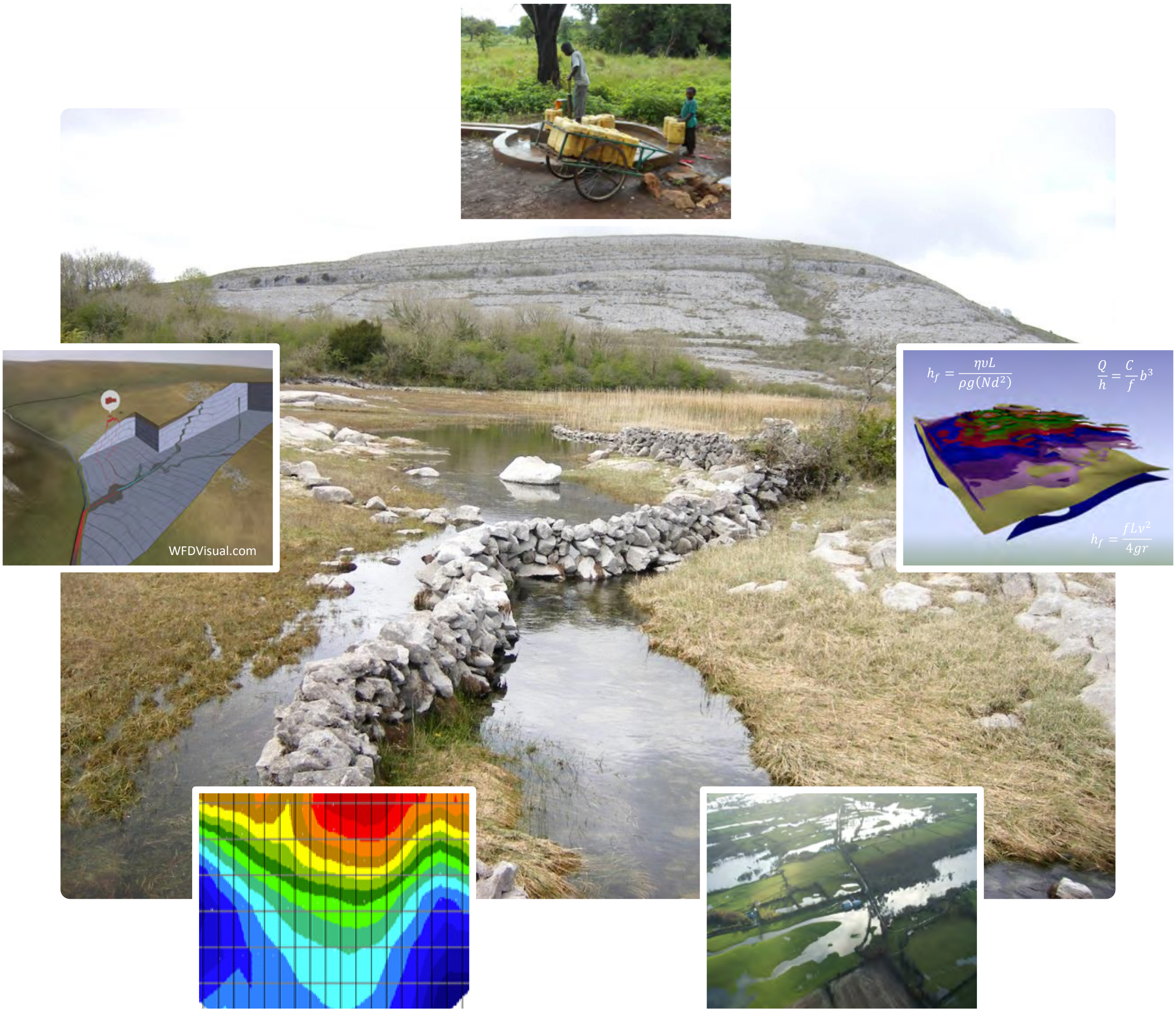
INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS - Irish Group

Integrated Hydrogeology: Contemporary Principles, Policy & Practice



Proceedings of the 35th Annual Groundwater Conference
Tullamore, Co. Offaly, Ireland

21st and 22nd April 2015

www.iah-ireland.org

INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS
(IRISH GROUP)

Presents

'Integrated Hydrogeology: Contemporary Principles, Policy and Practice'

Proceedings of the 35th Annual Groundwater Conference

Tullamore Court Hotel
Tullamore
Co. Offaly

21st and 22nd April, 2015

INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IRISH GROUP)

Founded in January 1976, the IAH-Irish Group membership has grown from 10 to over 130, and draws individuals from professional backgrounds ranging from academic to state agencies to private consultancies. The committee consists of a council of: President, Secretary, Treasurer, Burdon Secretary, Northern Region Secretary, Fieldtrip Secretary, Education & Publicity Secretary, Conference Secretary, plus a conference sub-committee.

Regular activities of the Irish Group consist of an annual two-day conference (currently held in Tullamore), an annual weekend fieldtrip, and a series of monthly lectures/ technical meetings. Funding for the association is derived from membership fees and the annual conference. We welcome the participation of non-members in all our activities. Other activities of the IAH (Irish Group) include submissions to the Irish Government on groundwater, the environment and matters of concern to members, organising the cataloguing of the Burdon library and papers, which are now housed in the Geological Survey of Ireland Library, invitation of a guest speaker (often from outside Ireland) to give the David Burdon Memorial Lecture on a topic of current interest, and contributing to the Geological Survey of Ireland's Groundwater Newsletter.

The Irish Group provides small bursaries to students doing post-graduate degrees in hydrogeology and pays the annual subscriptions of a few members in other countries as part of the IAH's Sponsored Membership Scheme. If you would like to apply for a student bursary, details can be found on the IAH (Irish Group) website shown below. IAH are encouraging members to highlight their local IAH Group to their colleagues/ students and to invite anyone they feel may be interested to join.

The IAH (Irish Group) is also a sponsoring body of the Institute of Geologists of Ireland (IGI).

For more information please refer to:	*http://www.iah-ireland.org*
Future events:	*http://www.iah-ireland.org/upcoming-events/*
IAH Membership (new or renewal):	*http://www.iah.org/join_iah.asp*
	http://www.iah.org/payonline

2015 Conference Objective

As with previous years, the 2015 IAH (Irish Group) Groundwater Conference can be expected to benefit hydrogeologists, engineers, local authorities, consultants, planners, environmental scientists, public health officials, professionals and practitioners from a variety of sectors involved with groundwater.

