and Ignorance

Complacency is, perhaps, an inevitable feeling at a time when most of us in Ireland live a life that is more comfortable than ever before in our history. Looking ahead can be threatening in circumstances where there are clear indications of instability to some degree or other. However, the very likelihood of instability means that there should an onus on us all to, at the very least, inform ourselves. Knowledge then has the potential to become the first step for future actions. There is an onus, in my view, on people like the readers of the Groundwater Newsletter – scientists and engineers who have the relevant technical expertise – to provide the leadership and information required to enable society to have an adequate basis for formulating their own views.

World-wide Context – the Age of Scarcity

Population Growth

The population of the world reputedly reached seven billion in 2011 and is predicted to reach

[1]Former US Secretary for Defense

[2]In all quotations in this article, where outdated sexist language is used, amendments have been made.

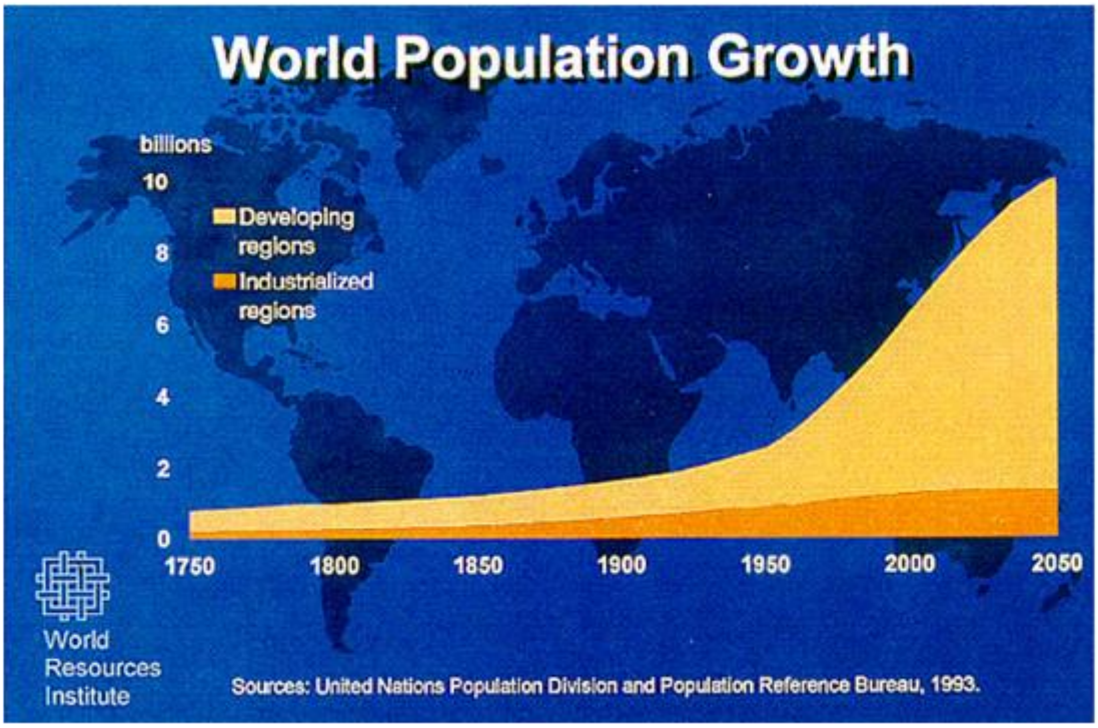


Figure 1. World population growth, from 1750 to 2050.

nine billion by 2050 (Figure 1) with most of the growth occurring in developing countries, thereby creating a greater need for resources.

Uncertain Political Structures

In a world with many totalitarian regimes and where representative democracies, by their nature, struggle to take a long-term view, can we be confident that the dependence of a healthy economy on a healthy ecosystem will influence short term political & economic considerations?

Growth and Sustainability

Economic growth is seen by governments world-wide as essential to alleviating the current economic problems, such as unemployment. Is this economic growth sustainable in terms of resource depletion and environmental impact? Or will human ingenuity and technological innovation mitigate the potential negative impacts of growth? We must ensure that the answer is 'yes' as our objective must be to "produce more with less".

Water: The New Oil[3]

The future may well be best illustrated by a quotation in 1995 from Ismail Serageldin, the former chairperson of the World Commission for Water in the 21st Century: *"Many of the wars this century were about oil, but those of the next century will be over water".*

Already there have been water riots and deaths in conflicts over water in Karachi, Gujarat and China, and there are continuing tensions in the Middle East and Egypt over water scarcity. Water is overtaking oil as the world's scarcest critical natural resource. "*But water is more than the new oil; oil, in the end, is substitutable, albeit painfully, by other fuel sources, or in extremis can be done without; but water's uses are pervasive, irreplaceable by any other substance, and utterly indispensable*" (Solomon, 2010.)

Some facts about water usage:

- Over the past two centuries, freshwater

[3]This section is based largely on material from "Water" by Steven Solomon. Published by HarperCollins. 2010.

usage has grown 2 times faster than the population.

- 1.1 billion people lack access to at least 4 litres per day of safe water to drink.
- 2.6 billion lack the additional 22 litres needed daily for rudimentary sanitation and hygiene.
- China has 20% of the world population but only 7% of its freshwater.
- India has 17% of the world population but only 4% of its freshwater.
- In both China and India, mining of groundwater is occurring and water levels are dropping in areas.
- Global warming poses a threat to the existing surface water resources in both China and India.
- Food production is water intensive:
  – 1 kg wheat needs ~0.7 m^3 water.
  – A glass of cow's milk requires ~1 m^3 water.
  – A well-nourished person consumes ~4 m^3/d each day in the food he/she eats.
- Exporting food is effectively exporting virtual water.
- As food production is water intensive, can we in Ireland make this a competitive advantage by giving a sufficiently high priority to water management that we ensure that our existing good water quality is protected and our poor water quality is restored to good?

European Policy Context

Resource Efficiency

The European Commission view can be summed up by the following quotations[4]:

"Minerals, metals and energy, as well as stocks of fish, timber, water, fertile soils, clean air, biomass, biodiversity are all under pressure. Whilst demand for food, feed and fibre may increase by 70% by 2050, already 60% of the world's major ecosystems that help produce these resources have been degraded or used unsustainably. Today in the EU, we use 16 tonnes of materials per person each year, of which 6 tonnes are wasted, with half going to landfill. If we carry on using resources at the current rate, by 2050 we will need the equivalent of more than two planets to sustain us, and the aspirations of many for a better quality of life will not be achieved."

The vision for the future in the EC Roadmap to a Resource Efficient Europe is as follows: *"By 2050 the EU has grown in a way that respects planetary boundaries, thus contributing to global economic transformation. It is competitive and provides a high standard of living with much lower environmental impacts. All resources are sustainably managed, from raw materials to energy, water, air, land and soil. Climate change targets have been met and biodiversity and the ecosystem services it provides have been protected, valued and substantially restored."*

Water Framework Directive (WFD)

The WFD is a critical policy driver for Ireland; it is powerful in concept in that it provides a policy framework which requires an integrated approach to policy-making and river basin management. It is an over-arching directive that aims to achieve greater policy coherence by linking with other relevant directives, as shown in Figure 2.

Ireland: Looking to the Future – Hopes, Wishes and Challenges

Governance Issues

That the environmental protection required for a sustainable future is given a higher priority and that the current fragmented governance arrangements for river basin management are rectified in parallel with the setting up of Irish Water.

While characterisation, monitoring and reporting are essential elements of the surface water and

[4] European Commission communication to the European Parliament and European Council, 2011

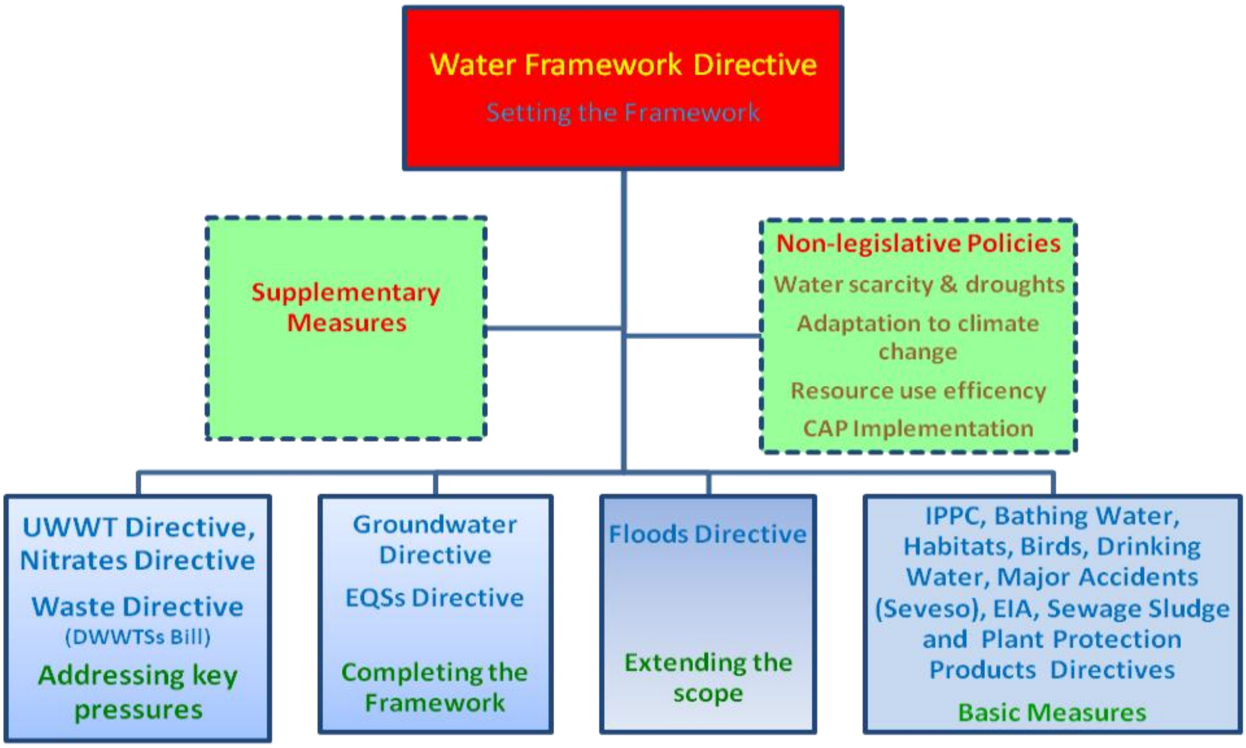


Figure 2: Illustration of the range of the WFD in connecting and integrating the legislative tools of European water policy (This figure is an amended version of a figure in "Support to Fitness Check Water Policy" Report prepared by Deloitte Consulting and the Institute for European Environmental Policy (2011)).

groundwater regulations, and of WFD implementation, the programme of measures is, arguably, the critical element for maintenance of existing good quality water and restoration of poor quality. It is also the most difficult to undertake successfully.

Currently, there is no single body having ultimate responsibility for river basin planning, and water management and protection. My wish for the future is that the governance arrangements will change such that one body will be given this responsibility; until this happens, environmental protection is unlikely to be adequately represented in achieving a sustainable balance between environment protection and development.

In addition, at this time of scarce resources and when our efficiency and competitiveness are essential for our future, integration of water protection measures undertaken by a range of public bodies – EPA, local authorities, GSI, IFI, DECLG, DAFF, MI, Teagasc, etc. – is essential.

Water Framework Directive

That the Surface Water (S.I. No. 272 of 2009) and Groundwater (S.I. No. 9 of 2010) Regulations, which give effect to the requirements of the WFD in Ireland, are accepted as necessary and beneficial, irrespective of the threat from European Court Judgements.

Food Harvest 2020

That the objectives of Food Harvest 2020 (for instance, a 50% increase in milk production) are achieved. Achieving these objectives will only be possible in circumstances where agriculture is sustainable in terms of maintenance of our good water quality and improvement of any poor water quality caused by agriculture. This will require greater appreciation of water and catchment management by the farming community.

Risk-based Decision-making

That the risk-based approach used with some success to-date in decision-making becomes more successful by ensuring that the pathway element of the source (pressure)–pathway–receptor (SPR) framework is included; this requires some knowledge, appreciation and visualisation of the geological and hydro(geo) logical properties of the country, thereby enabling the measures required to protect/ restore water to be focussed on critical source areas (CSAs). [Sadly, many geologists, particularly in the academic community, do not have the vision or leadership to realise the value of geological information in land-use planning, river basin management and environmental protection, and therefore do not give an adequate priority either in their teaching or research to the environmental geology area.]

Unnecessary Small Point Pollution Sources

That soiled water from 'dirty' farmyards and effluent from domestic wastewater treatment systems are not allowed to enter directly into water, thereby unnecessarily using up the limited capacity of ecosystems to accept nutrients.

Unless dealt with, small point pollution sources will reduce the likelihood of achieving Food Harvest 2020 objectives as they make it more difficult to achieve our water quality objectives. [This wish may seem trivial; however, note that the annual phosphate load from each of us can pollute almost 15 million litres of water. And, discharges from small point sources are preventable.]

"Integration" and "Smart Science"

That 'barriers in the mind' are broken such that the point made by James Lovelock (of Gaia Theory fame) in a lecture in Dublin a few years ago, as given in the Irish Times, becomes meaningless. Lovelock complained that *the scientific community was too divided "not for any bad reason but because biologists don't speak to chemists". Even within biology, there are now 30 branches "almost proud of the fact that they don't talk to one another".* This view applies not just to chemists and biologists, but can also be applied to geologists and others.

"Smart science" is vital is a means of Ireland achieving both a competitive economy and a good environment. We must set out to achieve an appropriate integration of knowledge, ideas, solutions and implementation between chemistry, biology and geology, groundwater and surface water, and science and engineering. Ways of achieving this include: pooling our existing knowledge more effectively; breaking down sectional and organisational boundaries; focussed research, with emphasis on integration of appropriate scientific and engineering areas within and among third level colleges; getting greater input from scientists and engineers working in consultancies; and, most importantly, getting the involvement of lands managers, such as farmers, planners, forestry-sector, etc. While this is happening to some degree, it needs to be fast-tracked.

Communication and Awareness

That, in the coming years, even if it means a somewhat lower 'standard of living' in the short -term, the majority of the Irish public will support effective environmental protection and water quality management; without this support achieving WFD and Food Harvest 2020 objectives are unlikely to be possible. Therefore, it will be vital that priority is given to communicating with, including in the process and getting feedback from, communities in both rural and urban areas. It is essential that there should be empathy with and understanding of the views and needs of these communities.

Donal Daly
Hydrometric and Groundwater Programme
EPA

The future for Groundwater in the USA

Kevin McCray, CEO of the National Ground Water Association, provides some insights into the future of groundwater in the USA

The United States is a geographically large and diverse nation, and as such, it has varying water resource issues, and varying perspectives on how those water resources should be managed. The National Ground Water Association (USA), while primarily focused upon the groundwater component of the hydrologic cycle, recognizes the interdependence of water resources. The Association recognizes that unlike surface water bodies which often represent natural boundaries, as well as artificial political boundaries between people, groundwater generally does not adhere to the same restrictions and will be found below natural and political boundaries.

The nation does not have a unified, federally-directed national water policy. More than two dozen federal agencies are engaged in water issues in the nation, a further complication to an already complicated issue. Additional political jurisdictions, such as state governments, county governments, municipal governments, water and natural resource districts, Native American interests, and private ownership issues, make evident the groundwater management challenge.

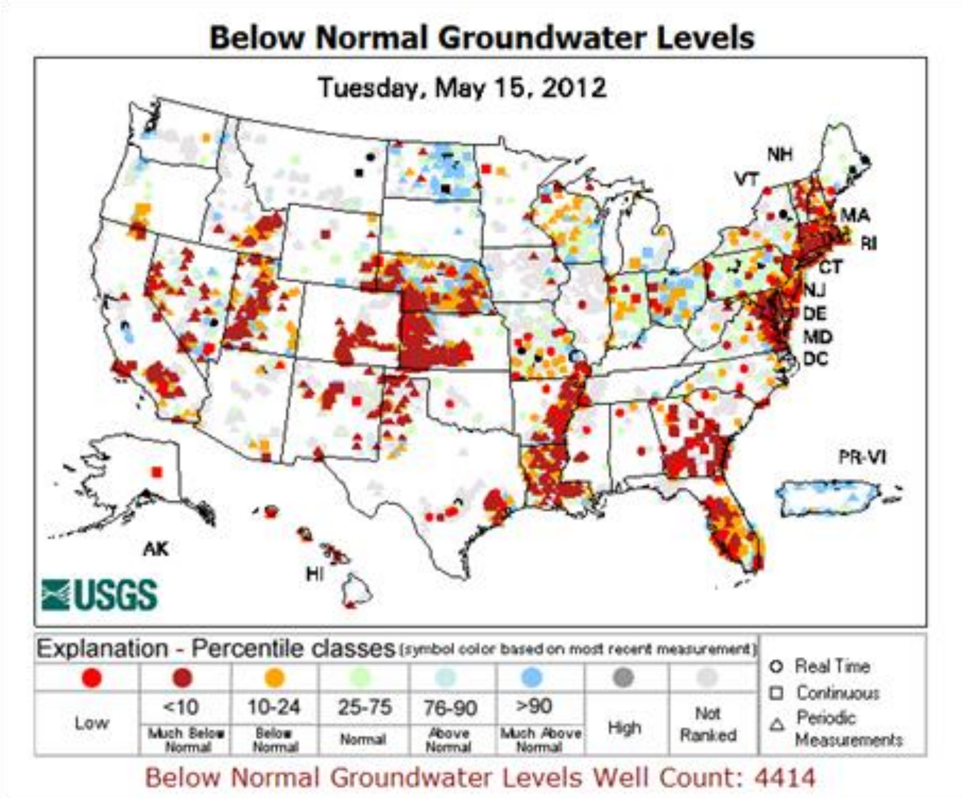
Regulatory organizations with groundwater responsibility have two fundamental concerns: quantity and quality. You may have many acre-feet of groundwater, but if the quality is not right, you may not have nearly the same amount. While efforts are underway to establish a national groundwater monitoring network, with several states now operating pilot projects to test the concepts, much remains to be done. Sufficient funding for establishment, and then, operation and maintenance of the network through cooperative funding with state governments, must be appropriated and then allocated.

There are nearly 40,000 groundwater-dependent community water systems providing drinking water to 88 million Americans. Of course, their concerns are focused on supply and quality of that supply. They are required to meet certain standards by the U.S. Environmental Protection Agency in terms of quality standards, and of course, those 88 million users expect there to be all the water available when they need it.

Additionally, our nation has 13.2 million occupied households served by their own private water well system. These systems are not federally regulated and the operation and maintenance of those systems, including the verification of the groundwater quality, are a homeowner's stewardship responsibility.

While there are varying groundwater management issues across the nation, it *may* be possible to generalize there is a movement away from a production mindset to one of management. This is particularly true in water-stressed regions, such as the desert regions of the southwest, home to cities of significant size and rapid population growth -- Phoenix, Las Vegas, Houston, and others.

Localized groundwater management is improving, although not everywhere and not consistently. In some areas there seems to be an unmeasured but growing awareness -- among not only scientists and regulators, but also the general public -- of the declines in groundwater levels and the related quality issues and energy costs relates to declining groundwater. More consideration, planning & human management



Real time and periodic groundwater level monitoring results from the USGS Groundwater Watch website

needs to be applied, particularly in the coastal regions so groundwater isn't over extracted, creating a need for seawater intrusion management.

Texas, a southwestern state, has recently suffered a historically severe and extended drought. There are 96 groundwater districts there. Five of the state's 16 regional water planning groups, charged with evaluating and recommending strategies to address water shortages, see brackish aquifers as important potential water supply sources. The Texas Water Development Board's Innovative Water Technologies group has taken on the roles of systematically mapping and characterizing the brackish portions of the 30 major and minor aquifers in the state, and funding projects that can provide tangible and replicable examples of water desalination technologies.

And yet, the Texas Supreme Court, the highest in the state, ruled on February 23, the groundwater under a landowner's holdings is their personal property, and thus, their own to pump and use, perhaps despite what the local groundwater district might have permitted.

In some regions overlying the Ogallala Aquifer, the nation's largest, management seems to be contributing to rising groundwater levels. Of course, groundwater mining continues in other Ogallala regions, but by implementing management schemes – including how the extracted groundwater is used – we may sustain groundwater for far longer than it would last without this oversight.

National controversy over a federal decision to delay construction of an energy fuels pipeline atop portions of the Ogallala is a recent example of the growing awareness of the water-energy nexus.

Some ecosystems are groundwater dependent, and thus, are vulnerable to environmental changes and increasingly to groundwater use. The importance of groundwater to ecosystems may perhaps be best illustrated by the federal Endangered Species Act and how the protection of aquatic species in groundwater-dependent surface water bodies may impact groundwater utilization and drive new management perspectives and practices.

Storm water management and capture is increasingly being integrated into water management throughout the U.S., often through the use of retention basins for infiltration. Issues of water quality, including the need for pre-treatment before recharge have slowed the adoption of artificial groundwater replenishment schemes.