2015 is the 35th Anniversary of the Annual IAH (Irish Group) Groundwater Conference. This year's theme is entitled '*Integrated Hydrogeology: Contemporary Principles, Policies and Practice*'. This year in conjunction with RudenAS Geo Solutions and Apex Geoservices we have organised a demonstration of borehole geophysics on Monday afternoon at Carton House, Maynooth, Co. Kildare. Following this, the two-day event is being held at the Tullamore Court Hotel and combines an impressive array of national and international speakers with exhibits, fine dining and a social evening. In general the conference will be broken down into the following main areas:

1. Hydrogeology in Context
2. Hydrogeology for Decision Makers
3. Early Career Hydrogeologists' Network
4. Groundwater Research
5. Hydrogeophysics

IAH (Irish Group) President David Drew will initiate proceedings with an introduction and welcome address. David will chair the opening session on ‘Hydrogeology in Context’ and will begin by introducing the first of two keynote speakers – Denis Peach, visiting Professor at Imperial College London and former Chief Scientist of the British Geological Survey. Denis will describe the need for a whole system approach to the subsurface if future challenges facing hydrogeology are to be met. Our second keynote address will be delivered by David Kreamer, Professor at the University of Nevada and Vice President for North America of the International Association of Hydrogeologists. David will elucidate the factors hindering efforts to enhance water quality and quantity, sanitation and hygiene (WASH), collectively known as hydrophilanthropy, around the globe.

After the coffee break will be the first of two sessions providing updates and insights into contemporary technical, legal and regulatory topics under the theme of ‘Hydrogeology for Decision Makers’. Angela Ryan (Irish Water) will open with a much-anticipated talk outlining the challenges in providing an effective national water supply and the role groundwater plays therein. Margaret Keegan and Pól Ó Seasnáin (Environmental Protection Agency) discuss communication strategies in managing private wells and Groundwater Regulations 2010 compliance guidelines, respectively. After lunch Owen McIntyre (University College Cork) will provide expert insight into the legal protection of ecologically-significant groundwaters, while the hydrological complexities of assessing damage to these important ecosystems will be discussed by Paul Johnston (Trinity College Dublin). Timely updates on the National CFRAM programme (Mark Adamson, Office of Public Works) and the recent Irish Soil Information System (Iolanda Simo, Teagasc) will round off the session.

The final session of Day 1 comprises the inaugural Early Career Hydrogeologists’ Network (ECHN) session. We are delighted to welcome Gillian Hurding, co-chair of the ECHN, who will detail the role early career hydrogeologists can play as groundwater advocates. Gillian will be followed by four talks on different aspects of hydrogeological research from young researchers representing the future of hydrogeology. At the end of a hard day, weary delegates will be treated to an evening of whiskey tasting and a light meal as part of a tour at the redeveloped Tullamore Dew Distillery.

Day 2 begins with an insight into current groundwater research topics. Prof. John Walsh (University College Dublin) will describe the new iCRAG research centre, a major new investment by SFI and industry. Research in the contemporary field of remote sensing for groundwater discharge evaluation will be described by Jean Wilson (Trinity College Dublin). Jonathan Vouillamoz from the Swiss Institute for Speleology and Karst Studies will then explain the KARSYS hydrogeological modelling approach which is currently being implemented on Irish test catchments.

In the closing session on hydrogeophysics we are delighted to welcome Fridtjov Ruden and Balazs Rigler of RudenAS, Norway, who will summarise the capabilities of modern geophysical borehole logging equipment. This talk will be complimented by Peter O’Connor (Apex Geoservices) who will outline surficial geophysical methods relevant to groundwater investigations. Finally Rachel Cassidy (Agri-Food and Biosciences Institute (AFBI), Queens University Belfast) will present a recently published study on the application of multi-scale geophysical techniques in catchment characterisation. Prior to lunch a final Q&A session will be followed by a closing address by the IAH (Irish Group) Conference Secretary, Owen Naughton.

After lunch the technical workshop will continue to provide an informal and interactive environment where delegates can learn and critique different field techniques, and bring their own experiences to the debate. This year Fridtjov Ruden (RudenAS) and Peter O’Connor (Apex Geoservices) will present preliminary results and initial comparisons of borehole logs and surface geophysical data from the field demonstration on Monday. We would like to give a special thanks to both RudenAS and Apex Geoservices for their generous contribution of time and effort to the technical programme this year.

2015 IAH (Irish Group) Committee:

President:	David Drew
Secretary:	Katie Tedd, Trinity College Dublin
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For more information and contact details please refer to: *www.iah-ireland.org*

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The proceedings for the 35th Annual Groundwater Conference 2015 will also be made available digitally on the IAH-Irish Group website within the next six months.

Proceedings published by: International Association of Hydrogeologists (Irish Group)

ISSN 2009-227X (Printed)
ISSN 2009-6151 (Online)

ISSN Key title "Proceedings of the 35th Annual Groundwater Conference (International Association of Hydrogeologists, Irish Group)"

‘Integrated Hydrogeology:
Contemporary Principles, Policy and Practice’
35th Annual Groundwater Conference

International Association of Hydrogeologists – Irish Group
Tullamore Court Hotel, Tullamore, Co. Offaly: Tuesday 21st & Wednesday 22nd April 2015

Programme Day 1, Tuesday 21st April

08:30 - 09:30 *Conference Registration; Tea, Coffee, & Exhibits*

INTRODUCTION

09:30 – 09:40 Welcome and Introduction
David Drew – *President IAH Irish Group*

SESSION 1: HYDROGEOLOGY IN CONTEXT

09:40 – 10:15 ‘An integrated whole system approach to the subsurface: the future for hydrogeology and hydrogeologists’’ – Denis Peach (British Geological Survey and Imperial College London)

10:15 – 10:50 ‘Hydrophilanthropy Gone Awry - How people promoting clean water availability, sanitation, and hygiene (wash) can actually injure communities’ – David Kreamer (University of Nevada and Vice President for North America, International Association of Hydrogeologists)

10:50 – 11:05 Q & A

11:05 – 11:30 *Tea and coffee*

SESSION 2: HYDROGEOLOGY FOR DECISION MAKERS I

11:30 – 11:55 ‘The future of groundwater in the National Water Supply’ – Angela Ryan (Irish Water)

11:55 – 12:20 ‘Poor drinking water quality in private wells: the effectiveness of a communication strategy’ – Margaret Keegan (Environmental Protection Agency)

12:20 – 12:45 ‘Overview of recently published Guidance for EPA Licensees for reporting compliance with the Groundwater Regulations 2010’ – Pól Ó Seasnáin (Environmental Protection Agency)

12:45 – 13:00 Q & A

13:00 – 14:00 *Buffet lunch in Tullamore Court Hotel*

SESSION 3: HYDROGEOLOGY FOR DECISION MAKERS II

14:00 – 14:25 ‘Legal protection for ecologically significant groundwaters under EU Law’ – Owen McIntyre (University College Cork)

14:25 – 14:50 ‘Defining hydrological damage in Groundwater Dependent Terrestrial Ecosytems’ – Paul Johnston (Trinity College Dublin)

14:50 – 15:15	‘The Floods Directive and National CFRAM programme: Assessment of groundwater flood risk’ – Mark Adamson (Office of Public Works)
15:15 – 15:40	‘Soils of Ireland: the Irish Soil Information System’ – Iolanda Simo (Teagasc)
15:40 – 15:55	Q & A
15:55 – 16:15	*Tea and coffee*
SESSION 4:	**EARLY CAREER HYDROGEOLOGISTS’ NETWORK**
16:15 – 16:30	‘The IAH Early Career Hydrogeologists’ Network – What role can early career hydrogeologists play as groundwater advocates?’ – Gillian Hurding (IAH Early Career Hydrogeology Network)
16:30 – 16:45	Hugh Cushnan (Queens University Belfast)
16:45 – 17:00	Eoin McAleer (Trinity College Dublin)
17:00 – 17:15	John Paul Moore (University College Dublin)
17:15 – 17:30	Sara Vero (Teagasc)
19:00	*Social event, including light evening meal, at the Tullamore Dew Distillery, sponsored by IAH (Irish Group).*

‘Integrated Hydrogeology:
Contemporary Principles, Policy and Practice’

International Association of Hydrogeologists – Irish Group
Tullamore Court Hotel, Tullamore, Co. Offaly: Tuesday 21st & Wednesday 22nd April 2015

Programme Day 2, Wednesday 22nd April

9:00 – 9:30 *Tea, Coffee & Exhibits*

SESSION 5: GROUNDWATER RESEARCH

09:30 – 09:55 ‘The Irish Centre for Research in Applied Geosciences (iCRAG) – a major new investment in research by SFI and industry’ – John Walsh (iCRAG, University College Dublin)

09:55 – 10:20 ‘Using GIS and natural tracers to evaluate groundwater discharge to lakes’ – Jean Wilson (Trinity College Dublin)

10:20 – 10:45 ‘KARSYS approach – an explicit conceptual 3D model for karst hydrogeology’ – Jonathan Vouillamoz (Swiss Institute for Speleology and Karst Studies, Switzerland)

10:45 – 11:00 Q & A

11:00 – 11:20 *Tea & Coffee*

SESSION 6: HYDROGEOPHYSICS

11:20 – 11:45 ‘The capabilities of modern geophysical borehole logging equipment and its integration with geological logs and surface geophysics’ – Fridtjov Ruden/Balazs Rigler (RudenAS)

11:45 – 12:10 ‘Recent developments in surface geophysical surveying relevant to groundwater exploration and protection’ – Peter O’Connor/ Shane O’Rourke (Apex Geoservices)

12:10 – 12:35 ‘Hydro-structural characterisation of catchments using multi-scale geophysical techniques’ – Rachel Cassidy (Agri-Food and Biosciences Institute)

12:35 – 12:50 Q & A

12:50 Conference closing address: Owen Naughton (*Conference Secretary* – IAH Irish Group)

13:00 *Buffet lunch in Tullamore Court Hotel*

TECHNICAL WORKSHOP

14:00 ‘Geophysical borehole logging survey’ – Fridtjov Ruden/Balazs Rigler (RudenAS)

14:30 ‘Surficial geophysical survey: Carton House’ – Peter O’Connor/ Shane O’Rourke (Apex Geoservices)

15:00 End of Workshop

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SESSION 5: GROUNDWATER RESEARCH

SESSION 6: HYDROGEOPHYSICS

SESSION I

AN INTEGRATED WHOLE SYSTEM APPROACH TO THE SUBSURFACE: THE FUTURE FOR HYDROGEOLOGY AND HYDROGEOLOGISTS

Denis Peach
British Geological Survey and Imperial College, London

ABSTRACT

There is now a growing realisation in the environmental and social sciences that to address the grand challenges that face the world a whole system approach is required. These challenges including climate change, natural resource and energy security and environment vulnerability raise multi- and inter-disciplinary issues that require integrated understanding and analysis. Not only must we model the whole physical Earth system, bringing together climate, ecological, hydrological, hydrogeological, and geological models to name but a few, we must link them to socio-economic models. This may well be the only adequate way to provide the necessary framework in which decisions concerning prediction and planning can be most appropriately made. The challenges for hydrogeologists are great. Historically investigation and research has centred on water supply and resource issues, followed later by the study of local point and regional diffuse contaminant transport problems. The water/energy nexus means that resources of all qualities become important, disposal of contaminated or highly saline waste waters from fracking or mineral/oil production waters threaten the integrity of aquifers and the traditionally reliable good quality of shallow fresh groundwaters. An understanding of fluid flow throughout the whole geological succession and interactions with surface water and between aquifers will be needed for sustainable development. Hydrogeologists must work across many disciplines and traditional boundaries if they are to help solve the natural resource development issues and problems of the twenty first century. This paper demonstrates through two examples the need for a truly comprehensive whole systems approach.

ECONOMIC, SOCIAL AND ENVIRONMENTAL DRIVERS AND THE ROLE OF GROUNDWATER AND HYDROGEOLOGICAL SCIENCE – THE GLOBAL CONTEXT

Groundwater is under increasing pressure world-wide from over-abstraction and degradation of its quality. It is a vital source of water to many rural communities, but also for municipal, industrial and agricultural water supply. Even in places where surface water is normally plentiful, groundwater can be an important resource in times of drought. However, it is vulnerable to pollution, and due to long travel times between aquifer recharge and discharge, contaminants, once present, can persist in groundwater for decades or even centuries. While groundwater is often a cheap resource to develop, monitoring and investigation are expensive. There are thus major challenges to quantify the extent of groundwater resources and their quality, natural recharge (and hence sustainable supply), the long-term impacts of abstractions and waste disposals, the impact of resource development (mining and oil and gas exploitation), and hence to provide the information needed for sustainable development.

There are a number of global drivers of change that are relevant to the development and protection of groundwater resources in the world over. These include increasing demand for water, from population growth and economic development, increasing need to safely and sustainably dispose of wastes to the subsurface, increasing pressures on groundwater quality, from domestic, agricultural and industrial activities, and concerns for climate variability and change, including increasing drought and flood risk.

The global search energy has direct impacts on groundwater flows and quality. Oil and gas is extracted from the subsurface where groundwater in some form is ubiquitous. The processes of exploitation require water and often involve the injection of fluids into the geological reservoir. For example, hydraulic fracturing or “fracking” has emerged as an important process for enhancing the recovery of oil and gas from shale. Both processes require water and produce volumes of contaminated water (co-produced and flowback), which are often re-injected into the exploited or deeper geological formations. The generation of nuclear energy requires the mining of uranium and the disposal or temporary storage of mine waste in tailings ponds, which has the potential to interact with the environment, including surface water courses and groundwater. The generation produces radioactive waste which must be either stored or more likely contained in a hydrogeological environment, for many tens of thousands of years, before it can be deemed safe. Coal-based energy production similarly raises issues of groundwater protection including pollution from abandoned mines and the management of acid mine drainage, as well as issues of power station atmospheric emissions and ‘acid rain’.

Groundwater issues associated with resource development extend well beyond the energy industries. The development of subsurface resources inevitably involves possible interactions with the groundwater environment. In such cases knowledge of groundwater flow and hydrogeochemical behaviour is essential for safe management of these activities. For example, potash mining produces large volumes of brine (particularly where solution mining is practised). This is often disposed of by injection into geological horizons much deeper that the mined formations, where the mine is distant from the sea.

Groundwater is also intimately linked to food and other agricultural production. Agriculture uses water for irrigation, livestock watering and other on-farm activities, and, globally and locally, groundwater plays a key role in providing water for some or all of these needs. In addition, agricultural land management changes the hydrological cycle and water quality, with impacts on groundwater recharge (and hence sustainability) and on groundwater quality.