Of course, management also implies sound water use practices. Miles of leaking water mains, while inadvertently contributing to groundwater recharge, are not effectively contributing to efficient and effective water management. A recent report from the American Water Works Association contends our nation needs to invest $1 trillion between now and 2025 for our public water systems, with replacement of pipelines on the order of half of that expense.

We've heard reports where it is considered acceptable for water mains to leak as much as 15 percent — sometimes more — of the system's treated water. A private water utility in a densely populated western U.S. community which had a finite water supply for its customers was able to grow its connections and its revenue by simply fixing its leaky infrastructure and capturing that previously lost water.

Technology contributes toward managed water resources. IBM has started a pilot program in Dubuque, Iowa using digital water meters in just 151 homes. By monitoring household water use and patterns, information could be created for homeowners about how to consume less and by alerting them to possible leaks. The pilot generated water savings of nearly 7 percent, which would be about 65 million gallons a year if extended to the entire city of 60,000.

Energy costs can be a contributor to groundwater conservation. As groundwater depths increase, head increases, and energy costs to move that water climb. Farmers and other users may turn off their demand until water tables recover to more cost-effective levels. Software that measures the water needs of crops more precisely means more effective water withdrawals, which can lead to more sustainable and managed use. Farmers have an incentive to be good water stewards — its how they grow the crops they sell. Industry is the same way. Using only what water you need and finding ways to engineer water out of manufacturing processes and the products results in water savings, as well as cost savings. Similarly, industry has recognized that it is less expensive to prevent groundwater contamination than it is to clean it up.

Some 67 percent of the nation's 79.6 billion gallons of groundwater withdrawn daily goes to agricultural irrigation; irrigation that contributes toward sales of at least as much as $13.5 billion for just the five crops of corn, soybeans, wheat, rice, and cotton. The U.S. actually reduced the volume of groundwater it withdrew for agricultural irrigation between 2000 and 2005 by about 8 percent. Of course, these are estimates and these estimates have gone up and down since 1970. Extended drought in groundwater dependent regions of agricultural America could drive those estimates upward. Fortunately, farmers are increasingly motivated to use only what they need – the energy costs of pumping water are a great incentive to use only the water needed, and we've developed resource management practices and oversight that also contribute to better groundwater use.

Water use for irrigation in the US in 2005. Nearly 90% of groundwater used for irrigation was withdrawn in 13 States. Amongst these, groundwater was the primary source of water for irrigation in the Midwest and South-central states, in Nebraska, Arkansas, Texas, Kansas, Mississippi and Missouri. Source: UGSS website

Recently a meeting of local, regional, national, and international water and environmental organizations and government agencies explored addressing the need for integrated water resources management in the nation.

A proposed memorandum of understanding (MOU) for the meeting participants was drafted for the stated purpose of promoting partnerships for and reducing barriers to the implementation of sustainable integrated water management. The MOU proposed better aligning programs and research, enhancing communication and information exchange, and establishing opportunities for joint activities supportive of adaptive, integrative water management planning. At present, the prospects for that MOU appear to be slim.

While man is the planet's most intelligent creature, sometimes he doesn't always act intelligently. Part of the huge groundwater challenge is how to increase public awareness of a resource that is out of sight, and thus out of mind and susceptible to stupid actions that pollutes or threatens this portion of the hydrologic cycle.

Unfortunately, the average citizen anywhere in the world probably fails to appreciate concern about groundwater supplies. As a resource in the subsurface, it tends to be out of sight and out of mind. When one needs water, and groundwater is the only water available, then it does take on a more consequential role and earned respect.

The entire planet, not just the U.S., could benefit from learning to use our water resources collaboratively, or conjunctively. Where both groundwater and surface water supplies are available, they need to be managed not as separate systems, but as part of the hydrologic cycle for the watershed.

Kevin McCray
CEO, National Ground Water Association

Kevin McCray has been the chief executive officer of the National Ground Water Association (USA) since 1995.

NGWA represents all of the professions involved with providing, protecting, managing, and remediating groundwater resources around the world. With more than 11,500 members in 60 nations, NGWA is a leader in professional development, knowledge dissemination, and advocacy on behalf of the safe and productive use of the resource, as well as of the professions of the industry. It collaborates globally with hundreds of organizations, and has formal cooperation agreements with nearly two dozen international groups serving science and technology.

national ground water association

www.ngwa.org

Water management for the future — lessons from Australia

The Australians are well practiced in water management… is there anything we can take from their experiences and apply here?

Australia is the land of extremes when it comes to water. Floods and droughts are part of the normal weather cycles and in a place where potential evapotranspiration is far higher than rainfall for most of the year over the majority of the country, it is no surprise that the Australians are well practiced at water management. In contrast to Ireland, water quantity rather than quality is the main focus of Australian water management practices, but in my view there are, nevertheless, lessons that we can learn here to prepare for the future, based on their experiences.

Australian State governments manage their water under an overarching piece of federal legislation, known as the National Water Initiative (NWI). The overall objective of the NWI is summarised as 'to achieve a nationally compatible market, regulatory and planning based system of managing surface and groundwater resources, for rural and urban use, that optimises economic, social and environmental outcomes'. Under the NWI, governments have made commitments to:

- prepare water management and sharing plans with provision for the environment
- deal with over-allocated or stressed water systems
- introduce registers of water rights and standards for water accounting
- expand the trade in water
- improve pricing for water storage & delivery
- meet and manage urban water demands

These commitments reflect the decision taken in Australia to make water a saleable or tradable commodity, with the hope that in so doing, they will achieve conservation and environmental outcomes. While I don't believe such a drastic step is an appropriate direction for Ireland to take, there are two key objectives of the NWI that I think we can learn from here: (a) to recognise the connectivity of surface and groundwater resources and manage them as a single resource, and (b) to ensure that stakeholders, particularly landholders, play a key role in the development of water management and sharing plans. The other area that I believe we should look to the Australians in is integrated catchment management.

Interconnected water resources

The Australians have fallen into a horrible trap. They call it 'double accounting'. Water licences and entitlements are big business in Australia. Agricultural productivity in many areas is dependent upon irrigation and securing enough water at the right time, and at the right price, is critical to profitability. Farmers tend to draw on their surface water allocations first because the surface water resources are so transient and unpredictable, and building reservoirs is expensive. Groundwater allocations are kept in reserve for drought periods when the surface water resources are no longer available. The problem is that the surface water and

Centre pivot irrigation technology in Tasmania

groundwater in these large river basins are essentially the one resource, and when you add up the total volume of water that has been allocated across the different groundwater and surface water allocation systems, the sum is greater than the total amount of water available. So who gets precedence? Whose entitlement is worth more than the other at the critical time? How can they be shared and transferred? How can an allowance be built in for the lag times in impacts of groundwater abstractions on river resources? How much is required to be left in the river to keep ecosystems alive in low flow periods? How can keeping that water in rivers be justified when entire crops, jobs and livelihoods are at stake? Add climate change, and the impacts of water hungry land-use changes such as new forestry plantations, into the mix, and you can begin to get a feel for the extent of the technical and political dilemmas the Australians now find themselves in (Young & McColl, 2009).

While I'm not suggesting that we are likely to reach equivalent levels of desperation for water in Ireland as in Australia, I do think that we would do well to learn from their mistakes and establish a truly integrated water management system whilst we still have the opportunity. The river basin districts are a good first step, but in my view, any future water accounting, entitlement or management systems must consider groundwater and surface water as one connected resource.

Multi-disciplinary water management

This leads on to the second lesson. One of the principle reasons in my view that the double accounting problem has arisen, is that surface water entitlements and groundwater entitlements have traditionally been quantified and allocated by different sets of professionals, with different educational backgrounds, located in different Departments: hydrologists and engineers managing the surface water resources on the one hand, and hydrogeologists managing the groundwater on the other.

This is the same, age-old, traditional split in expertise that we have also subscribed to on this side of the world. If we are to ensure we do not collectively inadvertently make management mistakes of the scale of the Australian double accounting problem, it will be important in the future that hydrogeologists, hydrologists, engineers, biologists, soil scientists and other specialists with an interest in water, share knowledge and experiences to work towards efficient and effective water management. With resources becoming more and more tight, and as we come under increasing pressure from the EU, this will become critical in my view. The days of working only within our discipline-specific comfort zones should be long gone.

Integrated catchment management

It is becoming a bit of an over-used phrase nowadays, but I believe that integrated catchment management, that considers all land and water activities in the whole of the catchment, from the headwaters out to the marine environment, is important for achieving long term successful environmental management outcomes. This is also something the Australians are becoming better at, due, in no small part, to the tireless campaigning by the 'poorer cousin' disciplines like the groundwater and estuarine sciences. In my view groundwater and estuarine professionals in Ireland need also to raise their voices to ensure their disciplines are incorporated into management frameworks in a meaningful way.

Stakeholder involvement

Finally, one other area in which the Australians have excelled in my view, is in the involvement of communities in water and catchment management. They do this well through three different means.

Firstly, the country is divided into Natural Resource Management (NRM) regions, akin to our RBDs, for the purposes of delivering on-

Demonstrating an aquifer model to the public

ground sustainable agriculture programmes (www.nrm.gov.au). The Federal and State Governments fund a small army of qualified people who operate as environmental extension officers in their regions. They draw up NRM plans with the local community, and farmers and landholders can access small scale grants to deliver on-ground works that will contribute to the objectives of the plans. Typical activities include rehabilitation of riparian areas, fencing stock out of rivers and streams, planting native trees, clearing weeds, restoring wildlife habitat corridors, etc.

Within the NRM framework, there is a massive volunteer Landcare movement (www.landcareonline.com.au) which comprises more than 6000 locally-based community groups who care for the natural resources of their areas. These groups can also access the grants for on-ground project works. Over 40% of farmers are involved in Landcare and many more practice Landcare farming. One of the spin-offs of these groups is that urban and rural urban people also often take part, which leads to a greater wider appreciation of the issues affecting farmers and the land use decisions they make.

Finally, it is a requirement of the NWI that landholders are consulted in the development of water sharing and management plans. This helps to achieve 'buy-in' into the plans and ensures a stronger likelihood that the measures will actually be implemented. As an example, although it was admittedly an extreme case, the consultation effort for two such plans I worked on involved monthly, full-day, round table meetings between irrigators, anglers, the hydroelectric agency, elected Councillors environmental interests and the Department, over the course of two years. Meetings included providing the group with modelled 'what if' resource allocation scenarios which were revised and updated as the development of the plans progressed. The resulting 'actions' in the plans reflected the operational practicalities that were unique to that system. This would have been unachievable without this level of input from the water users. In this particular case, which was very political and highly contentious, the most important outcome of the whole consultation process in my view, was the acknowledgement (I wouldn't go so far as to say acceptance!) and better understanding of the needs and values of other water users, that was gained by the meeting participants.

Stakeholder involvement in natural resource management in Ireland could be improved in my view, but it would need a substantial investment in dedicated liaison officers. The process is also very time consuming and funding for support grants would be required. The experience in Australia has been that if solutions to environmental problems can be found that benefit the relevant landholder, and if he/she can be supported financially to meet the 'out of pocket' costs of making a change, and in some cases the ongoing maintenance, the outcome is generally good.

We are at an important juncture in water management in Ireland and we have the opportunity to put truly integrated management systems in place. Lets hope we take it.

Jenny Deakin, TCD
Previously Head of the Groundwater Section, Dept of Primary Industries, Water and Environment, Tasmania, Australia

Groundwater Management – expensive luxury or policy priority?

Groundwater management has always been an important consideration for environmental regulators — but will it remain a priority, or is it at risk of becoming an unaffordable luxury?

Minewater rebound….. agricultural nitrates… over-abstraction…. legacy land contamination…. septic soakaways…landfill…nuclear waste disposal… coal bed methane…shale gas… droughts & groundwater floods…. This is big stuff! But society is not aware that hydrogeology is central to these issues. It's a specialist field, and the current economic climate means the number of practitioners is declining, in both the private and public sectors. Admittedly, investigation of groundwater problems can be an expensive process, with individual samples costing upwards of £10,000 by the time the borehole is taken into account. Include the cost of remediation, and two or three zeros can easily be added to the bill, even for isolated problems. So there is a risk that groundwater management, and hydrogeologists, could be considered an expensive luxury. It's a risk that is already manifest, and to halt it we need to get better and more visible at influencing decisions at a practical level.

As Scotland's principal environmental regulator, SEPA has been fundamentally changing its approach in recent years. Moving away from focusing on individual regulations and targeting its resources at compliance, SEPA is adopting a more 'harms based' approach – identifying key environmental problems, fixing them through problem-solving partnership projects, and raising awareness both of the issues and the importance of addressing them. This is the essence of 'better environmental regulation' as championed by Malcolm Sparrow, Professor of the Practice of Public Management at Harvard University, who has been training large numbers of staff from UK regulators over the past few years. "Find important problems, fix them, then tell everybody" is his simple mantra, but it is very much becoming the order of the day at SEPA, with changes to legislation and to the agency's funding model in the pipeline to accommodate it.

But what will that mean for the profession? It's all too easy for hydrogeologists to retreat into their traditional heartland, staying close to their drilling rigs and generating complex technical reports which bounce back and forth between consultants and regulators. But is that really the most valuable approach? Does anyone understand what we are saying, or what we are asking for? Do farmers, for example? Or landfill operators? Or policy-makers? Do consultants' clients really understand that a sound hydrogeological risk assessment, properly handled, can save money in the investigation and design of a new site, rather than simply ticking a regulator's box? Do operators understand the information required by regulators? Or that in many cases they are wasting money and even polluting their own water supplies when they fail to adopt best practice? Can academic insights better inform practical applications on the ground, rather than simply informing other academics?

What does all this mean for hydrogeologists as consultants, academics and regulators in the future? We know we are an important component of an integrated approach to identifying environmental harms, and developing and implementing problem-solving projects to address them. But if we're to avoid being considered 'expensive luxuries', we need to become excellent science communicators as well as excellent scientists. We need to be ready to put away the technical terms, come up with a solution and engage with people. We need to be ready to speak to the media, to meet face-to-face with sceptical farmers or landfill operators.

When we communicate effectively we enhance awareness and understanding of our profession, of the expertise we bring to partnerships, and of the contribution we can make to the environment, to the economy, and to the well-being of communities. The alternative is being branded expensive luxuries, and what's the use of that?

Groundwater management, and hydro-geological expertise, are both considered valuable components of SEPA's harms-based, problem-solving approach. But, we do have to become expert communicators as well as expert scientists. Once we do that, we can all start to see how we can continue to make a real difference.

Vincent Fitzsimons
Water Resources Unit Manager
Scottish Environment Protection Agency

Progression in groundwater protection and management
A Local Authority Perspective

Background

In Wexford, as in Ireland, there is a generally held public perception, that groundwater is not subject to the same level of contamination problems as is experienced by most other EU countries. This perception is largely due to the fact that groundwater flow and contaminant sources are neither readily observed nor easily measured, and the subsequent impact on the aquifer, and extent of its pollution can be generally slow to reveal itself and difficult to conceptualise (<u>out of sight, out of mind or we'll ignore it for as long as possible</u>).

In County Wexford 40% of our drinking water comes from groundwater sources found in two major aquifers (Figure 1): the volcanic aquifer that runs from south west Wexford to northeast Wexford; and the limestone aquifer in Fardystown. Groundwater also feeds our surface waters and in many cases, particularly in summer months, between 50% and 90% of the base flow of many rivers may be due to ground waters resources. It is therefore of vital importance that we protect our groundwater resources in order to maintain the quality of drinking water supplies and to remember that surface water quality will also be affected if contamination occurs.

The Problem

An increasing number of groundwater problems are however coming to the attention of scientific staff in the GSI/Groundwater, Local Authorities, and the EPA over the past 15 to 20 years, indicating that the above mentioned perception is not justified. These problems are both localised and increasingly regionally, where groundwaters are indicating elevated bacteriological, nitrogen, phosphorus and other contaminant concentrations. The contaminants are from a variety of sources such as discharges of sewage from single houses and housing developments as well as inappropriate control and application of animal and artificial fertilisers in agriculture. Microbial contamination of groundwater in Ireland is high, probably higher than in any other country in the EU with many areas indicating 30% of domestic wells are showing faecal pollution, while in some highly vulnerable thin soiled/ karst areas more than 50% are polluted (Daly, 2003). Since the mid 1980s, the GSI (Donal Daly and Co) and other researchers, have drawn attention to the importance of septic tank systems and farmyards as sources of groundwater pollution (Figure 2). This problem further elucidated in the early 1990s with further work by Daly, Thorn and Henry (1993).

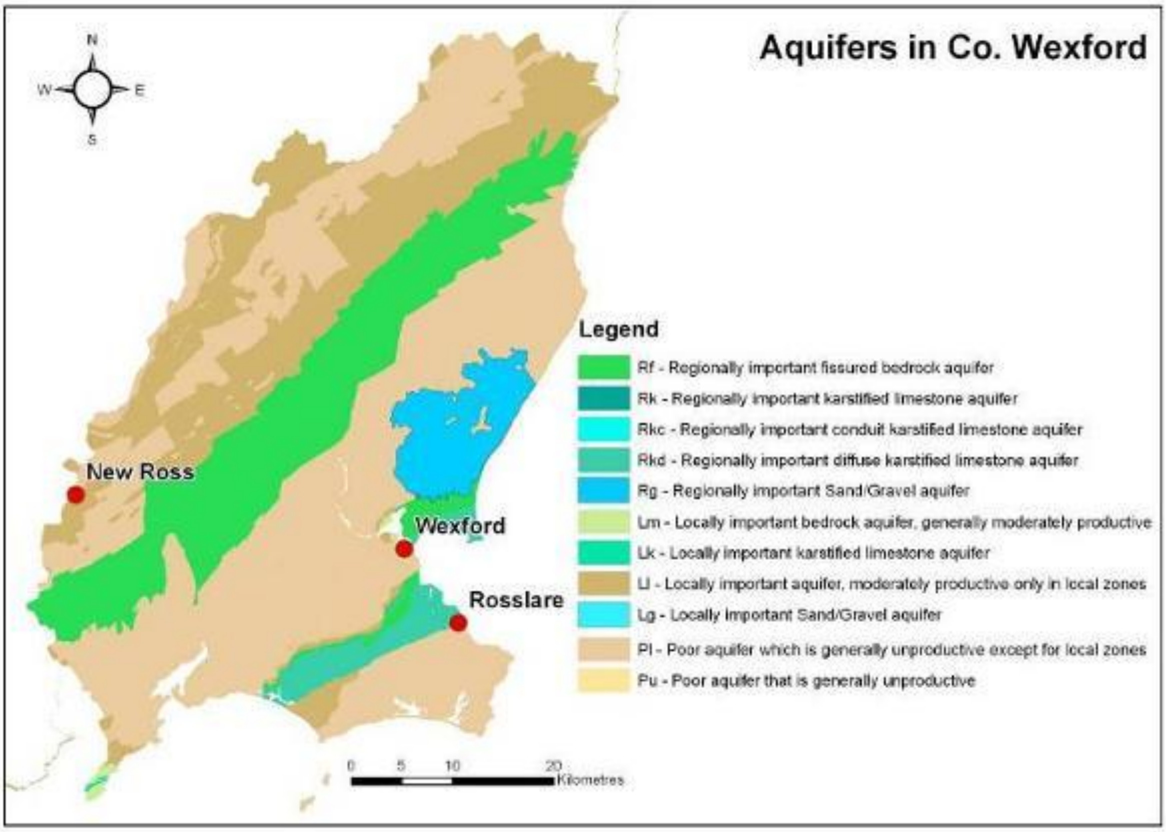


Figure 1. Simplified aquifer map of Co. Wexford

Surprisingly however, the seriousness of this problem is still not being appreciated both by the public, and more surprisingly even, by a large number of professionals both within and outside of the regulatory framework. This is a worrying position to be in given the vulnerability of our groundwater resources (Figure 3). The cumulative impacts of these discharges are not fully appreciated and it is not fully realised that the nutrients/contaminants in a "well" treated effluent do not just disappear and will eventually move over periods of time into ground water and thereafter into surface waters and marine habitats.

Septic Tanks and Groundwater: An Introduction.

Septic tank systems in the U.S. rank highest in the total volume of wastewater discharged directly into groundwater systems and are the most frequently reported source of groundwater contamination. One-third of all water borne disease outbreaks in the U.S. from 1971-76 were traced to the consumption of water from untreated groundwater sources. It has also been estimated that only 32% of the total land area in the U.S. has the geological and hydrogeological conditions which are required for the safe disposal of septic tank effluent.

Is the situation similar in Ireland ?