In addition to its role as a key water resource in times of drought, groundwater is an important element in many other natural hazards including earthquakes, landslides and floods. In particular, groundwater is an often overlooked aspect of flooding, both in river floodplains and internal drainage basins. More generally, groundwater is important in maintaining baseflows in rivers and groundwater storage is undoubtedly the most important global reservoir we have to draw upon in times of water scarcity.

Notwithstanding these science and management problems, the biggest drivers of governments and peoples are economics and societal culture. The “growth agenda” is firmly the aspiration of all nations as the world pulls itself slowly out of the financial instability and economic weakness of the last seven years. However, it is now accepted and policy of many governments, including those in Europe and North America, that what we do must be sustainable and represent value for money. The consequences of our actions and our decisions must be based on evidence and we need to be able to make forecasts, and if possible predict what might happen in the future, under changing circumstances and varying stresses. As population grows and demands for ever higher standards of living continue, the speed of change and the pressures on the water environment also increase. Given the increasing pressures on groundwater quantity and quality outlined above, there is an increasing need for improved understanding and an integrated approach to management in support of sustainable development.

IMPORTANCE OF HYDROGEOLOGY FOR NATURAL RESOURCE DEVELOPMENT IN SOUTHERN SASKATCHEWAN. CANADA

Much of this section results from a review of groundwater, hydrogeology and sustainability in Saskatchewan carried out in 2013-14 (Peach and Wheater, 2014). The hydrogeology of southern Saskatchewan is dominated by the Western Canada Sedimentary Basin (WCSB) and superficial deposits overlying the solid geology. The Phanerozoic rocks range from Cambrian to the often great thicknesses of glacial deposits. Figure 1 is a simplified cross-section running from southwest to northeast through the sedimentary sequence in Saskatchewan demonstrating the way the deposits thin to the northeast. Table 1 lists the major formations and indicates whether their lithologies include aquifers. The subsurface extent of the major aquifers, fresh water or brackish aquifers is shown on Figure 2. For the purposes of understanding the major likely research and management issues, the succession given in Table 1 can be split into four groups. Table 2 lists the main aquifers used for water supply purposes.

Figure 1 Principal hydrogeological units of southern Saskatchewan and the thinning of the sediments to the northeast (after Meneley, 1972)

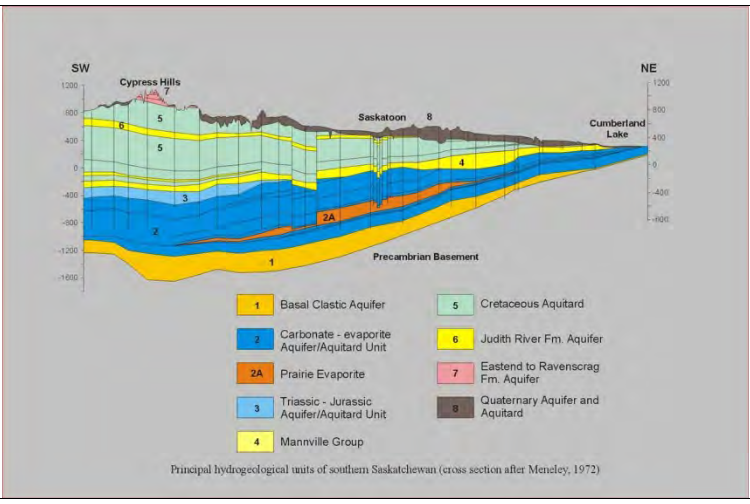


Figure 2 Distribution of water supply aquifers in Southern Saskatchewan (Davies and Hanley, 2010)

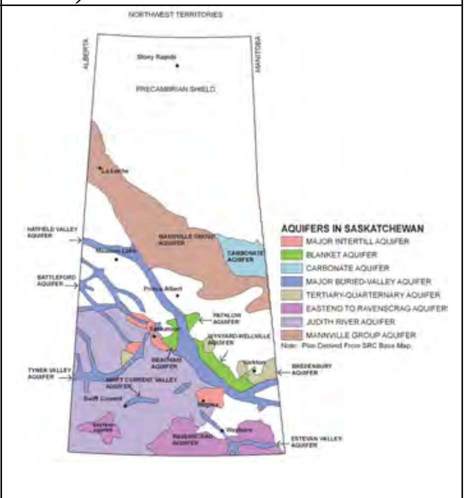


Table 1 Simplified geological succession and hydrogeology of southern Saskatchewan (Maathuis and Thorleifson, 2000)

GEOLOGY			HYDROGEOLOGY	
CENOZOIC	Quaternary	Upper Clastic Unit	Upper Aquitard	Buried-valley, intra, intertill, and surficial aquifers till, silt and clay aquitards
				Bedrock surface
	Tertiary			Paskapoo aquifer
				Eastend to Ravenscrag aquifer
MESOZOIC	Cretaceous			Aquitard
				Odannah aquifer
				Aquitard
				Horseshoe Canyon aquifer
				Bearpaw sand aquifers and aquitards
				Judith River/Belly River aquifer
				Aquitard
				Ribstone Creek aquifer
				Aquitard
				Milk River aquifer
				Aquitard
			Basal aquifer/aquitard system	Mannville aquifer
	Jurassic			Triassic-Jurassic aquifer/aquitard unit
	Triassic			
PALEOZOIC	Perm	Carbonate-Evaporite Unit		Carbonate-evaporite aquifer/aquitard (undifferentiated)
	Pennsylvanian			
	Mississipian			
	Devonian			
	Silurian			
	Ordovician			
	Cambrian	Basal Clastic Unit		Winnipeg/Deadwood aquifer
Precambrian				Impermeable base

Table 2 Hydrostratigraphic setting in the Regina area (Christiansen and Sauer, 2002)

TIME	STRATIGRAPHIC UNITS				
	GROUP	FORMATION	UNIT AND MEMBER	DEPOSIT	AQUIFER
QUATERNARY	Saskatoon Group	Regina Clay and Surficial Stratified Deposits		Silt and sand / Clay	Surficial Aquifer
		Battleford Formation	Upper till	Till	
			Armour Member	Sand and silt Pebbly sand Gravel	Condie Aquifer
			Lower till	Till	
		Floral Formation	Upper unit	Till Sand and gravel	Upper Floral/Regina Aquifer
			Pasqua Member	Upper unit silt and sand Lower unit silt, sand, and gravel	
			Lower unit	Silt, sand, and gravel Till	Lower Floral Aquifer
	Sutherland Group	Warman Formation		Till and stratified deposits	Sutherland Group Aquifers
		Dundurn Formation	Upper Unit	Till and stratified deposits	
			Lower unit	Till and stratified deposits	
		Mennon Formation		Till	
	Empress Group			Sand and gravel	Empress Group Aquifer
TERTIARY			Tertiary sediments	Silt, sand, and gravel	
LATE CRETACEOUS	Montana Group	Bearpaw Formation	Snakebite Member	Silt and clay	
			Ardkenneth Member	Sand and Silt	Bearpaw Sand Aquifer
			Bearpaw (Undifferentiated)	Silt and clay	
		Judith River Formation		Sand and silt	Judith River Aquifer
		Lea Park Formation		Clay	

Firstly the near-surface groundwater system is often intimately connected to the prairie pond systems. Although much research into monitoring ponds, pond overflows and shallow piezometer levels (Toth, et al., 2009 and Nachson, et al., 2013) close to the pond systems has been carried out, this has not been tied into the shallow aquifer systems which lie just a few metres below the base of the ponds. Essentially the pond systems are separated into many hundreds of very small (often much less 1 km^2) internal drainage basins. Understanding the roles of deep and shallow groundwater systems will improve the hydrological conceptual framework for the management of wetland ecosystems (van der Kamp and Hayashi, 2009). Much of southern Saskatchewan is largely disconnected from the main surface water river systems. Recharge processes to the uppermost aquifers, which are extensively used in rural areas for domestic supply and by farmers for livestock and other farming activities, are largely unquantified and have not been numerically modelled with any confidence so the sustainability of these aquifers is uncertain.

Beneath this upper 5-20 metres there are many Quaternary glacially-deposited aquifers (Table 2). These are inter-bedded with thick and very poorly permeable till deposits, where interstitial water has sometimes been shown to be many thousands of years old (Hendry,1988; Shaw and Hendry,1998). These aquifers tend to be discontinuous and of very variable thickness and hydraulic conductivity. Understanding flow and resource availability in these discontinuous Quaternary and the Tertiary units is a major challenge. They provide water supplies to many small towns and communities, for example Yorkton in the southeast of the province (Maathuis and Simpson, 2006). The morphology of these aquifers and their lateral heterogeneity and continuity are often unknown and their interrelationships with other aquifers not well understood. Their yields are usually low to moderate, but they are often the only sources of rural water supply away from the main rivers.

Thirdly the Quaternary overlies older bedrock, including aquifers of the Tertiary and Cretaceous clastic deposits. The Empress Group (Table 2) consists of cross-cutting buried valley sands and gravels. These buried-valley fills commonly function as aquifers that yield abundant groundwater. They can be tens of metres thick and infill valleys of a Tertiary and early Pleistocene drainage system and can form major aquifers that run longitudinally for several hundred kilometres. They have distinct morphologies and a distinct stratigraphic setting, which imparts them with distinct hydrogeological properties. Although there has been considerable study of their geology and hydrogeology

(Cummings et al., 2012), their distribution and the detail of their morphology is less well known, and the hydrogeological interactions with Quaternary aquifers or deeper aquifers like the Judith River aquifer are very uncertain. They are known to cut deeply into Bearpaw and Judith River aquifers, both of which are used for supply purposes (Slawinski and Glen, 1987; Cummings et al., 2012). Little modelling of these various interactions has been carried out and the origins of recharge to these aquifers is often uncertain, as in the case of the Estevan aquifer which suffered over-pumping in the late 1980s and early 1990s (van der Kamp and Maathuis, 2012). Here full recovery of the groundwater level seems to be still many years away and the sustainable yield of the aquifer has been revised downwards twice in the last 20 years as recovery has taken so long.

Lastly beneath the Judith River aquifer there are saline aquifers that have never been used to supply potable water, but are sometimes used for oil and gas operations and as fracking water. They are extensively used for the disposal of saline brines from oil and gas extraction or potash mining and processing. The most commonly used aquifers are the deep Cambro-Ordovician Winnipeg and Deadwood aquifers. These are often used by both industries. The Ordovician, Silurian, Devonian, Carboniferous and Permian deposits are, for the most part, composed of a very thick sequence of carbonates, evaporates and shales (including the Bakken shale from which oil is extracted). Within these lies the Prairie Evaporite Formation which contains the valuable Potash deposits. Problems include ingress of groundwater into the mines and the disposal of water pumped out of the mine either for groundwater control or from “bastard” brine mining.

The Aquistore CO_2 storage project will inject supercritical CO_2 into the Cambro-Ordovician flow unit that is comprised of the Deadwood Formation and the Winnipeg Formation. These formations are also used for similar purposes by the oil and gas industry and the potash mining industry. All of the activities that are developing the energy and mineral resources of Saskatchewan require the drilling of deep boreholes. In 2012 an estimated 29,600 wells produced 172.9 million barrels of oil, however boreholes drilled in the 1950s may be not be well sealed and may provide a vertical pathway between aquifers. This increases the vulnerability of shallower aquifers, particularly where fracking is being carried out (Jackson and Desseault, 2013).

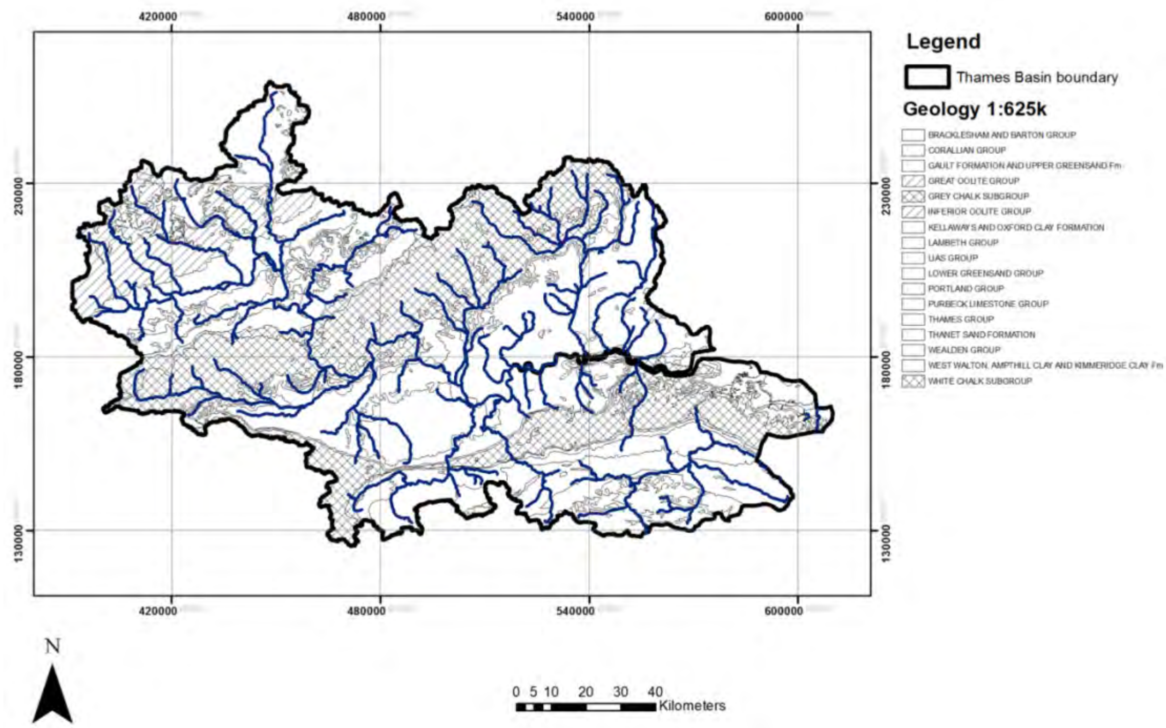
There are some broad conclusions that can be drawn from this appreciation of the hydrogeology, its complexity and the current economic, social and science drivers outlined above. Firstly greater competition for water supplies for industrial and agricultural purposes is likely to result in a greater demand on groundwater. Recharge is largely unquantified, whether directly from rainfall or indirectly from surface water. The dynamics of storage replenishment are uncertain, as demonstrated by the Estevan Valley aquifer’s slow recovery from over-abstraction but in other aquifers the flow regimes may be quite different. Also there will be greater competition for the use of geological pore space, for the disposal of contaminated brines and CO_2 from a variety of sources. The long-term impacts on the subsurface and the connection to the surface and to mines and to other fresher groundwater resources are currently unknown. Thus a holistic understanding of hydrogeology and flow processes is essential to sustainably develop the natural resources of Saskatchewan. This is in common with other parts of Canada, USA, Europe and the rest of the world.