Figure 2. Extract from Groundwater Newsletter No. 3, February 1987

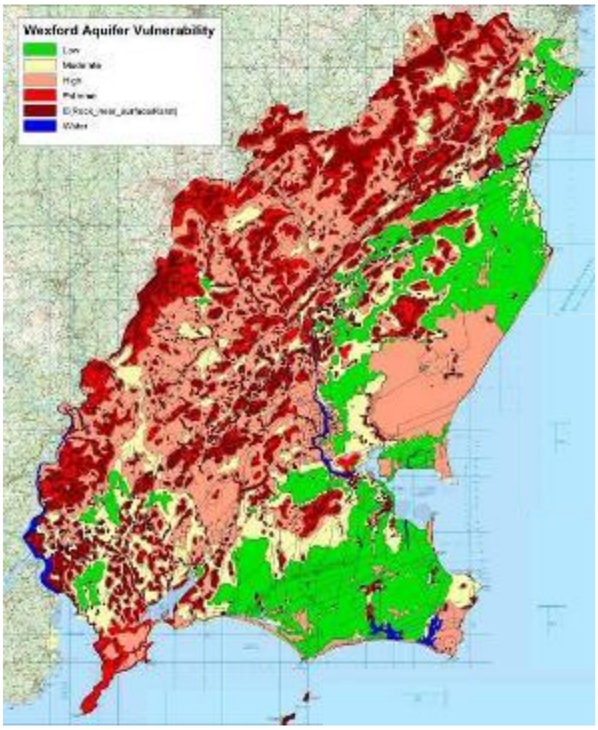


Figure 3. Wexford Aquifer Vulnerability Map

Figure 4. Map of domestic dwellings

Dilemma

Wexford aquifers face pressures from two sources. Firstly the county is home to a large, highly productive tillage and high intensity agriculture sector which accounts for a substantial part of the economy. Due to the intensity of the farming carried out, fertiliser applications are generally the maximum amounts allowed under the Good Agriculture Practice Regulations and are a mix of both artificial and organic manures, both animal and treated sewage sludge. A considerable proportion of the sludge's from the Ringsend wastewater treatment plant are exported to Wexford where they are utilised in tillage.

Secondly, and which this paper will deal mainly with, the county also had a large number of one-off houses in the countryside including, uniquely to Wexford, a considerable number of country based housing developments ranging from 5–7 houses. In 2011 it was estimated that there are approx 27 - 30,000 one-off houses, each with their own On-Site Wastewater Treatment Systems (OSWTS) or discharging to a communal wastewater treatment system (Figs 4 and 5).

Due to an abundance of coastline (200km) and beaches, there is also a high number of holiday home developments and mobile home parks in County Wexford, with many of these built along the costal areas on the east and south coasts.

Figure 5. Map of commercial registered premises

As can be seen from the above maps the extent of rural dwellings is fairly evenly spread across the county. On closer inspection, particularly with aerial photography (Figure 6), it will be clearly observed that there is virtually no road in the county, whatever the size, which does not have a sizable amount of housing development each with their own OSWTP.

Due to poor percolation rates in many areas due to the Macamore series soils and the fact that many of the rivers in the county have only limited assimilative capacity due to their small size, the problem of how do we in the Environment Section manage all of the discharges was quickly appreciated during the building boom years of the Celtic Tiger.

There is also the growing realisation that there is a limited capacity of the environment in its entirety to assimilate all that is thrown at it. If one sector is allowed to increase then other sectors will have to be reduced. This is becoming very apparent with regard to nitrates in groundwaters and also with other chemical species such as phosphorus etc as further research is carried out.

Figure 6. Aerial photograph of rural development

Protection & Management, Past & Present

The authorisation of discharges to groundwater in Ireland is currently regulated and authorised by either local authorities under Section 4 licences granted under the Local Government (Water Pollution) Acts 1977 to 1990 and their subsequent regulations, or by the EPA under IPPC licences for those sites which are prescribed under the EPA Act 1992.

The 1977 Act and more particularly the subsequent regulations laid down the regulatory framework on how discharges to waters are to be licensed. Under Section 3 of the Act all discharges of polluting matter to waters was deemed to be illegal, except those discharges which were carried out under licence granted under Section 4 of the Act. Section 4 states that all discharges to waters are to be regulated via a discharge licence with a number of exceptions such as discharges from municipal sewers, discharges from ships to marine waters, and for any discharge to groundwaters, <5 m^3/d, of a domestic type effluent.

It was recognised by Wexford County Council however, during the early part of the last decade that action was needed to address a deficit in how our discharges to waters were managed. This was due to the large number of Section 4 discharge licence applications to Wexford County Council during the building boom. During 2006 for example, in Wexford there were 120 Section 4 discharge licence applications received of which 24 applications were for Section 4 discharge licences in which it was proposed to discharge effluent to groundwaters. These applications were for housing developments ranging form 7 to 24 houses. During the same period there were approx 2700 planning applications for single houses and 750 planning permission applications for cluster developments of 2 to 5 houses of which 54% were granted, with most of them proposing to discharge the effluent to groundwater. As you can see the numbers were building up rapidly and while there was an attempt by the EPA to provide guidance on single house discharges in the early 2000's in ideal conditions, there was virtually no official guidance on how to deal with discharges of larger amounts, either to surface waters or groundwaters or to less than ideal ground conditions.

To that end in 2006 a set of advice notes were published by Wexford Co Co offering guidance to developers on how to assess the impact of a proposed development on the aquatic environment . These guidelines were compiled following many hours of telephone calls, letters, meetings and badgering various experts in the fields of both surface and groundwaters. In 2008 these notes were updated and condensed into one advice note which covered all discharges to all waters. Dealing with discharges to groundwaters specifically, the information we were requesting was for a full water quality and hydrological assessment of the underlying aquifer so as to ascertain what the aquifers quality and hydrogeological characteristics were before making a decision as to whether a discharge would be allowed to go ahead. Prior to this there was a tendency to look exclusively at the discharge itself and no cognisance of the receiving waters was taken. If the effluent met certain minimum standards then it was granted permission regardless of the quality or assimilative capacity of the receiving waters. The information we requested is seen in Figure 7.

Following receipt and assessment of the data with the application, the raw data were put into a spreadsheet which we had developed to assess the impact of the effluent on the aquifer quality. The calculations were very simple, looking at the vertical and horizontal dilution only, and made no attempt to look at dispersal characteristics, or attenuation of the effluent as it made its way through the soil and bedrock, or any other of a multitude of factors which would influence the impact the discharged effluent had on the receiving waters. It was however we believe a good first attempt to start to properly regulate the discharges and start to put some ballpark assessment of the impacts and thus start to protect our resource.

More recently the European Communities Environmental Objectives (Groundwater) Regulations, 2010 (S.I. No. 9 of 2010) (Groundwater Regulations) have given for the first time a comprehensive set of all encompassing set of groundwater standards. With the publication in 2010/2011 by the Local Authority Services National Training Group (LASNTG) of the guidance document "Guidance, Procedures and Training on the Licensing of Discharges to Surface Waters and Sewers" and more recently the Environmental Protection Agency document "Guidance on the Authorisation of Discharges to Groundwater" and its incorporation into the LASNTG, we have at long last reached a stage whereby we have for the first time a comprehensive suite of guidance documents for discharges to groundwaters. These have of course superseded our Advice Notes and are fully integrated into our assessment of all discharge licence applications.

Protection and Management, Future

Historically groundwater monitoring/protection in the Republic of Ireland focused on drinking water supplies and investigating the impacts of point source pollution. However, the WFD adopts a more holistic view of water resources, establishing links between groundwater and associated surface water and ecological receptors. Cumulative impacts on groundwaters of the many "small" developments and single house OSWTS discharges will be the next big thing to hit environmental assessments as it is something we have steadfastly ignored for many reasons.

Environmental regulation has reached a stage of sophistication in Ireland whereby non-professionals or professionals with no

6 DISCHARGES TO GROUNDWATERS

INFORMATION TO BE SUBMITTED WITH A WATER POLLUTION LICENCE APPLICATION OR PLANNING APPLICATION

The applicant is responsible for submitting all data in relation to quality and quantity of effluent and receiving waters.

To evaluate the impact of wastewater on receiving waters the following is required. **This may require the applicant to engage the services of a qualified hydrogeologist**:

1. A **Water Pollution Licence Application Form** completed in accordance with the Licence Application Explanatory Notes. Both are available on the Wexford County Council website at: http://www.wexford.ie/wex/Departments/Environment/WaterQualityandLicensing/
2. A description of the chemical and bacteriological composition of the effluent
3. A description of the chemical and bacteriological condition of the receiving groundwater at the discharge location *(see Appendix 1)*
4. Aquifer characterisation and vulnerability rating of the site *(see Appendix 3)*
5. Where the discharge is to a locally or regionally important aquifer, an examination of the aquifer in respect of extent, estimated volume of water and estimated rate of recharge will also be required. Identification of the existing or proposed uses of the water therein must also be setout. An aquifer map for County Wexford is available from the Geological Survey of Ireland website www.gsi.ie
6. Details of the source of the water supply for the development and details of any other wells and wastewater treatment systems within 100 meters of the development's treatment plant or percolation area (maps indicating the locations of these features to be included)
7. An assessment of the associated impacts of the discharge on the chemical and microbiological quality of the groundwater having consideration for the relevant legislation *(see Appendix 5)*
8. Details of proposals for dealing with sludge.

Items 2 – 8 must also be submitted with a Planning Application, unless the discharge is currently licensed under the Local Government (Water Pollution) Acts, 1977 & 1990.

Fig 7. Extract from Advice Note 3 indicating information needed for a groundwater discharge licence application

qualifications and significant expertise in the area cannot be expected to carry out the often complex assessment that is required for proper regulation and management of environmental matters. Gone of the days when Section 12 notices and blanket farm inspection is the apex of complexity in water quality regulation. We cannot remain where we have been for the past 35 years since the 1977 WPA was enacted. We need to involve considerably more experts, such as hydrogeologist, ecologists, riverine and fisheries specialists, etc in the assessment of all discharges to waters and in particular for groundwater assessments. Not only that they all need to take a more holistic view of what they are dealing with and more closely integrate their views and expertises together in assessing licence applications.

I believe that maybe now is a good time to broach shared services between local authorities whereby a hydrogeologist and other environmental specialists are employed as a shared service between a numbers of LAs, thereby gaining an expert who knows what they are talking about.

Brendan Cooney, Wexford Co. Co.

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Whither hydrogeology education?

Bruce Misstear looks at the options for students wishing to pursue an education in hydrogeology and the future for such courses

In 2003 I presented a paper at the annual IAH (Irish group) seminar in Tullamore on *Irish Hydrogeology and third level education*[1]. Much has happened since then, especially with regard to hydrogeology courses in the UK, so I feel an update is timely for this 50th issue of the *Groundwater Newsletter*. But first, a few words about the situation in Ireland.

I am often asked whether an Irish university will introduce a taught masters course in hydrogeology. In my view this is unlikely. To be viable, the course would need to attract students from outside Ireland as well as from within. Although there may be sufficient demand from international students, especially from developing countries, such a course could only run successfully if our Government was to offer a number of funded studentships. The former masters course in hydrology at NUI Galway was very successful when Government studentships were in place, but it shut down shortly after funding was withdrawn. Sadly, I see very little prospect of our Government providing studentships for a new course, especially given our current economic woes.

So what are the options for Irish graduates in geology, civil engineering or environmental sciences who wish to study hydrogeology? Within Ireland, both Trinity College and Queen's University run masters degrees in environmental engineering, and these courses include modules with substantial hydrogeology components (for example, in the case of TCD, modules on engineering hydrology, water resource planning, waste management and hydrological modelling all have a strong groundwater content). However, the educational objectives of such environmental engineering courses are not the same as those for specialist taught masters courses in hydrogeology. For the latter, students must turn to the UK or further afield.

The UK has a strong tradition of high quality teaching in hydrogeology, but the situation is fluid (oops) and, I believe, under threat. At the moment, there is the long-established full-time hydrogeology masters course at Birmingham, together with the more recent hydrogeology courses at Leeds and Strathclyde, the environmental hydrogeology course at Cardiff, the MSc in contaminant hydrogeology at the University of Sheffield and an applied hydrogeology masters in Newcastle (which includes a 'flexible learning' option whereby the degree can be taken over several years). However, the hydrogeology courses at Leeds and Cardiff will close from September this year, adding to the list of now defunct hydrogeology masters courses: University College London (the first of the taught hydrogeology masters, which ran from 1965 to 2001), East Anglia (1992-1999) and Reading (1992-c.2002).

The UK Natural Environment Research Council (NERC), which previously funded a number of hydrogeology studentships, has withdrawn its support for applied geosciences masters courses (including hydrogeology), and currently gives priority to funding of doctoral students. Whilst funding of research is important (as an academic I would say this), I believe that taught masters courses in hydrogeology make an essential contribution to our profession, producing hydrogeologists with a broad skill set in the science and practice of hydrogeology. The Birmingham MSc lost all its funded student-ships for the current academic year, suggesting that even this well-regarded course could be vulnerable in the future. Aside from the importance of funding *per se*, the award of student-ships is an indicator of the status of a course, and hence serves as a recommendation for other potential students. Thus loss of funding has far-reaching implications for the viability of a course.

The uncertain future of specialist taught masters courses in hydrogeology is exacerbated by the increasing numbers of masters-level “add-on” primary degree courses (partly stimulated by the requirements of the so-called Bologna declaration, with a 3+2 year two-cycle masters the norm in continental Europe, or 3+1 year MSci programme in UK) and also by the fact that, in the UK, there are now significant fees charged for primary degrees, so graduates are naturally more reluctant and less able to self-fund further education. There are a number of short-courses available in hydrogeology, including a diploma at UCL, but these do not constitute an alternative to the traditional full-time taught masters.

Aspiring hydrogeology students also have the option of studying abroad, including the USA, Canada or Australia, but these options are likely to be expensive when full costs are considered.

If we reach the point where there are insufficient hydrogeologists graduating with high quality masters in hydrogeology to supply the job market, then this will have serious implications for our profession. There is a danger that hydrogeological tasks in government agencies and consultancies will be carried out by staff who are not hydrogeologists, resulting in poor quality work. I worry especially that we will see a continuation of a modern trend whereby field data collection and drilling are not properly prioritised, or supervised, with a greater reliance being placed on desk-bound studies, including the application - or misapplication - of hydrogeological software.

Of relevance to this last concern, in the previous paper I also wrote about the ‘Lost tribe of hydrogeologists’, a phrase from an article in *Ground Water* which was used by the author to describe those hydrogeologists who had specialized in hazardous waste clean-up, often adopting a recipe book approach, and who had become dislocated from the world of groundwater resources. I also presented my own examples of the pitfalls associated with a recipe book approach and the need for hydrogeology education to encompass the fundamentals of our science and its application. I do not have time in this short article to develop this point further except to say that I feel it is still an issue, especially, perhaps, with the continued expansion of the role of groundwater modelling within hydrogeology, and professionals who regard themselves as modellers first and hydrogeologists second. Alas, many modelling studies are underpinned by a poor understanding, and hence poor conceptualis-ation, of the hydrogeology, and are overly-complex for the problem at hand. I shall leave the last word on this to Cliff Voss, Executive Editor of *Hydrogeology Journal*, who, whilst emphasising the value of models as tools for hydrogeologists, wrote in a recent editorial on ‘*Groundwater modelling fantasies’* that:

“the best way to go forward with practical management [of water resources] is to rise above groundwater models as final products, and instead, empower hydrologists to provide advice by using groundwater models in simple ways, that are intended to elucidate understanding. Pursuit of complexity in groundwater models intended for practical management is a diversion from the real work at hand.”[2]

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Future challenges in karst

David Drew provides some thoughts on where the future challenges lie in understanding groundwater in karst limestones

It is probable that most issues of the groundwater newsletter have contained an article related directly or indirectly to groundwater in karstified limestone. Obviously this is a reflection of the great importance of karstified aquifers as the source for public water supplies but it also reflects the emphasis placed on the need to understand and manage the karstic environment to a degree that is uncommon in other countries. This approach was pioneered by Bob Aldwell and David Burdon prior to the advent of the Newsletter but has since been vigorously promoted by GSI and more recently by the E.P.A. This has meant that Irish workers in the field of groundwater probably have a greater awareness of and knowledge of, the peculiarities of karst waters then their equivalents in other parts of the world and the information dispensed via the newsletter has been very important in this respect. For example, Ireland has an aquifer classification system that explicitly recognises degrees of karstification and has begun the systematic delimitation of robust SPZs for karst sources.

Karst aquifers are notoriously difficult to evaluate and are resistant to the methodology of conventional groundwater studies. As many consultants and researchers in Ireland can testify, the input of a great deal of resources can yield little in the way of certain answers. Two important aspects of karst in Ireland seem likely to be at the forefront of investigation in the immediate future.

Corrandulla karst spring, Co. Galway (*H. Moe*)

1. We understand quite well how groundwater behaves in upland, plateau karsts such as those of the northwest and the Burren, but these are areas with low demand for groundwater and comparatively few issues of water quality. Much less is understood

A quarry face in the lowland karst limestones in the Nuenna catchment, Co. Kilkenny (*J. Deakin*)

about the hydrogeology of the thousands of square kilometres of karstic limestone in low-lying areas whether it be the interfluve karst of Tipperary and Cork or the featureless lowlands west of the Shannon. It is in these areas that most groundwater public water supply schemes are located and in which economic activity and population density are greatest; yet the character of these aquifers is imperfectly understood. For example, water tracing is one of the most important investigative techniques used in karstic studies giving unambiguous information concerning directions and rates of groundwater flow. However, tracing experiments on the lowlands have a success rate (a positive detection of the tracer) of well under 50% compared with a success rate for tracing in upland areas both in Ireland and elsewhere, of 90% or greater. This implies that we cannot simply transplant the hydrogeological model for uplands karsts onto the lowland situation and that our conceptual model is therefore lacking in resolution.

2. Water quality in karst aquifers is also a topic worthy of further investigation, both in relation to pollution and in relation to the natural physical and chemical character of the groundwater which can give useful information as to the character of the aquifer. Strategies used for monitoring water quality in conventional groundwater systems commonly use sampling frequencies months apart or perhaps bi-annually and this is normally sufficient to characterise water quality adequately. This is probably not the case in karst waters where chemical and microbiological variables may vary wildly on a scale of days or even hours. Average values are of limited use without knowledge of extremes also. Semi-continuous sampling, possibly for relatively short periods of time, may be necessary although the resource implications are considerable.

Thus, problems remain, but Ireland has a record of addressing the peculiar nature of its most important groundwater systems at least the equal of other European countries in which karst water is of great importance – France, Slovenia and Croatia for example. And it is to be hoped that the impetus continues into the future to optimise the management of the karst groundwater resource.

David Drew

Karst features and traces in the lowlands of east Galway and south Mayo, GSI karst database

The challenge of emerging groundwater contaminants

Emerging contaminants, including a range of pharmaceuticals, industrial compounds and personal care and lifestyle products, are increasingly being found in groundwater but they are poorly understood.

What are emerging contaminants?

A large variety of trace contaminants are starting to be detected in groundwater at potentially environmentally significant concentrations. Such emerging contaminants (ECs) include not only newly developed compounds but also compounds newly discovered in the environment, in some cases due to analytical developments, and compounds that have only recently been categorised as contaminants. ECs include a host of different compounds including; pharmaceuticals and personal care products (PPCPs), pesticide metabolites/degradation compounds, veterinary products, industrial compounds/by-products, food additives as well as engineered nano-materials.

These types of compounds (largely organic) are used by society in huge quantities for many different purposes including, industrial manufacturing processes, human and animal healthcare, and the production and preservation of food, to list a just a few. In the last few decades there has been a growing interest in the occurrence of these ECs in the aquatic environment, their environmental fate and potential toxicity (Kümmerer, 2009). Due to the vast array of possible compounds, many published studies have selected ECs according to priority lists established, taking into account usage, predicted environmental concentrations as well as toxicological, pharmacological and physicochemical data (Hilton et al., 2003). To date the occurrence of ECs has been much better characterised in wastewater and surface water compared to groundwater.

Regulatory context

Monitoring of anthropogenic micro-organic pollutants in river basins is required within the framework of various national regulations within the EU, with the overall aim of protecting and improving the quality of water resources. As part of achieving this, groundwater bodies have to be assessed as being at “good status”. In assessing status, threshold values (standards) have to be established for pollutants that put the groundwater body at risk of failing to achieve any of its environmental objectives. Whilst for many chemical pollutants there is sufficient information to establish threshold values, in the case of many ECs the paucity of knowledge on occurrence, toxicity, impact, and environmental behaviour mean that threshold values cannot yet be set. However, in the future, if ECs are found to lead to the risk of pollution of groundwater, and have the potential to compromise environmental objectives, then standards (threshold values) will be required. Overall, the number of compounds that are regulated, through drinking water standards and/or environmental quality standards, is likely to grow in the coming decades.

Major sources of ECs, and pathways to groundwater

Sources of ECs in the environment that may eventually impact groundwater can be divided into point-sources and diffuse sources of pollution. Diffuse sources originate from poorly defined sources that typically occur over broad geographical scales. Examples of diffuse source pollution include agricultural runoff from bio-solids and manure sources, storm-water and urban runoff, leakage from reticulated urban drainage systems and diffuse aerial deposition. Diffuse sources of pollution have higher potential for natural attenuation in the soil and subsurface and a lower environmental loading compared to point sources, but they can be poorly defined with less direct/obvious links back to the ‘polluter’. As such, it continues to be a real challenge to monitor, regulate and assess their impact on groundwater resources.

In contrast, point sources of ECs originate from discrete locations, whose spatial extent/plume of pollution is therefore usually more constrained. Important examples include waste disposal sites (landfill sites, industrial impoundments, farm waste lagoons), industrial effluents (e.g. manufacturing plants, hospitals, food processing plants), resource extraction (mining), municipal sewage treatment plants and combined sewage-storm-water overflows, and septic tanks. Most published studies have focussed on point source pollution because this usually results in higher EC loading to a particular environmental receptor (surface water or groundwater body or aquatic species) and is easier to detect. Engineered solutions to point source pollution are perhaps more straight-forward, are seen to deliver the greatest environmental benefit, and as such attract the greatest funding. There is a stronger historical legacy of regulatory control on point source pollution, and the connection between the pollution and the polluter is often easier to define.

Occurrence of ECs in groundwater

Loos et al. (2010) reported results from the first pan-European reconnaissance of 164 groundwater samples collected and analysed for persistent organic pollutants from 23 countries. The most frequently detected compounds included ECs such as DEET (insect repellent), caffeine, perfluorooctane sulfonate (surfactant formerly used in coatings and fire-fighting foam) as well as carbamazepine (mood stabilising drug) and metabolites of the commonly detected pesticide atrazine.

A recent review of world-wide EC occurrence in groundwater by Lapworth et al. (2012) demonstrated that nanogram-microgram per litre concentrations are present in groundwater for a large range of ECs, as well as metabolites and transformation products. Under certain conditions this pollution may pose a threat to freshwater bodies for decades due to relatively long groundwater residence times, low potential for microbial breakdown and prevailing redox conditions. Overall, >180 different ECs have been detected in groundwater. Figure 1 summarises maximum EC concentrations found in groundwater (world-wide) for major groups of compounds: steroids and hormones; sweeteners and preservatives; 'life-style' compounds – e.g. caffeine; industrial compounds; personal care products (PCPs) and veterinary medicines. Table 1 summarises the occurrence of ECs in groundwater from regional and national reconnaissance studies.

Stuart et al. (2012) recently reviewed the types of ECs found in UK groundwater. Results from the Environment Agency for England and Wales showed 260 different organic pollutants were detected at more than 10 locations. There were frequent detections of the following ECs: caffeine (27%); DEET (10.6%), bisphenol A (plastics manufacture, 7.9%); carbamazepine (1.2%); triclosan (antibacterial agent, 0.8%). As an example, Figure 2 shows the widespread occurrence of caffeine in groundwater across England and Wales.

Antiobiotics and other pharmaceuticals and health care products are typical of emerging contaminants (*www.freeimages.co.uk*)

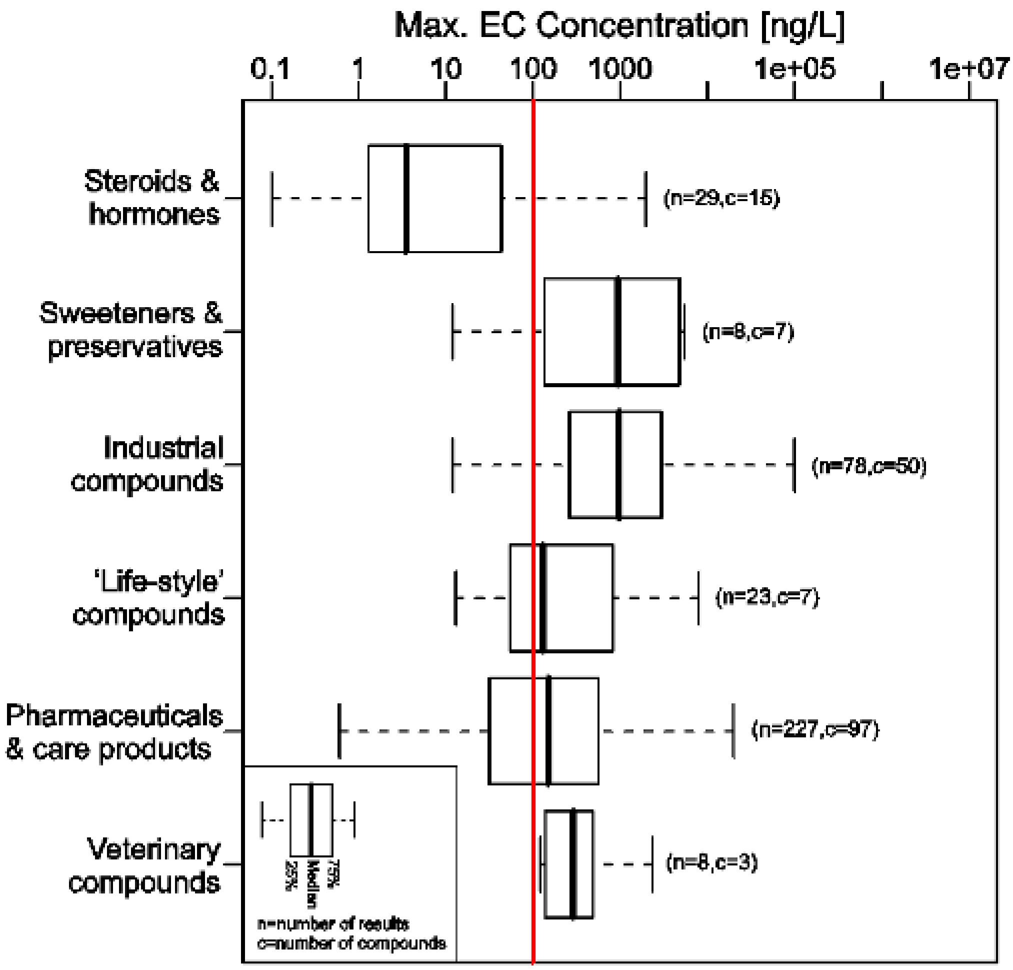
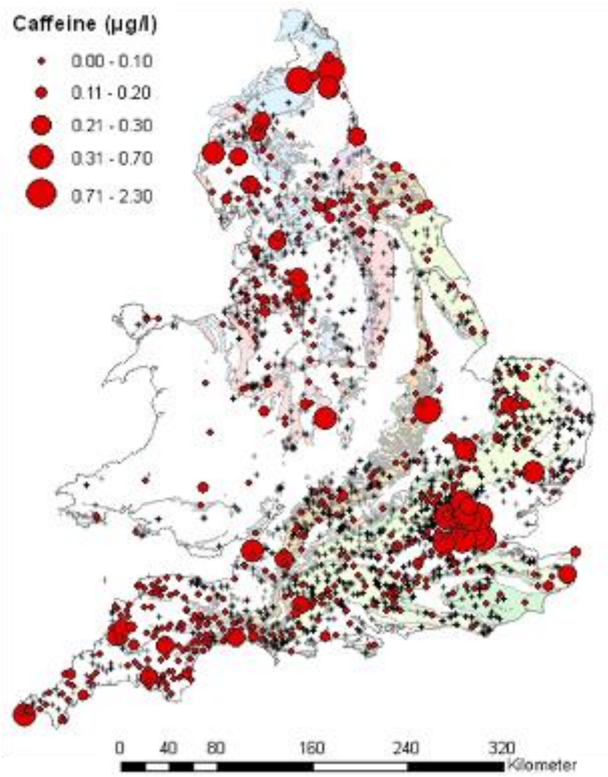


Figure 1. Box-plot of maximum EC concentration in groundwater (world-wide) for major groups of compounds. The red line shows the EU maximum acceptable concentration (100 ng/L) for individual pesticides in drinking water for comparison. Source: Lapworth et al. (2012)

Table 1. Occurrence of ECs in groundwater from selected published reconnaissance studies

Country	Study (sites, compounds*)	Maximum concentration (ng/L) /frequency (%)	Reference
England & Wales	Nation-wide survey (2644, >800)	DEET (6.5^3 ng/L, 10.6%), bisphenol A (9.3^3 ng/L, 7.9%), carbamazepine (3.6^3 ng/L, 1.2%), triclosan (2.1^3 ng/L, 0.8%), caffeine (4.5^3 ng/L, 27%), nicotine (8^3 ng/L, 4%), ibuprofen (290 ng/L, 0.3%).	Stuart et al. (2011)
France	Rhône-Alpes (70,51)	Salicylic acid, carbamazepine, and testosterone (100%), paracetamol and androstenedione >90%, diclofenac and sulfamethoxazole > 60%	Vulliet and Cren-Olivé (2011)
Germany	Baden-Württemberg (105,60)	β-blockers, analgesics, carbamazepine, diclofenac, antibiotics iopamidole (>10 ng/L)	Sacher et al. (2001)
USA	Nation-wide survey (47,65)	DEET (35%), bisphenol A (30%,), tri(2-chloroethyl) phosphate (30%), sulfamethoxazole (23%) 4-octylphenol monoethoxylate (19%)	Barnes et al. (2008)

*Number of compounds screened for in samples



` in groundwater across England and Wales. Source: Stuart et al. (2011)

Future challenges

A large variety of ECs are detected in groundwater at potentially environmentally significant concentrations as a result of both recent and historical activities. However, compared to other freshwater resources the occurrence of ECs in groundwater is poorly characterised. Recent studies have shown that important groups of ECs include a range of pharmaceuticals and personal care products, industrial and life-style compounds. Presently, very little is known about the occurrence and fate of anthropogenic nano-materials in groundwater, but this newly emerging group of contaminants will warrant further research in the future. To date, many national and regional studies have been biased towards potentially contaminated sites so the actual frequency and distribution in groundwater remains largely unknown. More systematic regional-scale studies are needed to assess the spatial and temporal occurrence of ECs in groundwater. In the coming decades, a growing number of ECs are likely to have drinking water standards, environmental quality standards and/or groundwater threshold values defined, and so a better understanding of the spatial and temporal variation remains a priority.

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Manufactured nanoparticles: assessing the mobility of a future class of contaminant

Nanotechnology holds huge potential for advances in a wide range of applications, yet we know little about the impacts of these tiny particles on the environment. New research is looking at their mobility

Nanotechnology

Nanotechnology is concerned with developing ways to exploit the novel properties of materials when they are reduced to the nanoscale, i.e. to within the range of 1–100 nm. 1 nm is ten thousand times smaller than the width of an average human hair. At this scale, materials display very different properties to those they display at larger scales, for example, vastly increased strength, reactivity or conductivity. Such properties potentially have very significant practical applications, and are of great interest to industry. Many types of manufactured nanoparticles are currently being produced, and the volume and diversity of these is set to expand rapidly. In addition to these purposely-manufactured nanoparticles, two other main classes of nanoparticle exist: natural nanoparticles; and incidental nanoparticles, that are produced inadvertently by manufacturing and other human activities.

Use of nanoparticles

Nanoparticles are already manufactured for use in many products, including cosmetics and sunscreens, textiles, surface coatings, medical products and many developments in electronics and information technology. A number of widely available products, including anti-bacterial socks and sportswear, will be familiar items from the high street (Figure 1).

The manufactured nanoparticles currently being produced are of many compositions and morphologies, including those based on carbon (e.g. carbon nanotubes and nanowires) and those based on metal compounds (e.g. oxides of zinc, silver, and titanium, often approximately spherical in shape). Some nanoparticles have multiple compositions, being coated with a compound different to that of the core particle. Where particles are in suspended form, it is normal to use a stabilizing

Figure 1. Examples of consumer products containing nanoparticles. The developers use the unique properties of nanosize particles to enhance the performance of the product, for example strong and light nanotitanium in tennis rackets or anti-bacterial nanosilver in sportswear and socks.

compound to avoid aggregation and sedimentation.

Given the huge range of possible types of nanoparticle, each with its own set of properties, the potential for future development is seemingly endless, with expectations that nanomaterials will provide cost effective solutions for issues in almost every aspect of human life. Examples of this range from developing drugs which can target particular organs to the use of nano-iron for fast and precise in situ treatment of groundwater pollutants (e.g. chlorinated solvents and organochlorine pesticides)(Zhang, 2003).

Concerns

The flipside to these exciting possibilities is that the unusual properties of manufactured nanoparticles could cause them to be a health risk to humans and the environment in general. The size and surface characteristics of nanoparticles are such that they could potentially be mobile within organisms and interact with their biological systems. For example, studies have reported impacts, even in some cases at ppm concentrations, through the production of reactive oxygen species and oxidative stress, protein denaturation, and interference with phagocytic (‘cell engulfing’) function leading to reduction in efficiency of infectious agent removal. Although much research is being undertaken to determine the risk posed by manufactured nanoparticles to biological processes, this is a vast field that is only in its infancy.

Whilst research into the toxicity of nanoparticles continues, environmental transport and fate must also be considered: we must not be taken unawares as we were when chlorinated solvents were first introduced. In the environment, nanoparticles potentially may be mobile, depending on particle surface speciation and the dispersal medium. This means they could have the potential to reach groundwater sources and become a threat to potable water and to indigenous bacterial populations, the latter being important to natural remediation of contaminated land.

The main routes to groundwater are currently suggested to be direct from point sources (Table 1), which include application of agrochemicals

Table 1. Examples of mechanisms which introduce manufactured nanoparticles into the environment [edited from Gottschalk and Nowack (2011)]

Source and release characteristics		**Examples**	**Environmental compartment**
Indirect release	Point sources	Nano-paints (run-off collected in sewer system) Application of sunscreen containing TiO_2 Engineered nanomaterial (ENM) as food additive Medical use	Water, soil (if biosolids with ENM removed during water treatment are applied on land)
		CeO_2 in fuels Dismantling of batteries Recycling of plastic/glass/metal with nano-coating	Air, soil
		End-of-life treatment (incineration) of nanotextiles, nanocomposites	Air
Direct release		Groundwater remediation	Groundwater
		Application of agrochemicals	Soil, air
		Use for water treatment	Water
		Leaching/draining from landfills	Groundwater, soil
	Diffuse sources (release from products)	Wear during use, e.g. from tires, textiles, etc.	Air, soil, water
		nano-TiO_2 wash off from sunscreen (in lakes, etc.)	Water
		Weathering, e.g. of outside paints	Soil, water
		Use of CeO_2 in fuels	Air, soil
		Spreading of biosolids onto land	Soil

and leaching from landfill sites. Other potential routes are accidental spills during manufacture, storage and transport of nanoparticles, and low volume exchange from surface water and soil moisture to groundwater.

Research into the mobility of manufactured nanoparticles in groundwater is essential in order to assess how important this pathway could be between nanoparticle sources and potentially vulnerable receptors. Their mobility will also serve to measure the importance of nanoparticle-facilitated transport of contaminants considered to be otherwise immobile.

Current research into nanoparticle mobility in groundwater

Research into the transport of nanoparticles in groundwater generally consists of lab experiments where uniform particles in electrolyte solutions are passed through columns of artificial porous material: such studies are aimed at isolating the main transport processes. The porous media used in such experimentation range from glass beads to aquifer material, the latter often being disaggregated, cleaned then packed into the column thus destroying their natural fabrics. Particle concentrations in the effluent and retained in the column material are measured (during and after the experiment respectively) and these data analysed to probe particle behaviour within the column.

Types of particle behaviour identified within porous media columns include:

- Free particles transported through the pore space without interaction;
- Particles interacting with each other (aggregation);
- Particles/aggregates attaching to the porous media surfaces;
- Particles/aggregates physically strained / filtered.

Changes in the physical and chemical state of the system, including changes in flow rate, ionic strength, pH, particle size and the heterogeneity of the properties of the particles and the stationary porous media, have been observed to affect transport behaviour. Particle aggregation and attachment to the porous media have also both been found to be reversible following slight alterations to the chemical equilibrium (e.g. Petosa et al., 2010). Attached particles can enhance the removal of suspended particles by the medium if the particles are attracted to one another ('filter ripening' of the medium), or, where the forces between the particles are repulsive, can reduce the efficiency of removal of particles attenuated by 'blocking' the surface of the column material. Particle transport models have been developed using the observations made during these column studies.

Research using intact rock columns

Little work has been undertaken using intact rock, so these modelling attempts are untested in conditions closer to those in the environment: most regulatory authorities are wary of allowing field experimentation in the absence of well-defined toxicity data. Rock columns may produce significantly different results for nanoparticle mobility, due to the increased heterogeneity of these systems and the presence of natural rather than artificially-generated surfaces. In contrast to homogeneous glass bead columns, aquifer rocks contain grains which are much more varied in shape, size, angularity, surface roughness and provenance.

Some preliminary work has been undertaken at Birmingham University on the movement of a range of manufactured nanoparticles through intact sandstone columns. Nanoparticle compositions investigated include silica, titanium dioxide, and antimony pentoxide. In general the same sorts of processes identified in the artificial column experiments have been observed, including ripening and blocking (Figure 2).

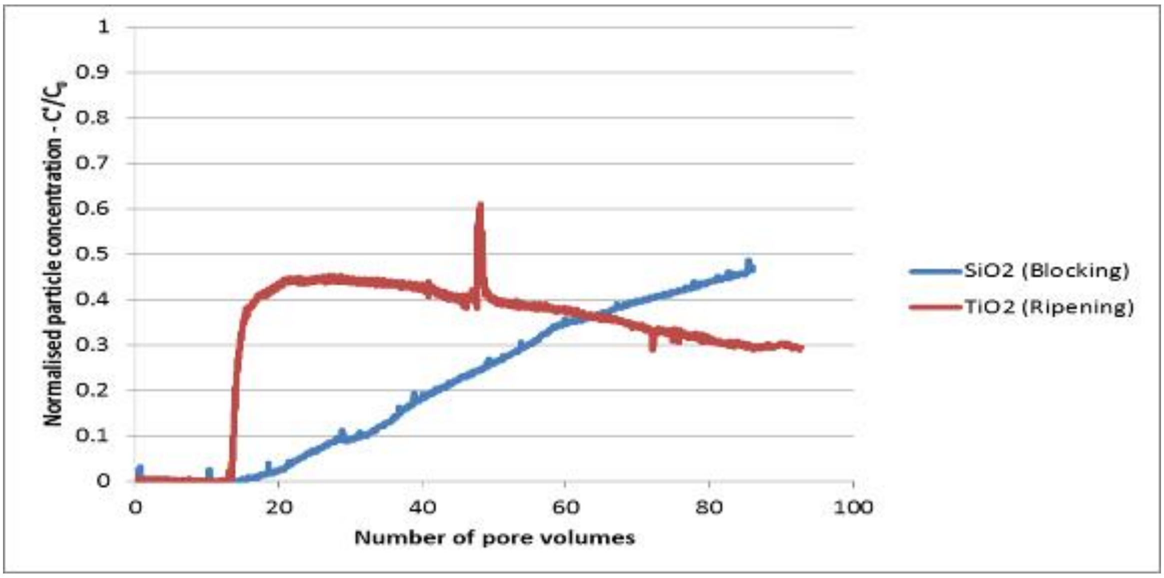

Figure 2. Breakthrough curves for SiO_2 and TiO_2 which demonstrate observations of blocking and filter ripening respectively

For example, in the case of 100 nm diameter silica nanoparticles, attenuation rapidly increases with ionic strength and at ionic strengths comparable with fresh groundwater there is almost complete attenuation: however, with extended injection, blocking appears to occur and breakthrough concentrations gradually rise. A significant proportion of SiO_2 particles can be released by change in ionic strength in some cases indicating that some of the removal is reversible. In the case of TiO_2 particles in low ionic strength suspensions, initial breakthrough concentrations are high, but subsequently ripening occurs, and breakthrough concentrations fall.

In addition to the intact sandstone column studies, in collaboration with Malvern Instruments, we have been investigating the heterogeneity of electrical potential on the rock surfaces: the results are showing that the surface electrical properties of the sandstones are essentially uniform thus indicating heterogeneity may not be an issue for the red-bed lithologies examined, a finding which, if substantiated, will ease some of the potential problems with quantification of the processes.

Work continues with the ultimate aim of quantitative prediction of nanoparticle mobility. At some stage, field testing will be necessary. This is particularly the case if we are to evaluate the mobility of nanoparticles in fracture flow systems: clearly in such systems, and especially in karstic systems, nanoparticles might be expected to be considerably more mobile than in intergranular systems.

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Review of groundwater levels in the south east highlights importance of groundwater level monitoring for the future

Analysis of some of the national groundwater level monitoring network data provides some interesting insights into aquifer properties. The data are now publically available in a database

Groundwater level monitoring, and the subsequent evaluation and interpretation of records, provides fundamental information on the nature of aquifers and the groundwater regime. Consistent monitoring over time allows hydrogeological trends to be identified and their implications assessed.

Groundwater level data have been collected in Ireland since the late 1960s. Typically, monitoring was conducted during the course of different projects implemented by the Geological Survey of Ireland (GSI) or local authorities. In the 1990s, the Environmental Protection Agency (EPA) took responsibility for groundwater monitoring in Ireland and set up a new national monitoring network for groundwater quality and levels. In recent years, and particularly in response to the implementation of the European Water Framework directive, the groundwater monitoring network in Ireland has been updated and expanded considerably.

As part of an EPA-funded STRIVE research fellowship, a review of groundwater levels was conducted. During this review groundwater level data and monitoring point (MP) information for historic MPs nationally have been collated into a publicly available database. Hydrographs with suitably long records in the south east have been analysed.

The geology of the south east is heterogeneous, comprising bedrock strata of principally Lower Palaeozoic, Devonian and Carboniferous age, with extensive and spatially variable overlying subsoil deposits. In general, groundwater flow in the bedrock is through secondary porosity and is dominated by fracture flow. The groundwater flow paths are likely to be shallow, predominantly in the upper layer of the aquifer, where there are enhanced weathering and open fractures. However, the karstified and dolomitised limestones may have permeable zones at greater depths. In contrast to the bedrock aquifers, sand and gravel aquifers provide an opportunity for intergranular groundwater flow.