A HOLISTIC APPROACH TO UNDERSTANDING THE HYROLOGY, HYDROGEOLOGY AND MANAGEMENT OF THE RIVER THAMES BASIN, UK

The River Thames Basin is home to 13 Million people, considerable industry and valuable aquatic ecosystems all of which require the effective and sustainable management of the water environment in the basin to thrive. A thorough understanding of the hydrology of the basin is vital to underpin this management to ensure the best use of resources. This is particularly important given the pressures of population increase, increasing water consumption and climate change. The geology of the Thames results in around 12 aquifers most of which are largely not hydraulically connected, except via the River Thames and its tributaries. These aquifers are very important for water supply and their provision of base flow that sustains the ecology of the river system in dry summer periods and droughts.

Holistic management of the system can only be undertaken effectively if an integrated understanding is developed. This has been shown by (Hughes et al in-press) and some of that work is described here.

Figure 3 Simplified geological map with main aquifers (after Hughes et al, in press)



The geology with the main aquifers in the basin is shown on Figure 3, with the Jurassic Limestone aquifers in the west and the Chalk of the Berkshire Downs, Chilterns and North Downs seen to the north and south of the River Thames in the centre of the basin. The hydrogeology of the Thames Basin can be thought of as an alternating sequence of major, minor and non-aquifers. Groundwater flow cannot, therefore, be passed laterally in the sub-surface across the whole of the basin. The River Thames and the majority of its tributaries are heavily baseflow dependent (Bloomfield et al., 2011), that is, the groundwater contribution to average surface flow is significant, i.e. >50%. Therefore, rivers are key to the interconnection of aquifer units (Figure 3). Baseflow discharged from aquifers in the upper part of the catchment can recharge the aquifers downstream. This means that a river model has to be included in the basin modelling composition. It also means that models of the aquifers must be able to interact with the river model. This provides a flexible approach and allows groundwater models to be developed separately, if required, and linked to a river model capable of simulating surface water hydraulics.

The variability of the extreme droughts of 1975/6, 1988-92, 2004-6 and 2010-12 droughts is used to show how spatial variability of weather interacts with the spatial heterogeneity of the hydrogeology. For Figures 4 (a) to (d) (after Hughes et al in-press) the rainfall is plotted as a percentage of 1961-90 long-term average for each 1 km^2.

Table 3. Summary of Q50 and baseflow index for recent droughts

	River Thames at Eynsham			River Thames at Kingston		
Period	Median (m^3/s)	%age average	BFI	Median (m^3/s)	%age average	BFI
LTA	9		0.686	35.6		0.589
1975/6	1.6	17.78	0.682	7	19.66	0.590
1988/92	4.5	50.00	0.587	20	56.18	0.481
2004/6	8	88.89	0.726	18	50.56	0.539
2010/12	4.6	51.11	0.687	12	33.71	0.570

LTA – Long-term average 1/1/1970 to 31/12/2012

As can be seen on Figure 4 the 1975/76 drought presents a consistent picture of very low rainfall over the whole basin. In 1988-92 there is perhaps a little more variation with slightly more rainfall over the Cotswold region in the west. However the 2004-6 rainfall appear to be distinctly lower over the Chalk aquifer of the Berkshire Downs and Chilterns than over the Jurassic Limestone aquifers of the Cotswolds, whereas there is a hint of the reverse in the 2010-12 drought. Thus rainfall variability is highly likely to have an impact on recharge to the various aquifers of the basin and hence base flow to the River Thames and its tributaries. A summary of the median and percentage of long term average flows in the Thames at Eynsham (downstream of the Jurassic Limestones but upstream of the Chalk and Kingston (the tidal limit of the River Thames), shown on Table 3 (Hughes et al in-press), shows this to be the case.

Also anecdotal evidence (pers comm, Jones) indicated that the 2004-06 drought had more impact on the east of the catchment than the west and that the baseflow from the Cotswolds supported the overall flow in the River Thames, also supported by the flows in Table 3.