Hydrograph analysis shows that the hydrogeological setting of a monitoring point (with respect to, for example, recharge area, discharge area or proximity to a river) is the dominant factor influencing hydrograph character in bedrock aquifers, with aquifer type and subsoil properties producing secondary effects. Further hydrograph analysis, in relation to effective rainfall and local hydrogeological setting, allowed a number of insights to be made such as: identifying examples of surface water control of groundwater and rejected recharge and examining the response of groundwater in the study area to global seismic events. Analysis of seasonal groundwater levels highlighted the

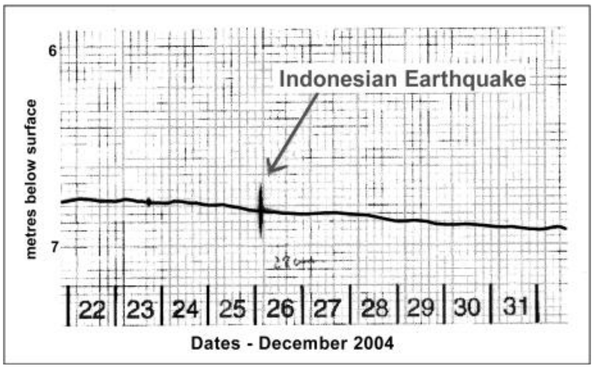

Chart recorder data from Knocktopher Manor showing groundwater level response to the 2004 tsunami

Updating groundwater level monitoring systems (a) GSI chart recording groundwater levels and (b) downloading groundwater level data from a data logger at an EPA monitoring point

differences in recession periods between aquifer types and over time, as well as allowing the calculation of aquifer parameters such as specific yield. Analysis of long term groundwater level trends has the potential to show the influence of long term factors such as climate or land use changes.

In the future, given the updated and expanded groundwater monitoring network, it should be possible to undertake further, more detailed analysis of groundwater behaviour from well hydrographs, including the application of statistical techniques to look for evidence of the impacts of climate change on groundwater resources. In the meantime, this work has shown the benefits of groundwater monitoring and the interpretation of currently available data.

Further information in:

Tedd, K., Misstear, B., Coxon, C., Daly, D., Hunter Williams, N.H., Craig, M. & Mannix, M. 2011. *Review of groundwater level data in the South Eastern River Basin District*. EPA STRIVE Programme 2007–2013. EPA, Dublin. Available from www.epa.ie

Katie Tedd
Trinity College Dublin

An extract spotted by Eugene Daly in the Churchill Museum and Cabinet War Rooms, in London

Allied Armistice Terms, 11 November 1918

1. Military Clauses on Western Front

Eight - The German command shall be responsible for revealing within the period of forty-eight hours after the signing of the armistice all mines or delayed action fuses on territory evacuated by the German troops and shall assist in their discovery and destruction. It also shall reveal all destructive measures that may have been taken (such as poisoning or polluting of springs and wells, etc.). All under penalty of reprisals.

An early reference to potential groundwater contamination!

Environmental Supporting Conditions for Groundwater Dependent Terrestrial Ecosystems

An EPA Strive funded research project has developed conceptual ecohydrological models for 11 types of GWDTEs in Ireland

Project Background

The EU Water Framework Directive (WFD) promotes the combined management of surface waters and groundwaters and requires the protection of groundwater for its environmental value, in addition to its protection as an important resource (Daly, 2009). This progressive piece of EU legislation requires Member States to ensure that all groundwater bodies (GWB) maintain good groundwater quantity and quality. To achieve this, the status of each GWB must be classified as either 'good' or 'poor'. A series of chemical and quantitative status tests must be applied to GWBs at risk from anthropogenic pressures. Assessments of GWB-mediated significant damage to Groundwater Dependent Terrestrial Ecosystems (GWDTEs) are an essential component of these status tests. GWDTEs are habitats that occur where the water table is at or near the surface of the ground and they directly depend on groundwater for a significant proportion of their water supply. Work to date has identified major information deficiencies in relation to assessing significant damage to GWDTEs and consequently the status tests have only been applied to a few sites. This project was commissioned by the Environmental Protection Agency of Ireland to inform the development of appropriate status tests relevant to GWDTEs and to highlight knowledge gaps.

Project Deliverables

- Review of relevant EU and national legislation, GWDTE research activities and applicability of currently available spatial datasets.
- Conceptual models of GWDTE hydro-ecology to illustrate the nature of groundwater connections, anthropogenic pressures and to identify potential indicators of ecological quality.
- Proposed trigger and threshold values based on conceptual hydro-ecological models of selected GWDTEs.
- Assessment of major threats to GWDTEs.
- Inventory of key knowledge gaps relating to GWDTE status assessments

GWDTE Types under investigation

GWDTEs designated as Annex I habitats under the EU Habitats Directive have been the main priority of work on GWDTEs to date. Article 6 of the WFD required Member States to create a register of Protected Areas by 2004 to include all surface water, groundwater and GWDTEs designated for conservation under other EU legislation. A programme of measures aiming to achieve good groundwater status, including the prevention of significant damage to GWDTEs, will assist in the achievement of favourable conservation status under the Habitats Directive. GWDTE types under investigation by the project are presented in Table 1 an summarised below.

Alkaline fens are typified by peat-forming small sedge communities or tufa-producing brown moss communities on consistently water logged soils (European Commission, 2007). The water supply is base rich and often calcareous.

Cladium fen is characterised by dense stands of *Cladium mariscus (Saw Sedge)*, often in occurrence with *Caricion davalliana* or other *Phragmition* species. This fen type often occurs in association with alkaline fen, but also with acid fens, wet meadows and other reed bed and tall sedge communities.

Transition mires are transitional between acid bog and alkaline fen, in which surface conditions can range from markedly acid to base rich

Table 1 GWDTE types for which chemical and quantitative status tests are being developed. *indicates a priority habitat for conservation under the EU Habitats Directive owing to a distribution largely restricted to the EU.

EU Habitats Directive Annex 1 Habitat Type	NATURA 2000 Site Code
Alkaline fen	7230
Calcareous fen with *Cladium mariscus* and *Carex davalliana**	7210
Transition mire (quaking bogs)	7140
Petrifying springs with tufa formation (*Cratoneurion*)*	7220
Northern Atlantic wet heaths with *Erica tetralix*	4010
Turloughs*	3180
Active Raised bog*	7110
Machair (* in Ireland)	21A0
Residual alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior**	91E0

(European Commission, 2007). The instability of the habitat gives rise to the term 'quaking bog'.

Petrifying springs are hard water springs with active formation of tufa. They are generally point or linear features, and are typically dominated by bryophytes (European Commission, 2007), but as water disperses below the spring head, species-rich flushes can occur with higher plants.

Wet heath occurs on areas of relatively shallow peat (30–80 cm depth), where there is a fluctuating watertable rather than permanently waterlogged peats (Fossitt, 2000). Wet heath often forms mosaics with blanket bog and dry heath and is characterised by abundant *Calluna vulgaris, Erica tetralix, Molinia caerulea* and *Sphagnum* mosses.

Turloughs are depressions in karst that flood intermittently with groundwater and lack a surface outflow. The hydrological regime is dynamic and varies markedly across sites. Turloughs differ from other GWDTEs in that they have distinct aquatic and terrestrial phases.

Active raised bogs are often circled by a wetland fringe, known as the lagg zone, which is usually characterised by fen communities

Alkaline Fen (*S. Kimberley*)

Transition Mire (*V. Rossekova*)

Petrifying Spring (*M. Lyons*)

Turlough (*S. Kimberley*)

Alluvial Woodland (*K. McNutt, Courtesy of NPWS*)

(Fossitt 2000). The lagg zone depends strongly on groundwater and can be significantly impacted by surrounding hydrological conditions (Kilroy et al., 2009).

Machairs are coastal semi-natural grassy plains, restricted to western Ireland and Scotland, formed of calcareous sands. Sands are gradually eroded down to the water table and shifting wet and dry patches characterise the habitat (Fossitt, 2000).

Alluvial woodland is mainly dependent on surface water although groundwater can also be a significant secondary water source. The project is concerned with the type associated with springs/seepages that flow throughout all/most of the year.

Progress

Conceptual ecohydrogeological models were developed for 11 GWDTE types in Ireland. The purpose of the models is to provide a user-friendly summary of the key hydrogeological characteristics of each type and potential ecological responses to chemical and quantitative pressures. The UK methodology for determining groundwater nutrient threshold values was applied to calcareous fens in Ireland with limited success owing to data limitations. We could however compare nitrate and phosphate groundwater concentrations among calcareous fens in good ecological condition with UK fens in good and poor condition. The end-of-project workshop on May 30th will discuss project findings among interested parties.

Sarah Kimberley and Catherine Coxon
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A review of the EPA Hydrometric programme

Hydrometric work has been undertaken by the EPA and its predecessors – An Foras Forbartha and the Environmental Research Unit – since 1972. The main focus has been on providing relevant low and medium hydrometric data and statistics; OPW, the other main national hydrometric body, are responsible for measuring and analysing flood levels and flows. In addition, the EPA is the lead national body in collecting and analysing groundwater level data. The EPA hydrometric programme is run jointly with the local authorities. In early 2011, the hydrometric network consisted of:

- 262 river and lake stations with electronic recorders;
- 163 staff gauge only stations;
- 134 electronic recorders on wells and springs.

As part of its policy of reviewing its work programmes, particularly in the context of declining staff resources, the EPA decided to undertake a review of the hydrometric programme. The review was undertaken by a group consisting of EPA and OPW staff (Vincent Hussey and Peter Newport) and two external members – Niall Sweeney, the former Offaly County Council County Manager, who chaired the group, and Noel O'Keefe, Cork County Engineer and representative of the County and City Managers Association.

Taking a flow measurement

The report outlines the many uses that high-quality hydrometric data support, including water resource management, public safety and economic development. An objective scoring procedure for assessing these uses, and the quality of the data at all hydrometric stations in the EPA and OPW networks, was developed to rank the 425 EPA/LA (including 163 staff gauge only stations) and 379 OPW hydrometric stations. Based on the results from this process it was found that 98 EPA/LA stations (including 86 staff gauge only stations) had a score of zero indicating that there was no longer a requirement for these stations or that the quality of the data was inadequate. It was recommended that these stations be dropped from the hydrometric programme. The scores conferred on the remaining stations and the scoring procedure will be used in the future prioritisation of the programme, particularly when requests for new hydrometric stations are being considered.

The Report contains 10 recommendations and an action plan for the future EPA hydrometric programme.

The final report can be downloaded from the EPA website at the following link:

http://www.epa.ie/downloads/pubs/water/flows/name,31899,en.html

Rebecca Quinn
Hydrometric and Groundwater Section
EPA

Mícheál MacCárthaigh
1953 to 2012

Micheál MacCárthaigh, who died on 16 April 2012, was a serving senior staff member of the Environmental Protection Agency (EPA). He was an authority on the national hydrometric network – the network of gauging stations used for the measurement of river flows, and for the measurement of water levels in rivers, lakes and groundwaters – vital for the understanding, protection and sustainable use of Ireland's water resources. He also had a strong and active commitment to the Irish language and a keen interest in Irish culture and history, especially old historical maps.

He was born in Waterford in 1953 and educated at De La Salle, Newtown, Waterford. An excellent student, he was the recipient of scholarships, including in 1969 the Earl of Cork scholarship. He graduated as a civil engineer from UCD in 1975 and took up employment in the Office of Public Works (OPW), where his work included a survey of the Boyle River catchment.

In 1978 he left OPW to join An Foras Forbartha (AFF) – the National Institute for Physical Planning and Construction Research – where he took up an appointment in the Water Resources Division. When AFF was abolished in 1987, the functions of the Water Resources Division were transferred to, and he was appointed to, the Environmental Research Unit (ERU) within the Department of the Environment. The ERU lasted until the establishment of the EPA in 1993, and along with the rest of its environmental staff, he was transferred into the new agency.

From the time that he joined AFF, and through the various organisational changes, his primary area of work was the hydrometric programme, to which he developed a strong commitment, with a detailed knowledge of the precise purpose and value of each of the several hundred individual gauging stations. The careful processing of the data from this network, to yield high quality reliable information, was something he recognised as being of prime importance, and his commitment to this task was always clearly evident. He represented Ireland at international meetings on water, and produced papers giving overviews of the national water resources. He took pride in providing reliable hydrometric data to those who needed it, such as local authorities, state bodies and consultants - whether it was for the purpose of planning for future water supplies, designing bridges, or guiding the protection of the aquatic environment.

Established before the digital age, the hydrometric network was transformed under his guidance into a modern network, including extensive telemetry. With other partners, his was instrumental in developing an advanced system for deriving flow statistics at ungauged sites on rivers.

He was active in Engineers Ireland – the Institution of Engineers of Ireland, of which he was a Chartered Member. His involvement included serving as Chairman of both the Water and Environmental Section and the Civil Division of the Institution. He was deeply involved in supporting the general field of hydrology in Ireland and was a serving member of the national committee for the UNESCO International Hydrological Programme. He also pursued further education, and in 1996 was conferred with a Master's degree in Engineering Science for his thesis on Groundwater Resources in Ireland.

He was very cognisant of people's rights and entitlements. Besides serving for an extended period in EPA as Honorary Secretary of the SIPTU union committee, he readily shared his knowledge of the pension, tax and social welfare codes with all. Many people have good reason to be grateful to him for this.

He was generous too in sharing his knowledge of old Irish maps, and supplied copies to those with an interest in them. The cause of the Irish language was dear to his heart. It was particularly apt then that in 2011 he presented a paper 'Suirbhé Sir William Petty ar Éire: The Down Survey (circa 1654)' to An Roth of Engineer's Ireland. He worked tirelessly in his own modest way to promote the language. For example, the availability of Irish on the Bank of Ireland ATMs is due, in no small measure, to his persistence in taking up this issue with the Bank.

Whenever he took up an issue, in whatever sphere, he pursued it to the end with great attention to detail, and yet always remained a thorough gentleman in his dealings with people. Despite the difficulties and discomfort posed by ill health over the years, he remained positive in his outlook and courteous and friendly to all. Meeting him was always a true pleasure, and he always had some nugget of useful practical information, or quirky joke, to share. He had a great interest in music and played the classical guitar.

He had been at work just a few days before the sudden illness which led to his death, peacefully, in St James's Hospital surrounded by family and friends. He is survived by his wife Sorcha.

Larry Stapleton
Former Director
Environmental Protection Agency

It was with great sadness that we learned of Mícheál MacCárthaigh's untimely passing in April. Besides the EPA, Mícheál made a huge contribution to a number of other organisations, including the Geological Survey of Ireland, which was noted and reflected on in a recent GSI quarterly staff meeting.

Specifically, Mícheál made a significant, positive input on GSI's Consultative Committee, frequently offering support and sound advice. He also worked alongside GSI Groundwater staff on hydrological and hydrogeological aspects of the Water Framework Directive and in other areas, such as on the International Hydrological Programme Committee.

In his contributions, Mícheál held his ideas firmly, but always offered them gracefully and with his customary good sense of humour. Moreover, Micheál will be remembered by GSI staff for his incredible, encyclopaedic memory, which often yielded nuggets of useful, and sometimes curious, information.

We remember Mícheál fondly and with gratitude for his assistance to the GSI, and to the wider technical communities. We extend our sincere condolences to his colleagues at the EPA and most particularly to his family. He will be greatly missed.

Koen Verbruggen, Taly Hunter-Williams and
Monica Lee
Geological Survey of Ireland

The awareness of groundwater quality issues amongst private well users in Ireland

Research shows that the majority of private well users are aware of likely contaminants but don't treat or maintain their water supplies and have a low level of awareness about grout seals

Introduction

Groundwater resources currently supply water to approximately 26% of the Irish population, with 17% of the population, in excess of 720,000 people, using private groundwater supplies from two main source types: small private supplies (SPS) — private, unregulated groundwater supplies typically serving individual households — and private group water schemes (PrGWS), which are committee or shareholder run schemes serving fewer than 50 people, or supplying <10 m^3/day (www.cso.ie). Many of these supplies are at risk from microbial and chemical contaminants from a variety of point and non-point sources, including agriculture and septic tanks, of which there are up to 450,000 in Ireland. In addition to numerous potential contamination sources, many of the private wells are poorly located, designed, constructed and/or maintained. Furthermore, often little or no treatment is employed, resulting in increased susceptibility to contamination, and potentially, increased human health risk, particularly from waterborne enteric pathogens. Currently, there is no legislation in place addressing the design, construction and maintenance of private groundwater supplies. It is therefore important for well owners to be aware of these issues so as to minimise any potential health risks. In the case of rural groundwater supplies in Ireland, the level of awareness is assumed to be low. However, no investigation of this awareness has been carried out previously.

The following article presents findings from 227 awareness surveys, carried out with private groundwater users in Ireland, over five study areas in counties Kilkenny, Meath, Offaly, Westmeath and Wicklow. Slightly over half of respondents were male (56%), with approximately 75% of surveys completed with borehole users/owners, and the remaining 25% completed with users of shallow hand-dug or spring wells. The full results of the study are presented in Hynds (2012).

Results

As regular well maintenance, adequate treatment and regular water quality analyses may be considered to be three primary modes of protection against consumption of contaminated groundwater, consumers' levels of awareness and attitudes and behaviour towards these were investigated. A high level of awareness was found with regard to knowledge of previous water quality analysis, with only 6% of respondents exhibiting a lack of awareness of whether or not their well had been tested. However, approximately 37% of respondents' sources had never been tested for chemical or microbial quality, with a figure of 54% amongst hand-dug well users. Furthermore, a significant proportion of hand-dug well users (55%) indicated that they would not be prepared to pay for water quality analysis of their source. A high level of awareness was exhibited by respondents regarding the presence of water

Historical hand pump, Co. Offaly

treatment systems, with <1% of respondents unaware of the presence or absence or treatment; however, almost 63% of respondents stated that no treatment system was currently being used. These figures were 89% and 55% for hand-dug well and borehole users, respectively. Where treatment was found to be in place, approximately 58% of the systems were ion-exchange (water softener) units; therefore, no effective pathogen attenuation was likely. Just over 18% of consumers were unaware whether any previous maintenance or rehabilitation work had been carried out at their source, with a mean well age of just over 24 years. Of those respondents who were aware of whether or not any previous maintenance had been undertaken, just under 57% stated that no previous maintenance had occurred, with a figure of 75% for borehole users. Further analysis found that over 27% of private groundwater supplies had none of the three protective measures (well maintenance, treatment system or periodic water analysis) present. Only 6.2% of respondents stated that all three barriers were in place.

Respondents were asked a number of questions regarding their well design and construction details and the involvement of groundwater professionals during the well design/ construction phase. A composite "source awareness score" was then used to quantify overall awareness. An overall mean of 79% (7.9/10) suggests a generally high overall level of source awareness among respondents. However, some variation was evident between hand-dug well and borehole users, with means of 87% and 78%, respectively, indicating a marginally higher source awareness among hand-dug well users.

Perhaps of particular interest to the readers of this Groundwater Newsletter, it was found that while water diviners were involved in the location of almost 69% of private wells (74% and 66% of hand-dug wells and boreholes, respectively), only 16.5% (6.4% and 21% of hand-dug wells and boreholes, respectively) of respondents indicated any Local Authority involvement, while as few as 1.3% acknowledged the involvement of a professional hydrogeologist during the well design/ construction phase.

Previous studies have shown that "local" pathways can be important routes for contaminant ingress into a well (involving rapid bypass mechanisms whereby contaminants enter the water supply as a result of poor well design and/or construction) than aquifer pathways. There was found to be an overall higher level of awareness of well design/ construction details among hand-dug well users than borehole users ($p = 0.002$) (Table 1).

The low level of awareness exhibited in relation to the use of waterproof grout seals is a cause for concern, as the annular space between the lining and the drilled/dug hole is likely to be a significant pathway for pollutants to enter the well, resulting in localised contaminant pathways.

Table 1. Level of awareness of design and construction details of private wells

	Total (% aware)	Borehole users (%)	Hand-dug well users (%)
Well diameter	48.9	44	64
Well depth	63.4	61	71
Average watertable depth	33.9	28	53
Use of liner/casing	61.2	60	68
Use of grout seal	22.5	17	39
Pump type	59	59	61

Further questioning centred around the respondents' awareness of potential groundwater contaminants, contaminant sources (in general and in relation to their own well), and the potential adverse health effects of contamination. Approximately 59% of respondents identified at least one potential hazard within 100 m (generalised inner protection zone) of their well. However, subsequent questioning revealed that approximately 73%, 88% and 82% were aware of the presence of slurry/fertiliser spreading, grazing animals and septic tanks, respectively, within the inner protection zone, suggesting that at least 14%, 29% and 23% respectively, did not recognise these activities as being "potential contamination sources".

Respondents exhibited a relatively high overall awareness of *E coli*, *Cryptosporidium* and nitrate as potential groundwater contaminants; however, a knowledge gap remains concerning other contaminants, particularly rotavirus and *Giardia* (Table 2), both highly infectious enteric pathogens. Further questioning found that 30% of respondents were not aware of any illnesses or symptoms associated with drinking from contaminated groundwater water supplies. Also, respondents with increased awareness of potential groundwater contaminants were found to be more likely aware of potential health hazards arising from consumption of contaminated groundwater ($p < 0.001$).

As with source awareness, a scoring methodology was developed for contaminant awareness and showed a mean composite contamination awareness of 71% (7.08/10) among respondents, with no significant difference between source types. Source awareness and contamination awareness were found to be highly correlated among borehole users (i.e. those that had a higher level of awareness of their water source typically also had a higher overall level of awareness of groundwater contamination and the potential effects); however, this association was not found to exist among hand-dug well users.

Finally, respondents were asked to rate their overall source satisfaction and, in general, a high level of satisfaction was found (Mean: 4.53/5) — although, interestingly, a negative correlation was found between source satisfaction and contamination awareness. In particular, those respondents exhibiting an awareness of potential adverse health effects of groundwater contamination were generally less satisfied with their source ($p = 0.001$).

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The authors gratefully acknowledge the financial support provided by the EPA STRIVE initiative.

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Table 2. Level of awareness of potential groundwater contaminants

	Total (% aware)	Hand-dug well users (%)	Borehole users (%)
Faecal coliforms	95	95	95
Rotavirus	26	23	27
Cryptosporidium	74	70	75
Giardia	4	0	5
Manganese	33	25	34
Lime (hardness)	96	96	96
Nitrate	78	70	81

Tellus Border Project: Regional airborne geophysics and geochemistry surveys for management of surface and groundwaters

New data delivered by the Tellus Border project will provide information to help map illegal landfill contaminant plumes, geothermal hotspots, geochemical groundwater contaminants and depth to rock

The Tellus Border project is a European Union INTERREG IVA funded mapping project that will collect scientific data on soils, waters and rocks across the six border counties of Ireland (Donegal, Sligo, Leitrim, Cavan, Monaghan and Louth) and integrate these with existing data collected in Northern Ireland as part of the Tellus project in 2007. The project is led by the Geological Survey of Northern Ireland, in conjunction with project partners the Geological Survey of Ireland, the Queen's University Belfast and Dundalk Institute of Technology. Mapping will be completed through two operations which began in July and September 2011 respectively – a ground-based geochemical survey sampling soil, stream water and stream sediments and an airborne geophysical survey. These surveys will provide regional and catchment-scale data which will inform environmental management and support sustainable development of our natural resources, including groundwater and geothermal resources.

The Tellus Border project was conceived as a follow up to the award-winning Tellus surveys in Northern Ireland which occurred in 2004-2007 and 2007-2010. The Tellus surveys developed a number of innovative techniques to assist the assessment of groundwater, which are now being developed further and extended into the border region of Ireland. The airborne geophysical survey operates three instruments – an electromagnetic (EM) coil system, a magnetometer and gamma ray detector – while flying at a low altitude of 60m. The EM instrumentation is an active system which sends an electromagnetic signal into the shallow subsurface. The technique proved effective in many instances within Northern Ireland in identifying localised changes in groundwater conductivity associated with landfill and industrial sites (Figure 1). A complimentary postdoctoral research project at Queen's University Belfast will develop the technique further and apply it to the border region, where illegal landfills have historically presented a problem for local authorities. The technique has the potential to be an effective tool in the assessment and management of landfill pollution plumes, supplementing traditional intrusive investigation techniques.

The magnetometer is a passive system which measures variations in the Earth's magnetic field, arising from the magnetic properties of different rocks. The technique allows a great level of detail in deep geological structures to be delineated. Figure 2 shows faulted basaltic dykes cutting across the regional geological terrain in the Fermanagh-Tyrone area, detected during the Tellus survey of Northern Ireland. These deep, impermeable features have significant potential to compartmentalise regional groundwater flow and their influence extending into the border region will shortly be revealed through the completion of the Tellus Border survey.

On the basis of the Tellus airborne radiometric surveys and Magneto Telluric (MT) survey data, areas of geothermal potential have been mapped, along with structures indicating deep conductive zones through which heat could be transported to the surface. This work, in conjunction with the IRETHERM project (www.iretherm.ie), has indicated that the Mourne Granites may be a good target for deep enhanced geothermal system or "hot dry rock" energy exploration. Work continues within the Tellus Border and IRETHERM projects using available geophysical data to assess the potential

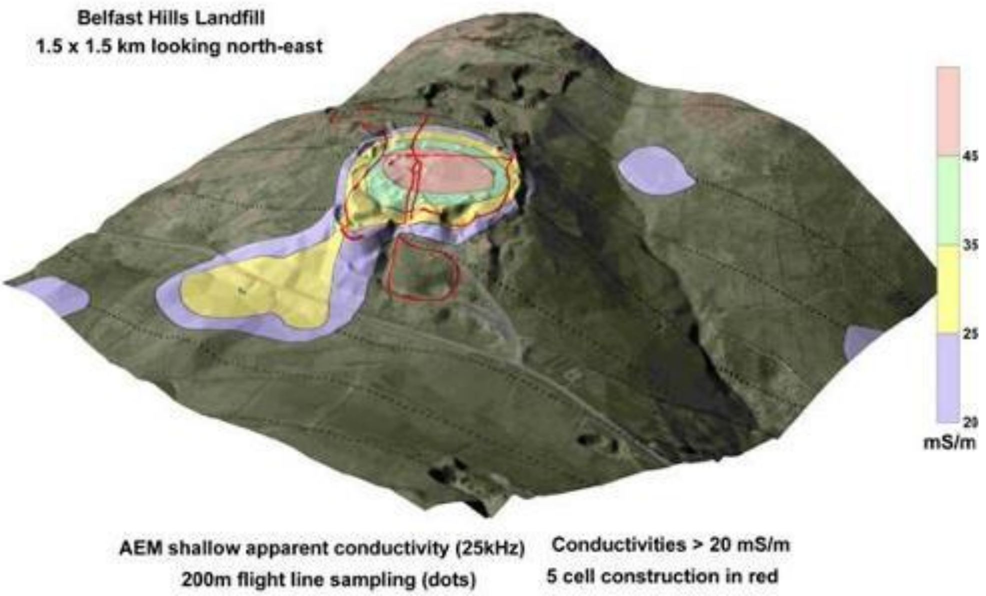

Figure 1. Conductivity anomaly associated with a leachate plume emerging from the Belfast Hills landfill as observed by the 2006 Tellus Survey. Survey flight lines are dotted (Beamish, 2007)

of geothermal sources in the Mourne Granite region and other similar areas.

Groundwater protection schemes have been developed by GSI for all six counties in the Tellus Border study area. Depth to bedrock (DTB) is a key dataset which feeds into the assessment of groundwater vulnerability and has traditionally been determined from borehole records. New methods to model overburden

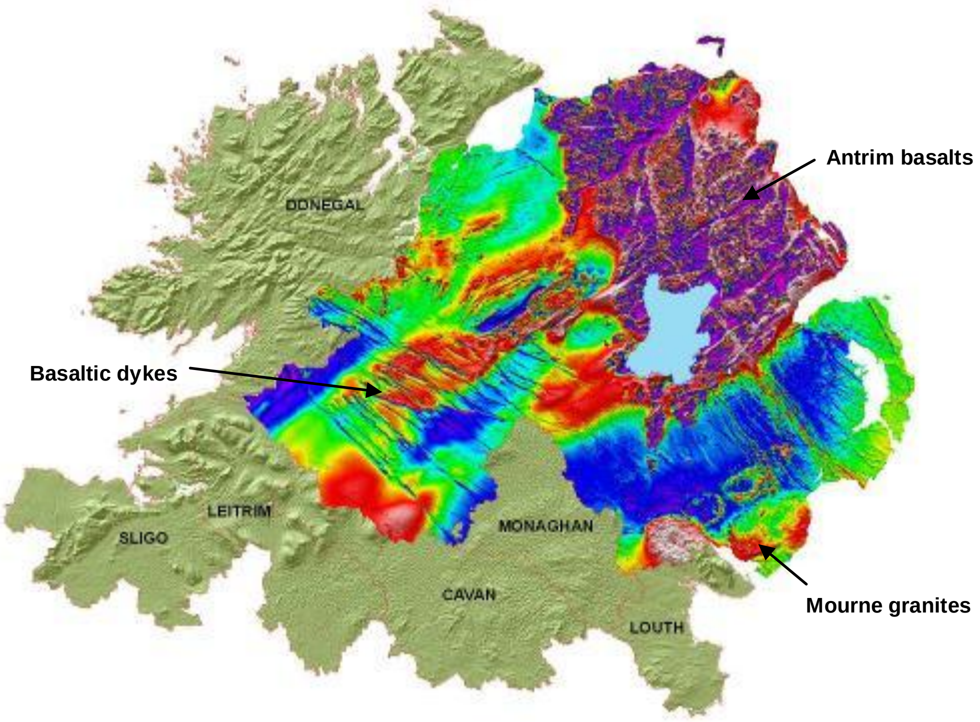

Figure 2. Magnetics data for Northern Ireland, clearly delineating the Antrim Basalts, Mourne Granites in Co. Down and basaltic dykes cross-cutting the Fermanagh and Tyrone area

thickness derived from airborne geophysics include EM inversion and measuring radiometric signal attenuation due to peat. It is hoped that these datasets will supplement borehole data and provide new, detailed information on DTB for updating groundwater protection schemes in the future.

In addition to the airborne survey, a ground-based geochemical survey is also underway as part of the Tellus Border project. Although chemical characterisation of groundwater will not be undertaken directly, over 3,500 samples each of soil, steam water and stream sediment will provide a rich dataset to assist in the understanding of the natural geochemical status of groundwater in a catchment context. Of particular interest is the provenance of potentially harmful elements in groundwater, such as arsenic. Several areas in Ireland have naturally-occurring high levels of arsenic in drinking water supplies and the geochemical dataset will provide new, regional-scale information on the natural occurrence, speciation and mobility of elements like arsenic in the water environment.

River Basin Districts (RBDs) that cross political boundaries present particular challenges for effective cross-border catchment management under the Water Framework Directive. There are three cross-border RBDs in the Tellus Border study area: the Northwestern, Neagh Bann and Shannon International RBDs. Tellus Border will contribute to the objectives of these RBDs by seamlessly integrating data from the Tellus (Northern Ireland) project and thereby gaining better understanding of regional water quality. The project will sample lower order streams than those that are regularly monitored and will provide a picture of water quality in the upper reaches of the catchments for the first time.

The airborne survey aircraft, a De Havilland Twin Otter operated by Sander Geophysics Ltd of Ottawa, Canada. The magnetometer is in the foreground on the nose cone and the EM coils are on the wingtips.

Soil sampling on Inishowen Peninsula, Co. Donegal.

The Tellus Border project is funded by the INTERREG IVA programme of the European Regional Development Fund, which is managed in Ireland and Northern Ireland by the Special European Programmes Body (SEUPB). The project is co-funded by the Department of Environment (NI) and the Department of the Environment, Community and Local Government (RoI). Maps and data will be made freely available to all interested stakeholders including landowners, local authorities, planners, policy makers and the general public in 2013. Project updates, including the latest flight schedules and geochemical sampling sites, are available at www.tellusborder.eu.

Mairéad Glennon, Dr. James Hodgson and Ray Scanlon Geological Survey of Ireland)
Dr. Marie Cowan and Mohammednur Desissa (Geological Survey of Northern Ireland)

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A stochastic method of assessing the pollution potential of burial grounds

Using the UK Environment Agency protocol, an assessment for a proposed burial ground and crematorium in the Dun Laoghaire-Rathdown area is presented

Fifty issues is a most worthy achievement and must be due in no small part to consistent contributors and dedicated editing. The library that the Groundwater Newsletter provides is an excellent resource and a testament to all its supporters. In contrast to the pollutant sources referred to in this paper, it can safely be said that the Groundwater Newsletter has achieved immortality.

'Assessing the Pollution Potential of Cemetery Developments' is the title of UK Environment Agency guidance protocol ref. no. SCHO0404 BGLA-E-P. It provides technical guidance on how to calculate the pollutant concentrations in infiltration from burial grounds and to assess their impact. Whilst much of the approach will be familiar to the Irish hydrogeological community, there is some variation in terminology and methodology. A synopsis of an assessment as applied to a proposed burial ground and crematorium in the Dun Laoghaire-Rathdown area is presented as follows.

Potential Pollutants and Impacts

The principal chemical constituents of human body dry matter are identified as carbon (80.6%), nitrogen (9.2%), calcium (5.6%), phosphorus (2.5%), potassium (0.7%) and sulphur (0.7%). The chemicals Cl, SO_4, NOx, NH_4, PO_4, Fe, Na, K , C, Mg, Cu and Zn are identified as the principal inorganic constituents of body decomposition fluids. In studies conducted with appropriate ground conditions, only ammonia, chloride and sulphate have been detected beyond the burial plot. In sites where there is a potential impact to groundwater, elevated ammoniacal nitrogen is the pollutant most likely to be detected. In certain irregular cases, mostly associated with inappropriate interment within the saturated zone and/or surface water proximity, elevated TOC, BOD, COD and ammonia have been detected beyond the burial plot.

Formaldehyde is the only trace organic associated with burial, due to its use as an embalming fluid. It degrades rapidly and no detections in excess of 0.01 mg/l have been encountered beyond the immediate vicinity of burial plots in trial studies.

Coliform bacteria, Clostridia, Faecal Streptococci and Pseudomonas Aeruginosa are associated with body decay. Their fate in the subsurface is seen as analogous to that of putrescible matter in landfill where pathogen decay rates on separation from hosts are a matter of days. No groundwater impact has been recorded in studies of putrescible matter in UK landfill sites and the UK EA document concludes that the lack of evidence of subsurface impact in the UK and elsewhere is due to immobility and attenuation of organisms in the ground. Specific assessment

Glasnevin Cemetery (www.glasnevintrust.ie)

has similarly concluded that there is no effective risk of Creutzfeldt-Jacob manifestations.

In respect of surface water impact, studies have yielded no information which unequivocally link changes in surface water quality with burial grounds. In a few irregular cases, anecdotal evidence has suggested a grey discolouration of surface water in close proximity to graveyards and in association with heavy rain. In respect of soil pollution, having reviewed a comprehensive number of related studies, the authors conclude that soil pollution by cemeteries does not occur.

Carbon dioxide and methane are identified as the principal gases associated with the decay of bodies and can be expected to be odourless. Small volumes of sulphurous gases are also emitted and very occasionally diphosphane has been identified, usually under saturated conditions. It is calculated that a 70 kg corpse generates 10 to 40 cubic metres of CO_2 and CH_4 gases under anaerobic conditions, over a decay lifetime of 10 years. However aerobic conditions prevalent in the subsurface around burial plots are predicted to result in a reduced generation and subsequent emission to atmosphere of the order of 10% of this volume. A determination of a potential emission to atmosphere of 2.5 cubic metres per decade per 70 kg corpse can be made. Equilibrium in respect of emissions is assumed in the report to be attained after 10 years. On the basis of 100 burials per annum, a total annual CO_2 and CH_4 emission of 250 cubic metres per annum is predicted for the proposed development. Studies found no evidence of aerial pathogenic or organic gas emission issues in association with burial grounds. Organic-rich topsoil is seen as beneficial in that it hosts methane-reducing bacteria which in turn lead to a reduction in emissions.

Attenuation

The action of microbes are expected to result in the breakdown of ammoniacal nitrogen first to nitrite and then nitrate. The EU Guideline and Limit values for Nitrate (as N) in drinking water are 5.6 mg/l and 11.3 mg/l respectively. Table 1, Page 7 of the EPA Wastewater manual for small communities, leisure centres and hotels lists septic wastewater characteristics as containing ammoniacal nitrogen (N) at 45.6 mg/l (57 mg/l NH_4) and Total N at 55 mg/l. Domestic sources are quoted at containing ammoniacal nitrogen of 31.5 mg/l (N), 39.4 mg/l NH_4 and 40.6 mg/l TON. It is further recognised that modern conventional treatment of wastewater has a limited effect on Total N in wastewater.

Site Specific Infiltration Values

Annual infiltration (I) is equal to annual rainfall (P) minus Actual Evapotranspiration (AE) and Runoff (R). Using local meteorological data and the methodology employed in the UK EA

Table 1. Effluent Conc/200 burials/annum (UK P223 Table B5 Modified)

Year #	Cum Burial Area (m^2)	Infiltration (I) @323 l/m^2	NH_4 kg/70kg burial	NH_4 Conc. mg/l	Cl kg/70kg burial
1	2,500	807,500	0.87	215.5	0.048
2	5,000	1,615,000	0.44	54.5	0.024
3	7,500	2,422,500	0.22	18.2	0.012
4	10,000	3,230,000	0.11	6.8	0.006
5	12,500	4,037,500	0.05	2.5	0.003
6	15,000	4,845,000	0.03	1.2	0.002
7	17,500	5,652,500	0.01	0.4	<0.001
8	20,000	6,460,000	<0.01	0.3	<0.001
9	22,500	7,267,500	<0.01	0.3	<0.001

Table 1. Effluent Conc/200 burials/annum (UK P223 Table B5 Modified)

FACTOR	BURIAL AREA ATTRIBUTE	VULNERABILITY SCORE
Overburden Type	Friable sand	7 – 8 (High)
Minimum Overburden	1m (interment level)	7 – 8 (High)
Minimum Depth to Water	<5m (interment level)	9 – 10 (V High)
GW Flow Mechanism	Fissure only	7 – 8 (High)
Aquifer Type	Poor Aquifer (PI)	1 – 2 (v. Low)
Abstraction point	>400m	1 – 2 (v. Low)
Watercourses	>30m <50m	7 – 8 (High)
Springs & Drains	None	1 – 2 (v. Low)
	Total:	**40–48 (Intermediate)**

protocol for burial grounds, conservative determinations of respective infiltration values for chippings and for grass surfaces at this site are 460 mm and 308 mm. The areas of chippings and grass are calculated as 1.25 m^2 and 11.25 m^2 per burial plot respectively.

Concentrations of ammoniacal nitrogen and chloride are predicted in infiltration from the burial area using the UK Environment Agency's stochastic model. Equilibrium is predicted after 10 years.

It is concluded that the predicted average concentration of Total N will be less than those of domestic or community wastewater systems after 2 years. Predictions of concentrations of ammoniacal nitrogen in infiltration using the UK stochastic model become insignificant after 5 years.

Chloride is commonly present in groundwater at concentrations up to 50 mg/l and the EPA Threshold Value is 187.5 mg/l. The predicted maximum average concentrations of chloride in infiltration of 11.89 mg/l are not considered to pose a risk to groundwater.

Site Vulnerability Score

The risk assessment process in Appendix A of the guidance protocol invokes a determination of a *Vulnerability Class* for the site. Numerically the vulnerability score can range from 8 to 80, the median being a score of 44. Scores of 8–32, 33–56 and 57–80 are ranked as *Low*, *Intermediate,* and *High* respectively. Using a precautionary conservative approach, a site Vulnerability Class of *Intermediate* is determined (Table 2).

Groundwater Protection Response

In determining the appropriate response in respect of groundwater protection, the UK Environment Agency apply the same approach to burial grounds as that used for landfills. At this site it is appropriate to use the analogous Geological Survey of Ireland Response Matrix for Landfills. In this case the matrix yields a R2[1] response which is quoted as follows:

*"**R2[1]** Acceptable subject to EPA guidance or licence conditions.*

Special attention should be given to checking for the presence of high permeability zones. If such zones are present, the risk of leachate movement to these zones must be insignificant. Special attention must be given to downgradient wells and projected future development of the aquifer."

The full report is in the public domain and is available from SM Bennet & Co Ltd upon request <bennet@iol.ie>.

Shane Bennet, S.M. Bennet & Co. Ltd

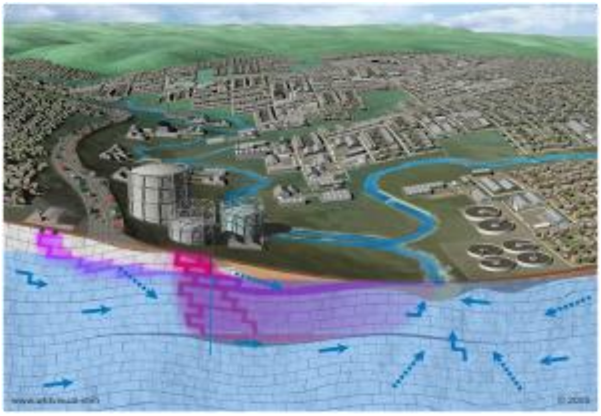
[Editor's note: The risk of impact of burial grounds can also now be assessed using the new EPA Guidance framework, see next article.]

Guidance on the Authorisation of Discharges to Groundwater
A new report from the EPA

The Groundwater Regulations (S.I. No. 9 of 2010) introduced groundwater quality objectives to which public authorities have a duty to respond, both in terms of promoting compliance with the requirements of the regulations and taking all reasonable steps to 'prevent and limit' the inputs of pollutant substances to groundwater. This technical guidance has been prepared by the EPA to assist public authorities in this capacity, with the primary aim of introducing a consistent approach and methodology as to how new discharge activities should be assessed, how to reach a defensible decision as to whether the activity should be authorised or not, and what steps or mitigation actions might be needed in order to grant authorisation.