Figure 4a Rainfall 1976 drought

Figure 4b 1988-92 drought

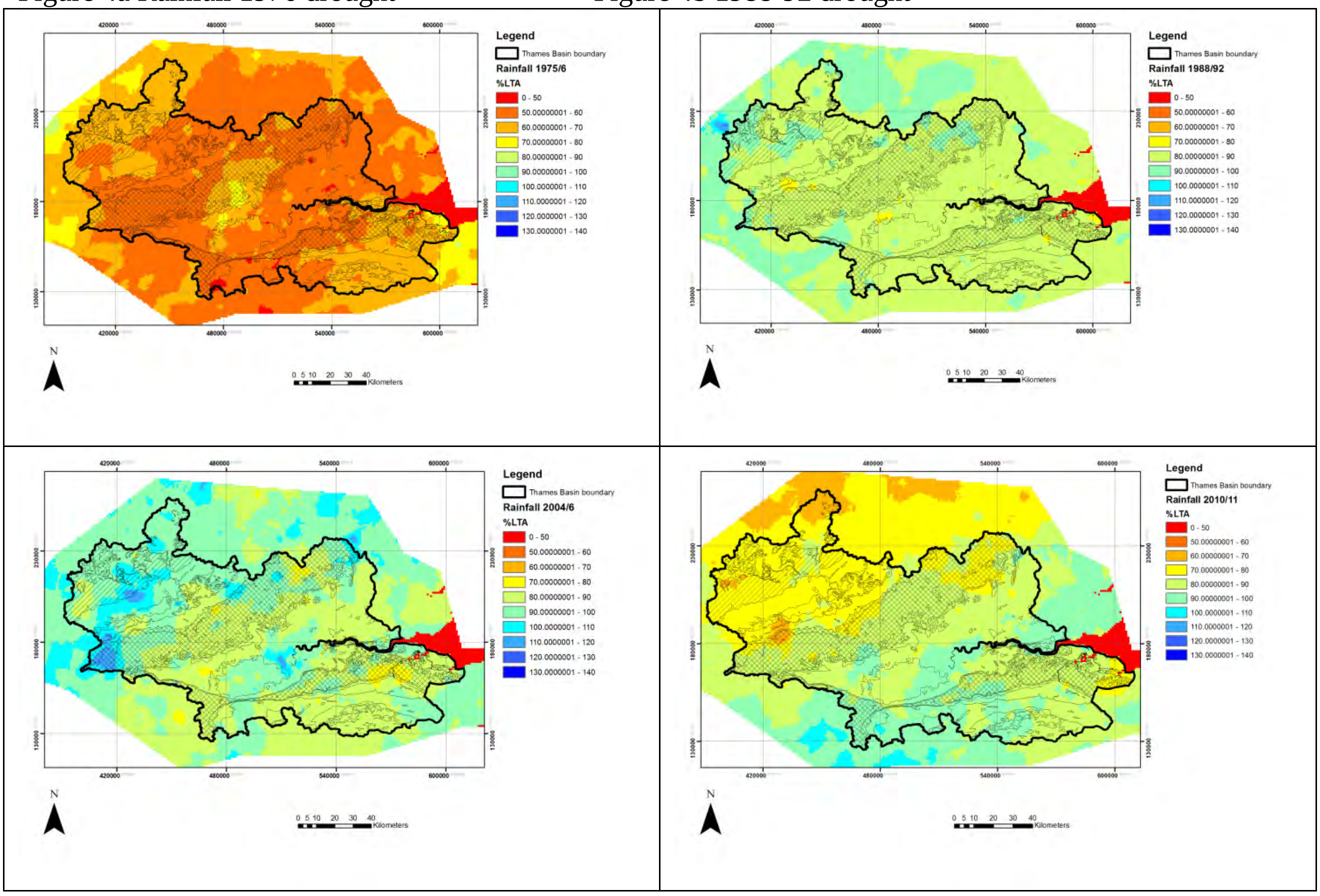


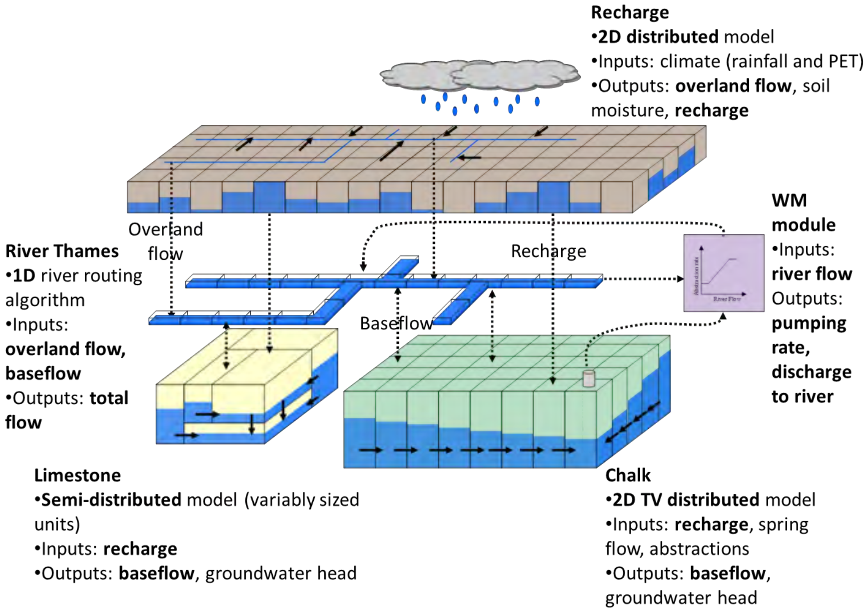
Figure 4c Rainfall 2004-6 drought

Figure 4d Rainfall 2010-12 drought

The spatial variability in rainfall and hence recharge interacts with the hydrogeological heterogeneity of basins. This must be taken into account by modelling and analytical approaches. So in order to model the Thames basin hydrology the whole basin must be considered and both surface and groundwater flows must be considered. A suggested regime (Hughes et al in-press) is that shown in Figure 5. The model system includes groundwater models of both the Jurassic Limestones and the Chalk, a river model linked the groundwater models and management models to apply the operational systems that are used for licensing and practical engineering purposes in the Thames basin. This has to some extent now been done in the British Geological Survey Thames Integrated Model and is discussed in Mansour et al., 2013 and Hughes et al in press

CONCLUSIONS

Figure 5 Model linkages for the Thames Integrated Model (Hughes et al in-press)



The examples of complexity in the hydrogeology of the phanerozoic geological succession, and the interdisciplinary nature of the management necessary to achieve sustainable development of natural energy and mineral resources and water resources for the benefit of mankind and the environment indicate that no longer can hydrogeologists work only within their disciplines. They must embrace those areas of science (including social sciences) and engineering that interact with groundwater flows and quality and link to them through appropriate modelling and analysis. Nevertheless holistic approaches suggested here mean that much more data will be required to validate the models so campaigns for more monitoring are to be welcomed and encouraged.

ACKNOWLEDGEMENTS

The data for the Figure 3 was provided by Centre for Ecology and Hydrology, UK and processed by Dr Majdi Mansour. Andrew Hughes commented upon the manuscript.

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HYDROPHILANTHROPY GONE AWRY: HOW PEOPLE PROMOTING CLEAN WATER AVAILABILITY, SANITATION, AND HYGIENE (WASH) CAN ACTUALLY INJURE COMMUNITIES

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ABSTRACT

Efforts to enhance water quality and quantity, sanitation and hygiene (WASH) around the globe, also known as hydrophilanthropy, can be hindered by a variety of factors. Solid, long-term improvement can be obstructed by the thoughtless acts of would-be hydrophilanthropists, like the lack of observance of regional norms, customs, mores, and traditions in host countries, or by more complicated interpersonal relationships, such as the lack of coordination with communities both before and during installment of local improvements. Other stumbling blocks can include: absence of long-term strategic planning; insufficient scientific and engineering design and construction; poor anticipation of future events and complicating issues; use of inappropriate technologies that do not fit into the community; lack of educational programs, (both for the community to understand and provide stewardship for the project, and for the education of the those installing WASH facilities by the community); and absence of meaningful project follow-up. This paper seeks to use select historical and literary figures and events to underscore types of human failings and activities that compare with behaviors that can instigate the failure of WASH endeavors. This is strictly a heuristic exercise, designed to entertain as much as inform. Just as there is no single way to undermine well-intentioned water and sanitation efforts, there is likewise no exclusive approach to achieve successful WASH development that will suit all circumstances. But avoiding common mistakes can bring essential resources to villages, and in the process empower communities, diminish sickness and mortality, and advance the human condition.

INTRODUCTION

Hydrophilanthropy embodies humanitarian actions which increase and sustain clean water in areas of need. On the whole, hydrologists, water engineers, and social scientists dealing with water are, by nature, inclined to improve the human condition. Often by dint of their professional vocational choice alone, they have motivation to address resource problems of global import. Likewise, many members of the general public are inspired to lend a hand in tackling world-wide water, sanitation and hygiene challenges (often referred to by the acronym WASH). The scale of those challenges can be enormous.