The technical guidance, therefore, focuses on the technical assessment that should be considered for a new discharge to groundwater activity, whereby the activities are first screened for risk of potential impact, and a decision is taken with regard to the level of technical assessment that may be required to demonstrate that a site:

- Is hydraulically suitable and has sufficient infiltration capacity; and
- Has sufficient attenuation capacity to ensure that the discharge will not result in an unacceptable impact on receptors and non-compliance with groundwater quality standards and objectives.



The Guidance Manual advocates that the scope and degree of complexity of technical assessment should be proportional to the risk posed and the hydrogeological setting of the site, whereby details of the technical assessment should address questions surrounding source-pathway-receptor risk factors and relationships, as governed by the conceptual model of the site.

Where risk of impact is identified, the impact should be quantified and verified through monitoring. The nature and scope of the monitoring should be guided by the conceptual model of the site and a site-specific understanding of potential pollutant pathways. The monitoring should be both proportional and representative: proportional to the specific nature of the pollutant types and magnitude of potential problem; representative in the sense that sampling points have to 'intercept' the pollution migration (pathways) away from the pollution source.

In summary, this Guidance provides:

- A framework for considering discharges to groundwater;
- Details on the information needed on which to base decisions;
- An emphasis on conceptual understanding and particularly of considering the 3-dimensional flow regimes beneath sites;
- Background details on legislation, minimum reporting values for selected hazardous substances, relevant water quality standards and relevant calculations.

The Guidance Manual was prepared, on behalf of the EPA, by Henning Moe and Lorraine Gaston, CDM Ireland Ltd. It can be downloaded from the EPA website at the following link: www.epa.ie/downloads/pubs/water/ground/dischgw/

Donal Daly, EPA

Stable oxygen isotopes in hydrogeological investigations – is there a practical use?

Stable isotopes have not been widely used in Irish hydrogeological studies to date, despite being a commonly used tool elsewhere. Shane Regan looks at their application.

History

Isotope hydrology has long been used as a technique to better understand the water cycle (Aggarwal et al, 2005) and its hydrological fluxes. Following World War II radioisotopes were easily available, due to the expansion of the nuclear energy industry, and were used as artificial tracers in groundwaters and surface waters so to better understand their mixing patterns, transit times and transmissivities. However, the injection of radioisotopes into natural water bodies soon became obsolete and research into the use of "environmental isotopes" began.

Initially, tritium, a radioactive isotope used in nuclear testing in the 1940's was used, as it was inadvertently introduced into the hydrological/ water cycle (where it is also present in natural amounts). The tritium excess in the water cycle brought about a new understanding of its dynamics on a global scale, knowledge which researchers later applied to local hydrologic systems. Thereafter, isotope hydrology, in conjunction with the development of mass spectrometers equipped to measure isotope ratios (McKinney, 1950), quickly expanded as a discipline of the hydrological sciences. Stable isotopes – most notably hydrogen (H) and oxygen (O) as H and O, are principal elements in hydrological, geological and biological systems.

The emphasis in the early stable isotope studies was, amongst others, on understanding the global patterns of precipitation, the linkages between the stratosphere and troposphere, the residence times of waters in different stages of the water cycle, the differences between different climatic areas of the globe and the linkages between climate and stable isotope signatures. Such work was, and has continued to be, carried out by the Isotope Hydrology Section of the International Atomic Energy Agency (IAEA) in Vienna, who has had a station measuring the isotopic content of precipitation in Ireland, on Valentia Island, since 1957.

There has been much work done on using stable isotope techniques in regional hydrological studies and there are many textbooks that deal with their application and technical considerations – most notably 'Environmental Isotopes in Hydrogeology' by Clark & Fritz (1997). This article will briefly demonstrate their application in an Irish hydrogeological study, in particular their usage in (1) identifying zones of groundwater discharge from bedrock and subsoil lithologies and (2) application to a mixing model that separates groundwater flows from surface water runoff/overland flows.

Measurement

Stable environmental isotopes fractionate into separate light and heavy fractions and they are measured as the ratio of the two most abundant isotopes of a given element. In the case of oxygen, it is the ratio of ^{18}O, with a terrestrial abundance of c. 0.204%, to common ^{16}O, which represents c. 99.796% of terrestrial oxygen (Clark & Fritz, 1997). Measurements are referenced to mean ocean water composition due to the predominance of ocean water in the hydrosphere and, compared to the rest of the hydrological cycle, the relatively homogenous isotopic composition of ocean waters. A standard hosted at the IAEA, referred to as the Vienna Standard Mean Ocean Water (VSMOW), is the reference used for all international water sample measurements. Isotopic abundances are reported as $\delta^{18}O$ values, with units expressed as permil (‰). $\delta^{18}O$ values are extremely low.

There has been remarkably little work carried out in Ireland using stable isotope techniques in hydrological/hydrogeological studies. A large reason for this is that a suitable, and affordable, laboratory with a mass spectrometer equipped to measure the isotopic ratios of oxygen and hydrogen has not been available. However, the Department of Geology in TCD recently (2009) acquired the instrumentation to upgrade its mass spectrometer so to enable the measurement of the $^{18}O/^{16}O$ ratio in water samples. Collaboration has since ensued between the Department of Civil, Structural and Environmental Engineering and the Department of Geology, to investigate the potential use of stable oxygen isotopes in wetland and turlough/ karst system ecohydrological/hydrogeological studies.

Clara Bog hydrogeological study

Recent research on Clara Bog (Regan, 2012), funded by the National Parks and Wildlife Service, shows that raised bogs are complicated hydrogeological systems with a dependency on groundwater — discussed in GSI Groundwater Newsletter no. 49. A tract of the research was to establish the linkage between the wetland and the regional groundwater table as artificial drainage has created complicated surface water-groundwater interactions. Quantifying infiltration, recharge and runoff fluxes are imperative to understanding the bogs position in the regional hydrological cycle, and geochemical and isotopic analysis techniques have been employed to help quantify these rates of flux.

The geology of the Clara area may be differentiated into a succession of peat, lacustrine clay (low permeability), mineral subsoil (permeable till) and limestone bedrock. Differentiating between shallow groundwater flows in the mineral subsoil and deeper groundwater flows in underlying limestone bedrock became important following the generation of a groundwater numerical model for the Clara hydrogeological system. Up until the creation of the model, differentiating between groundwater flow/level in till and limestone was not deemed overtly important as boreholes (six in total) with piezometers measuring water level in both units indicated the levels were nearly always coincident, implying little vertical movement of groundwater flow.

However, calibration of the numerical model necessitated the inclusion of a highly transmissive zone (30-120 m2/day) in the limestone to account for an area of till where the hydraulic head is particularly low (Figure 1). Modelling therefore implied that deeper groundwater flows were locally important and that the limestone, as well as the mineral subsoil, is connected to the bog system.

Identifying zones of discharge from shallow and deep groundwater

Water in an aquifer or groundwater body will have a distinct $\delta^{18}O$ isotopic signature. As rain falls on the surface, the water that infiltrates and ultimately recharges the groundwater table will have a relatively enriched $\delta^{18}O$ signature as the water molecule, while exposed on the surface over a sufficiently long time period, will have undergone evaporative processes before it infiltrated downwards. However, if the aquifer is recharged quickly, the water molecule will preserve a signature resembling meteoric water as the water molecule will not have undergone as much evaporation. The water molecule does however undergo fractionation processes, which are temperature dependent, in the groundwater body. Using stable isotopes in a hydrogeological study is therefore only useful if distinct 'water types' can be identified – if the water molecule in a groundwater body is simply a mean of the precipitation $\delta^{18}O$ isotopic signature, it is of no real practical use.

The Clara hydrogeological system is well instrumented with piezometers measuring hydraulic head in peat and subsoil units. There are three hydraulic structures used to calculate flow rate in drains which have a significant groundwater flow component, two of which are

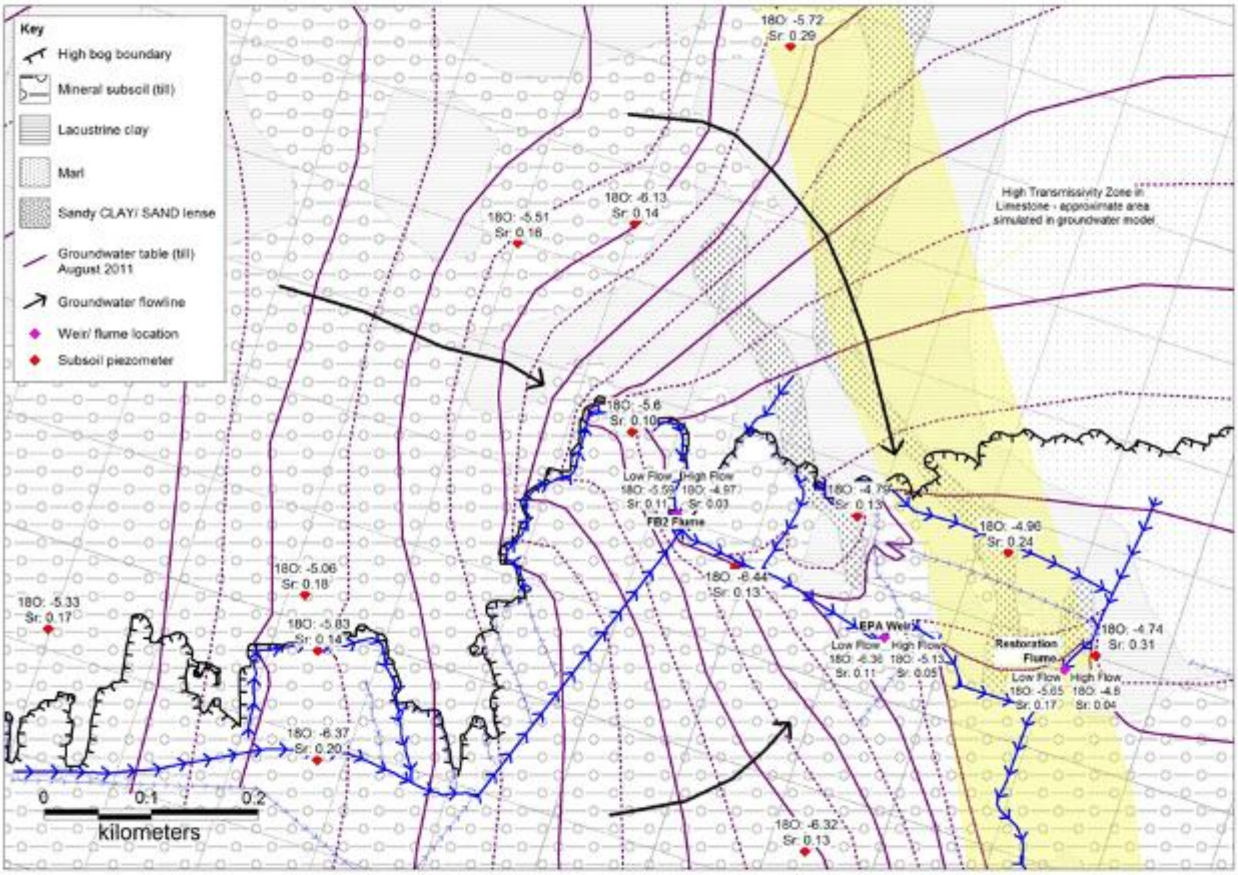


Figure 1. Location of study area, instrumented drains and subsoil piezometers. Note: Strontium concentrations (mg/l) and δ^{18}O values (‰) refer to water samples taken in till subsoil and from low and high flows in three instrumented groundwater-fed drains

flume structures, designed specifically to measure runoff in drains that could not be instrumented with a weir.

In the Clara region, the δ^{18}O value of rainfall is between -4.5 and -4.8‰, with the overall average being c.-4.7‰. Figure 1 illustrates δ^{18}O values measured from piezometers measuring water level in till subsoil. The δ^{18}O value of groundwater in till ranges between -5.1 and -6.9‰ and has an average value of c.-6.2‰. The δ^{18}O value of peat, overlying lacustrine clay/till ranges between -5.5 and -7.4‰ and has an average value of c. -6.4‰. There is a distinct difference between meteoric water and shallow groundwater in the till unit. The water that recharges the till has undergone evaporative processes before, and during, infiltration, giving it a separate δ^{18}O to surface water runoff. However, there are areas where the δ^{18}O signature of shallow groundwater is similar to rainfall, suggesting quick recharge – which is highly unlikely as these particular areas are overlain by a significant thickness of lacustrine clay which has permeability in the order of 10^{-7} m/day.

Also plotted on Figure 1 are strontium (Sr) concentrations from the same waters analysed for δ^{18}O. The average Sr concentrations in rainfall and overland flow following a storm event have been calculated to be c.0.001 mg/l. The average Sr concentrations in peat substrate are marginally higher (average: 0.01 mg/l) and significantly higher in till, with an average concentration of 0.15 mg/l. However, there are areas where the Sr concentration is significantly higher (between 0.2 and 0.3 mg/l), and these areas coincide with enriched δ^{18}O signatures. Elevated Sr concentrations such as these suggest a limestone provenance – there are artesian pressures in this region, an area of cutaway bog, and it seems groundwater is moving upwards, periodically, from limestone to till, and this seems to explain the observed Sr concentrations.

At first glance it might appear contradictory to have an elevated Sr concentration and an enriched $\delta^{18}O$ signature. However, if groundwater is indeed moving upwards from limestone this is perfectly reasonable. Limestone in the Clara region is massive in texture and groundwater flows in a system of fractures and conduits – i.e. it is most probably karstified. The $\delta^{18}O$ signature suggests limestone is recharged very quickly, and this is why $\delta^{18}O$ is enriched – the groundwater itself will have a residence time long enough to account for the observed Sr levels. Analysis of waters from piezometers installed to limestone outside the region (Figure 1) also finds the limestone $\delta^{18}O$ signature to be enriched – particularly adjacent to an esker, located < 1.0 km north of the area in Figure 1.

The areas with enriched $\delta^{18}O$ values and elevated Sr concentrations also coincide with the high limestone transmissivity area simulated in the groundwater model. The high transmissivity region was inferred based on the hydraulic heads measured in till subsoils – there are no piezometers in limestone in this particular area. Thus, using $\delta^{18}O$, coupled with geochemical data, a distinction can be made between shallow groundwater in till, and deeper groundwater in limestone.

Geochemical-stable isotope mixing model

The composition of water in a drain will depend on its origin and hydrological history. Groundwater-surface water mixing models, or hydrograph separation models, are built on the premise that the two main components in the runoff stream – overland flow/surface water runoff and base flow/groundwater discharge can be identified using an appropriate tracer. To construct such models, the tracer, which may be artificial or natural, must be chosen so that (1) it is significantly different to water from overland flow in a storm event and (2) it may be assigned to a specific and distinct source.

Solutes that are present in groundwater are derived from two main sources: (1) input from rainfall and (2) acquisition during weathering and water-rock/subsoil interactions. The concentration of a solute will invariably increase the longer it is in the groundwater system due to contact with the surrounding geological materials — solutes with concentrations that reflect their relative residence times are effective environmental chemical tracers. In this study, useful geochemical tracers, in addition to Sr, were Silica (SiO_2), Calcium (Ca) and Magnesium (Mg). However, neither Ca or Mg (and also electrical conductivity) indicate flows from deeper groundwater in the area described earlier — Sr and SiO_2 do; perhaps because they require longer residence times to become sufficiently elevated above levels found in glacial till.

The chemographs in Figure 2 plot Sr and $\delta^{18}O$ versus flow rate, both of which are power law relationships, for three instrumented drains in the Clara region. A flume, referred to as the Restoration Flume (Figure 1), plots differentially to the other two drains — Sr concentration is significantly higher at low flows and the $\delta^{18}O$ versus flow rate plot follows a different trend at higher flows. Both phenomena can be attributed to upward flows from underlying limestone.

To separate overland flow from shallow groundwater flow in till and deeper groundwater flow in limestone, it is necessary to construct a three component mixing model (there is an additional fourth component, peat, which is omitted here). Two geochemicals, Sr and SiO_2, detect groundwater flow from limestone, but an additional conservative tracer is required to detect limestone discharge at higher flows – e.g. a stable isotope. Therefore it is advantageous to combine a geochemical and stable isotopic

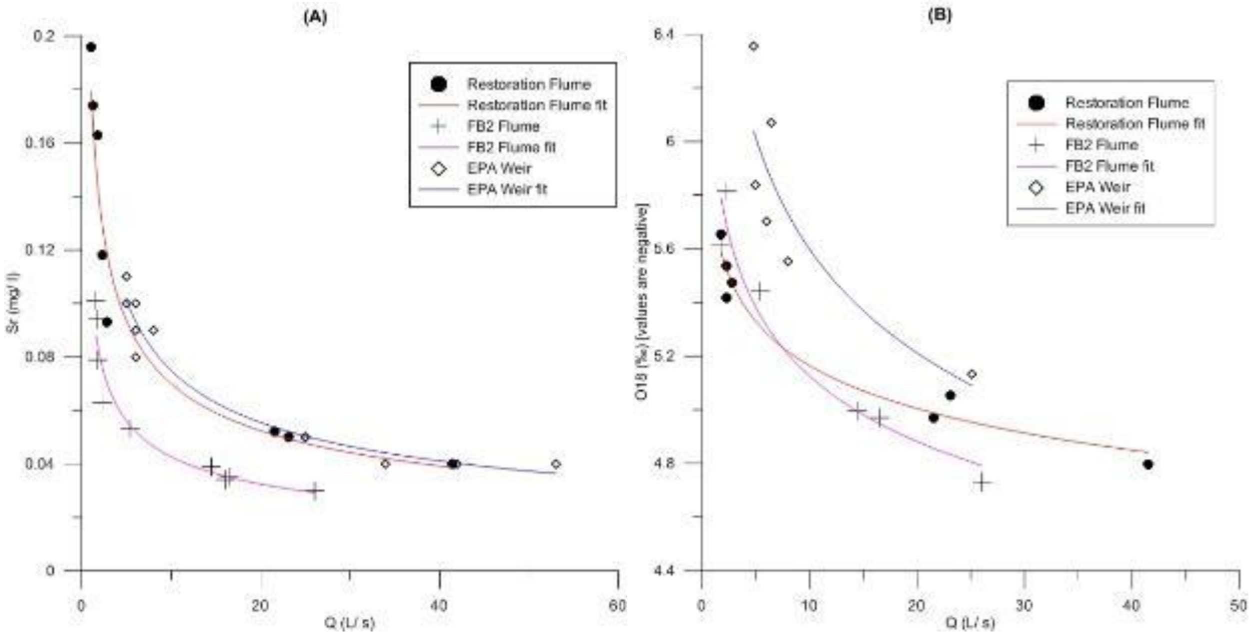


Figure 2. (A) Strontium (mg/l) v. flow rate (l/s). (B) δ^{18}O(‰) v. flow rate (l/s)

tracer, and a chemical mass balance equation may then be formulated as follows:

$$C_bQ_b + C_tQ_t + C_nQ_n = C_TQ_T$$

where C is either Sr concentration or δ^{18}O, Q is discharge and the subscripts T, b, t and n refer to total, bedrock, till and new water respectively. There are three unknowns in the equation – discharge from till, limestone and 'new' water from overland flow. The unknown components are solved using a set of linear equations and calculating proportions of flow using the two tracers — Hinton et al (1994) describe this methodology.

Figure 3 displays a separated hydrograph for the Restoration Flume between January 2011 and January 2012, using the tracer data. As alluded to earlier, the δ^{18}O signature of surface water is highly sensitive to evaporation. Surface runoff following heavy rain periods has a δ^{18}O signature similar to rainfall. The surface runoff signature will change and become more enriched due to partial evaporation in intermittent periods as runoff is released from storage on the bog surface rather than coming from directly from rainfall. However, the volumes of water released in such periods are relatively minor, in an overall flow balance, and have been accounted for in the mixing model.

Over the hydrograph period c.28% of runoff is groundwater from till and limestone; 9% of which is from limestone. Between late April and early September the overall groundwater contribution in the drain is very high, >70%, except for isolated wet periods. The hydrograph also shows that the groundwater contribution from limestone is greater than the till contribution in storm events – indicating limestone is recharged very quickly, possibly through a fracture or conduit zone which becomes most active during storm events. The inferences from the hydrograph match those made from the Sr and δ^{18}O observations and chemographs in Figure 2.

Conclusion

Stable oxygen 18 isotopes have proved to be useful in the Clara hydrogeological study, identifying an area where groundwater from deeper limestone is contributing to base flow. A combined geochemical-stable isotope mixing model enables the separation of shallow and deep groundwater flows from overland flow. The same application could conceivably be applied to

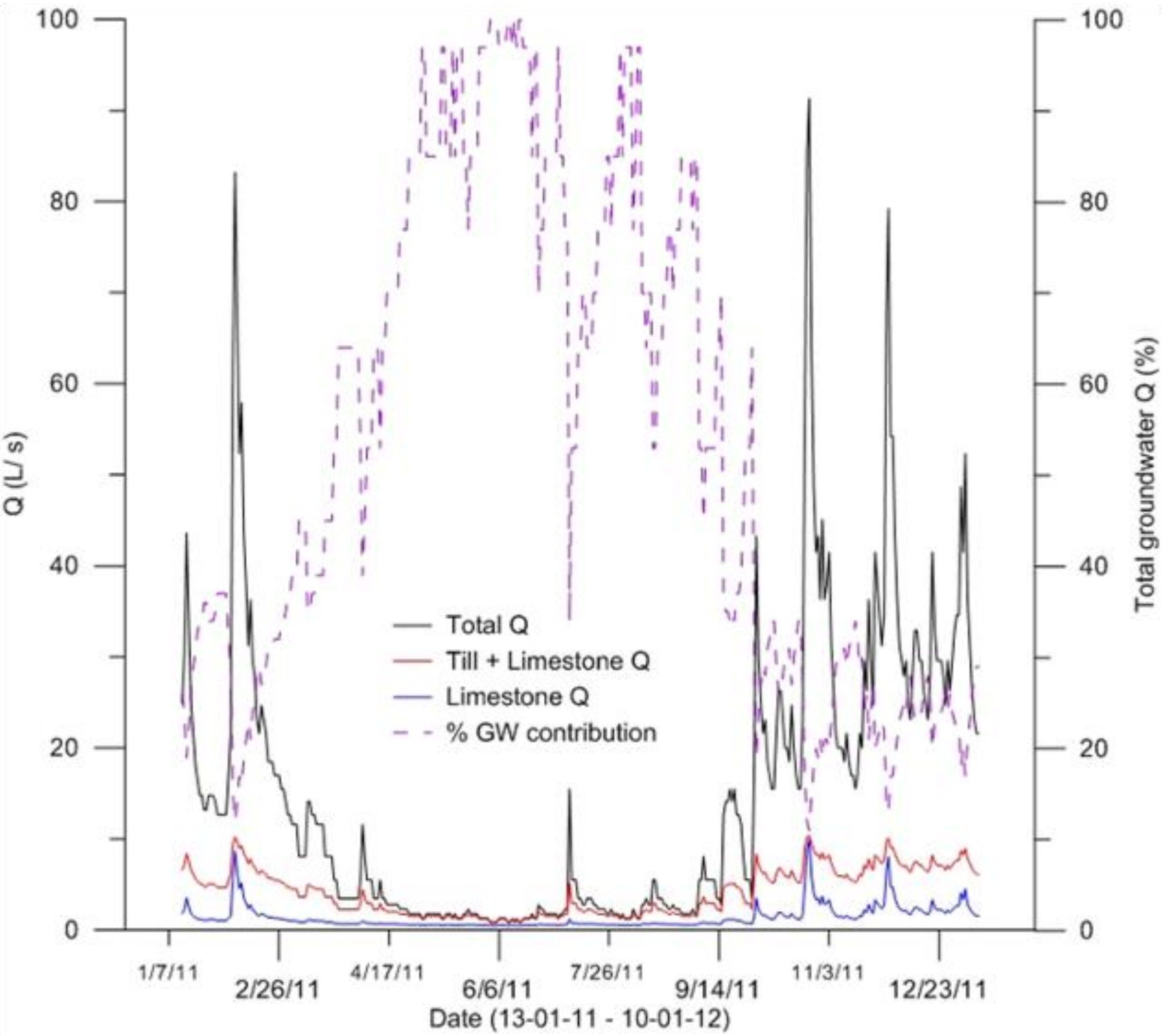


Figure 3. Restoration Flume hydrograph with baseflow separation (Jan 2011 – Jan 2012)

other groundwater investigations in Ireland, particularly areas where the groundwater isotopic signature will be distinct from precipitation, such as in wetland and karst hydrogeological settings.

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Hydraulic fracturing — an introduction to the concept and initial implications for the future of Irish groundwater

Introduction

Hydraulic fracturing, 'fracking', is a controversial technique employed in the extraction of shale gas through the use of a high pressure mixture involving sand, water and particular chemicals.

The aim of this article is to briefly introduce the subject within the Irish context, with an 'indication' of the processes involved, the primary concerns related to potential impacts on groundwater resources, and the future of fracking in Ireland. In order to balance the argument, some mention is given to the approach of currently interested parties as well as highlighting their basic environmental objectives in any future development of this hidden resource.

Overview of the process at work

Fracking refers to the process of drilling down and creating tiny explosions to shatter and crack hard shale rock to release the gas inside. Water, sand and chemicals (including rock dissolving fluids, for example pumping down hydrochloric acid 'acidizing') are injected into the rock at high pressure which ultimately will allow the gas to flow out to the wellhead. Gas injection forms could typically include propane or nitrogen.

The process is carried out vertically or, more commonly, by drilling horizontally to/ within the rock layer with the objective of intercepting multiple fissures which are widened as a result of the high injection pressures, and essentially 'held open' by the injected sand particles. The process can open up new pathways to release gas or can be used to extend existing channels. The operational water is pumped back up to the wellhead where it is recovered as chemically mixed wastewater and often stored temporarily in open pits/ lagoons for subsequent treatment which eventually may also form part of the new injection mixture. The process is depicted simply in Figure 1.

Groundwater and initial concerns

Fracking is the hydraulic fracturing of rocks to extract small amounts of gas using high pressure water and, historically, appears to be laced with a blend of potentially toxic chemicals. Research has indicated that this stimulation process may also leach/ mobilise specific contaminants, such as arsenic, out of the exploited bedrock which could ultimately lead to some contamination of groundwater. It has also caused methane to escape into fresh water aquifers infiltrating public groundwater supplies as demonstrated in recent case studies in the USA.

The process of fracking is used in 9/10 natural gas wells in the USA, and has been heavily criticised by US environmentalists who argue the practice can end up polluting drinking water in the surrounding area. In fact, it appears various concerns have been raised worldwide about environmental risks and other negative impacts associated with processes and technologies applied in the extraction of shale gas. Some of these initial concerns and questions are summarised in Figure 2.

But what exactly are the current concerns and inferred 'dangerous chemicals' when looking at the business of fracking and protection of water resources? Research undertaken at the Tyndall Centre, University of Manchester, has focused on investigating environmental impacts of shale gas (Tyndall, 2011). With reference to water, such impacts include *inter alia* the following:

- surface and groundwater contamination associated with chemicals used in the hydraulic fracturing process,
- the mobilisation of sub-surface contaminants such as heavy metals, organic chemicals, and naturally occurring radioactive materials (NORMS);
- hazardous wastewater generation and its disposal;

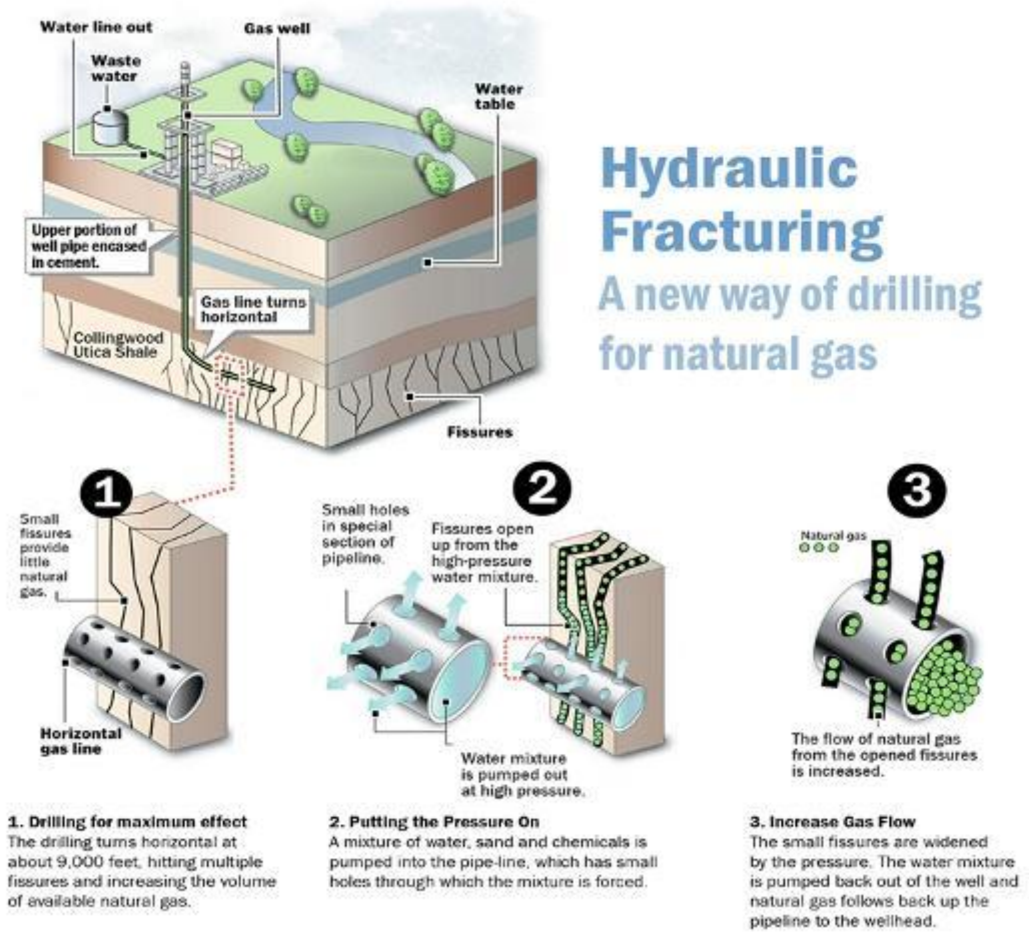

Figure 1. Hydraulic fracturing processes

- resource issues including abstraction of significant quantities of water for hydraulic fracturing processes; and
- land use and landscape impacts.

The report goes on to stress that fracturing and 'flow back' fluids (including transformation products and mobilised subsurface contaminants) contain a number of hazardous substances that, should they contaminate groundwater, are likely to result in potentially severe impacts on drinking water quality and/or surface waters/ wetland habitats (GWDTEs). The severity will depend on, for example, the significance of the aquifer for abstraction; the extent and nature of contamination; the concentration of hazardous substances; and connection between ground and surface waters.

More specifically, examples of chemicals/ hazardous substances that have been associated with the fracking process in the USA to date include:

- chemical additives for the fracturing liquid and drilling mud,
- toxic organic compounds,
- corrosion inhibitors,
- buffer/ pH adjusting agents,
- solvents and surfactants,
- methane & natural gas elements,
- brine, salt and sulphates, and
- hydrocarbons (e.g. benzene additives).

Added to the above list are other unidentified and potentially toxic chemicals that return, in the liquid fraction, to the surface following fracturing (Earthworks, 2012). It must be noted, however, that emissions associated with the use of water and chemicals in the process will depend on the water source and type of

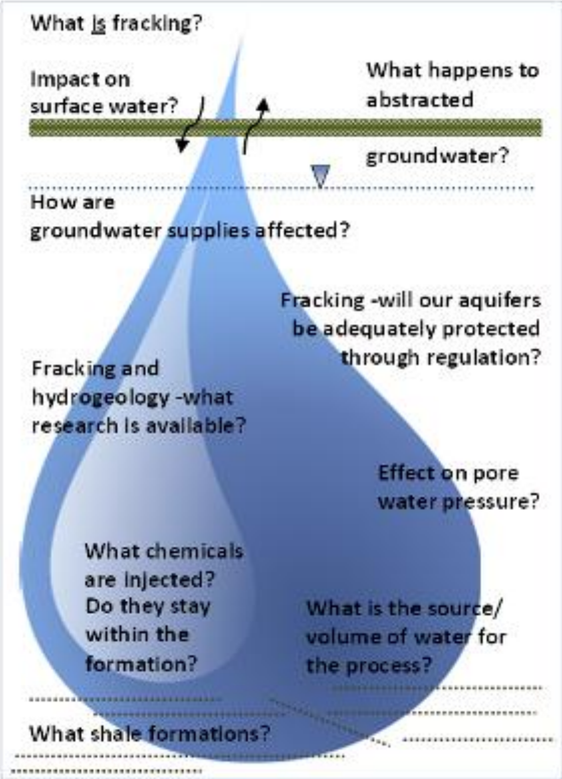

Figure 2. Concerns and questions about fracking

chemicals used, which are often site-specific, are contingent on the geology of the formation and are often commercially confidential as reiterated by the Tyndall Centre.

The business of fracking can lead to up to ~75% of the water injected in the process remaining (i.e. trapped) within the target bedrock which could continue to contaminate groundwater for years. Residual injected waters may also 'plug' geological fractures through water retention or indeed chemical reactions which could impact on the permeability of that formation or where overlain by permeable sedimentary rock. The returned estimate of ~25% (or possibly greater) is treated at the surface for possible re-use within the system set-up. Previous fracking work in the US has witnessed disposal of this water within the ground leading to ground stabilisation issues, not to mention potential impact on the hydrogeological regime.

But what of the volumes of water required for the process? In a recent radio interview (RTÉ, 2012), the Canadian company Tamboran Resources, with an interest in sites in Ireland, cited for example statistics as 1 million gallons (~3.8 million litres/ML) of water injected in a well with a return of 90% in the first month, and an estimated 3.8ML of brine wastewater produced over the life time of the well. Note: in the US, a single deep shale well may use between 7.5 and 19 ML of water. Therefore, in a well pad with, e.g. 6–8 wells, then 'millions' equates to a high-volume approach which must be taken both in the context of current water resource availability in Ireland as well as the under-development of groundwater resources.

Balancing the argument

In a recent Irish Times article (2011a), the question was put as to whether fracking represents 'clean energy'. Research by the Tyndall Centre (2011) has demonstrated how the ext-raction of shale gas risks contaminating groundwater and surface water. Consequently, any contamination of groundwater and surface water from this industrial process will have knock-on effects on the future availability of our groundwater resources, impacting on a range of industry types, in particular Irish agriculture.

The potential for billions of euro of extractable shale gas for example in the Leitrim/ Cavan/ Donegal area, could be seen as a serious positive side to the argument. However, it poses the question of whether the local communities in these target landscapes should embrace the potential economic benefits claimed with the prospect of a 50-year gas boom or risk the possibility of some environmental degradation (The Irish Times, 2011b). Yet, recent mining developments have in fact shown that this type of exploration can indeed be done well.

In terms of negative impact potential on groundwater, what 'if' the process is done correctly, as has been the case in North America with many successful projects cited to date. For example, Tamboran Resources (2012) 'commits to utilise absolutely no injected chemicals in [their] hydraulic fracturing operations. [They] will conduct fracture stimulations with only sand and water cleaned or recycled at the surface. All recovered water will be stored in secure tanks at surface for recycling in the fracture stimulation of subsequent wells to reduce water use'. While the issue of mobilising contaminants is always possible, the company emphasizes maintaining the integrity of each well and have also proposed monitoring *inter alia* groundwater quality before, during, and periodically after all of its well site operations 'with gathered information duly submitted to Regulators and Council planners as well as publicly displayed on the company's website and made available to all residents'.

Whatever the initial opinion, does this subject not represent a real opportunity for Ireland to lead the way in accurate regulation and control of what is essentially a novel mining exercise in this country?

The future of 'fracking' in the context of Irish groundwater

The interest of Tamboran Resources in fracking activities in Ireland is mentioned above. Indeed, the company currently holds a Licensing Option, granted by the Petroleum Affairs Division (PAD) of the Department of Communication, Energy, and Natural Resources, in the Republic of Ireland. This option will 'assist Tamboran in analysing and reprocessing existing data (collected by prior operators over the past 50 years) as well as drilling shallow (100m to 200m deep) pilot boreholes in order to collect additional rock samples'.

Tamboran (2012) details its 'primary exploration focus is the Bundoran Shale, with secondary potential in the Mullaghmore Sandstone and Benbulben Shale'. It is also assessing opportunities in north Leitrim (RTÉ, 2012). All locations would be assessed for the extraction of gas from shale bedrock at a depth of hundreds of metres, with any potential extractive works proceeding *without* the intended use of chemicals as those listed above. The company itself has proposed the idea that 'fracking' could help pave the way to Ireland becoming self-sufficient in terms of its energy output by 2022.

With regard to the view of public representatives, both Roscommon and Leitrim County Councils have unanimously voted against fracking as have the Town Councils of Bundoran and Donegal, citing concern over potential environmental impacts including on groundwater (The Irish Times, 2011). This highlights obvious opposition to the idea particularly in those areas with geology favourable to the subject under discussion. It may also stress a lack of formal policy to support fracking with the need to formally review and ascertain the sustainability of the process. (Note: the University of Aberdeen has just completed a desk-based study for the EPA (www.epa.ie). The EPA is envisaged to be a statutory consultee at the EIS stage of shale gas projects).

One key aspect to any 'new' business activity is research into the pros and cons of same, together with prediction of the benefits but also the risks associated with the potential impacts of that activity. If one is to look more specifically at the future of Irish groundwater in Ireland, then perhaps a comprehensive review of recent positive examples of where fracking has been successful is necessary. Furthermore, the development of fracking should be subject to more thorough research into the impacts of the process water requirements and potentially hazardous chemical use on Irish hydrogeology (as a minimum at the EIS stage) prior to any expansion of the industry being considered. This could also follow the lead prompted by the recent USEPA study plan (2011).

In terms of groundwater protection the Irish State will need to invest in improving the scientific understanding of fracking and its impact on groundwater and drinking water

IAH International Looks to the Future

Continued from back page…

meet the Association's informing and educating role both within and outside the groundwater professions, as a means of advocating for the better appreciation of the role of groundwater and the need for its better protection and management. Responding to the wishes of our members, we also need to be providing career and training information, and provide better communications and website facilities for our National Chapters and commissions.

Not forgetting its Irish roots, the Burdon Network will continue to strengthen its links with other like-minded organisations such as the African Groundwater Network and Hydrogeologists Without Borders to bring practical encouragement and support to groundwater colleagues in the developing world. We are continually reminded of how professionally isolated our colleagues in developing countries can feel, and how much they appreciate even the modest support that a small organisation like IAH can give.

Finally, like all similar professional associations, our strength is in our individual members and national groups and we have set challenging targets for increasing both of these. The Irish national chapter of IAH has always been one of our strongest, and there is much to be learnt from you in relation to encouraging groundwater professionals to join IAH. We need to share the experiences of our strongest chapters with those which are just developing, and hope you would be willing to do that. I congratulate you on reaching the fiftieth groundwater newsletter, and wish you well for the next fifty.

John Chilton, IAH (International)

Hydraulic Fracturing

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resources before writing it off. This could be initiated by a review of published literature, analysis of existing datasets, specific (positive and negative) scenario evaluations and modelling exercises, and laboratory and field case studies but also driven through the EIS stage. Such an approach will provide the necessary transparency for regulatory control in order to build/enhance essential environmental safeguards.

In summary, fracking is part of a national issue, not a local debate. Ultimately, if Ireland is to sustainably continue to develop its natural resources and continue to protect our groundwater resources, while keeping with the objectives of the Water Framework Directive, then hydraulic fracturing will need to be viewed centrally as a question of national informative and consultative debate. This is a pre-requisite to any form of 'water-tight' regulation.

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Previous issues available at www.gsi.ie

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IAH International Looks to the Future

To continue to prosper, IAH must respond to the changing scientific and professional concerns of its members. From time to time, all organisations should look critically at their operations, and Council agreed in 2008 on the need for comprehensive review of what continuing and new activities IAH should be undertaking and how we should be doing them. This has become the IAH "Forward Look" and has resulted in a broad plan of action to take us up to 2020. The steps in this process have been extensively reported in our regular newsletters and a summary is available at:
http://www.iah.org/downloads/annual_reports/forwardlookweb.pdf

So what has been achieved so far? The strong science base of IAH has always been our commissions, but these must respond to the changing focus of hydrogeological science and practice. As part of the Forward Look process, IAH has conducted a comprehensive review of its commissions to ensure they remain active and take on new issues and challenges in groundwater. A new structure has been established which embraces commissions, networks, working groups and panels, each with slightly different objectives, activities, outputs, obligations and ways of working. Details of the new and renewed commissions and networks are on the IAH website and many would welcome the active participation of new members.

Building for the future also means welcoming and encouraging young professionals. An initial and very lively young scientists' meeting at the Krakow congress has quickly grown into an active Early Career Hydrogeologists Network which has been formalised within the new commission structure. A second meeting was held in Pretoria, and the Network is now formally represented as an observer at Council and will be a very active participant in the upcoming congress in Canada. An associated part of this building process is the desire to develop a mentoring programme within IAH. An online survey has confirmed the widespread interest in such a scheme, with many members enthusiastic to receive mentoring or to become mentors. We are looking at the ways other similar associations have done this, and during 2012 we will be working to get this underway within IAH.

We also need to adapt to the changing ways in which professionals and others communicate. The IAH LinkedIn group first developed by Sophie Vermooten now has more than 500 members, and continues to grow and to facilitate technical discussion threads on groundwater topics, publicity for meetings and career opportunities. If you have not joined up, you should take a look.

Much of what IAH would like to achieve in terms of education and professional development, enhancing member benefits and improving communication depends on the website. A strong and active website is the shop window of any organisation, and we will be starting from this year to overhaul the design and content of the IAH website, so that it can more effectively host and facilitate many of the developments we wish to pursue. In particular, we need to use the web much more effectively to

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