While health figures do not do justice to individual suffering, and irreparable environmental damage is not adequately reflected in statistics, the numbers can be staggering. While estimates vary, the World Health Organization and UNICEF (WHO 2014) calculate that 748 million people do not have access to clean drinking water. The mortality attributed to lack of clean drinking water is estimated at 3.4 million deaths per year, or roughly 10,000 a day, many of which are children (2.2 million) (Sauer 2010). According to the World Bank (2014), one billion people practice open defecation and those without access to improved sanitation number over one third of the earth's population - about 2.5 billion. These approximations, and others like it, do not show the whole picture, as clean water scarcity can have far reaching and cascading effects. These effects include: malnutrition caused by agricultural shortages and lack of irrigation water, population displacement and migration in response to drought, economic losses due to worker illness and absenteeism, and lack of educational opportunities for children who must collect household water from distance (often with gender-bias harming young girls). Water scarcity and poor water quality not only profoundly affect human communities, but ecosystems throughout the world.

Water professionals and the general public respond to this continuing humanitarian and ecological crisis with hydrophilanthropic efforts which can range from successful sustained activities, (that improve the well-being of villages and municipalities and produce healthy biotic communities), to dismal failures which can produce more harm than good. Understanding the many pitfalls of engaging in WASH efforts, and conversely, realizing the strategies for successful clean water projects, can better prepare well-motivated people to create lasting resources and encourage community capability and self-sufficiency.

This article is a bit of a tongue-in-cheek approach to describing the many pitfalls of hydrophilanthropy, drawing on admittedly questionable analogies with historical figures and events, and fictional characters. The attempt here is to approach a deadly serious topic in a lighthearted way, by focusing on the human failings and inadequacies of many "do-gooders" who blunder into communities and situations they often do not understand. These well-intentioned individuals are sometimes out of their depth, sometimes blindly and patronizingly holding their cultural, religious and societal values to be superior to the communities they are attempting to serve. And they sometimes do more harm than good.

In writing this, the author appreciates and gratefully recognizes that many WASH efforts achieve positive and sustainable results that improve the world, community by community. The topic of WASH failure is approached here in a very casual, allegorical fashion. Nevertheless, the article does not lose sight of the irony of how the comedy of befuddled, naïve, inexperienced and/or ill-prepared hydrophilanthropists, convinced of their own good works and superior methodologies, can add to the tragedy and dire circumstances of their individuals in recipient (or should I say "victim") communities. The light-hearted tone belies the more sober and urgent message: the need to carry out philanthropic WASH projects in a considered, effective and sustainable way.

SELECTED ALLEGORICAL WAYS HYDROPHILANTHROPY CAN BE BUNGLED

The Antonie van Leeuwenhoek View - Not Looking at the Broad Picture

A well-meaning person or group of people can put in a perfectly good borehole in a village, which is drilled and constructed perfectly, placed in a high-quality productive aquifer, close to residents it is intended to serve, producing clean water in abundant quantities, in a community that is in great need of the resource. But if the well is placed in the backyard of someone the community hates, the well-intentioned hydrophilanthropist can start a water war that can last generations. Like van Leeuwenhoek, the Father of Microbiology, peering into his creation, the microscope, these folks might see their objective clearly, but miss the bigger picture in their periphery. Their tunnel vision might match that of Antonie, the first to view single celled organisms he called "animalcules", who was probably not aware of his surroundings as he stared into his magnifying lens. There is real importance outside the immediate scope of WASH endeavors, and the human and ecological environment for these activities is not an isolated animalcule in magnification, but they are linked, expansive, multifaceted systems that change with time.

Not anticipating all possible outcomes of WASH undertakings can cause unforeseen societal harm on either a small or far-reaching scale, and even cause massive calamity resulting in the illness and death of many innocent individuals. A classic example of the van Leeuwenhoek WASH syndrome (sic.) is the case of arsenic in boreholes in Bangladesh and India. Inadequate pre-testing, and the absence of any data on aqueous arsenic groundwater concentrations in reports by the British Geological Survey, led to the drilling of thousands of contaminated tube wells for potable water supply in Bangladesh and

India in the 1980s and 1990s. Many of these boreholes were drilled by UNICEF and other philanthropic groups. Over 100,000 people are projected to have been sickened by high concentrations in shallow wells regionally (Brahic 2004), and according to Hossain (2006), arsenic poses a hazard to an estimated 57 million people in Bangladesh. Each year another 270,000 have been calculated to have had associated cancer deaths, because long term ingestion of arsenic has been related to cancer of the kidneys, lungs, bladder and skin (Brahic 2004). The human suffering caused by what some have called *one of the largest mass poisonings in history*" has been tremendous, and in the words of Richard Wilson of Harvard University, "*Bangladesh makes Chernobyl look like a Sunday-school picnic*" (Clarke, 2001). Clearly in their limited assessment of the large flood-plain groundwaters of Bangladesh and India, the British Geological Survey did not foresee complicating factors, or reflect those uncertainties in their technical reports.

Mr. Magoo Myopia – Not Planning and Anticipating the Future

Or maybe the analogous eye disorder should not be van Leeuwenhoek's tunnel vision (Kalnienk vision), but myopia, a clear vision of what's up close, but fuzzy at distance. In this case the unseen distant view would be adverse future implications to a community resultant from an individual water or sanitation project. Older readers might know of a classically nearsighted cartoon character created in 1949 by the United Productions of America studio, Mr. Magoo, who might well serve as the standard bearer for this affliction. This character was unaware of his limitation and made a mess of various day-to-day projects. In WASH projects there is a need for clear vision, insight, and long term planning for sustainability.

The Neville Chamberlain Approach - Doing the Minimum and Hoping It Will Be Okay

Neville Chamberlain signed the Munich Agreement in 1938 and forever would be known as having a policy of "appeasement" toward Adolf Hitler's Nazi Germany. His expectation was that this concession of ceding the Czech region of the Sudetenland to Germany would be enough to bring future peace. The analogous expectation, that any WASH effort however minimal or stopgap will always be beneficial, is equally unrealistic. Incomplete projects with no follow-through, can experience physical breakdowns in pumps, well casings, and screens, leaving resultant water quality and quantity more diminished than before the project was initiated. This, unfortunately, is the case in much of the developing world. For example, a survey of 21 African nations conducted January 2009-December 2011 found that 36% of installed well pumps were non-functional (Rural Water Supply Network Work Plan) and more specifically, the International Institute for Environment and Development (IIED 2009) reported that in the Menaca region of Mali, 80% of water points are "dysfunctional", and 58% are in need of repair in northern Ghana. According to the Netherland's International Water and Sanitation Centre (2009), concerning wells,

> *"In the last 20 years, 600,000–800,000 hand pumps have been installed in sub-Saharan Africa, of which some 30 percent are known to fail prematurely, representing a total failed investment of between $1.2 and $1.5 billion".*

By not mounting a full and sustained effort, WASH "appeasement" undertakings might have short term gain, but long term ruin.

The "Twerking" Approach - Not Respecting Local Cultural and Religious Norms

At the 2013 MTV Video Music Awards, singer Miley Cyrus took to the stage in a nude-coloured bikini, "twerking" suggestively. The term "twerk", which was added to the Oxford dictionary that same year, is a type of provocative dance, with hip thrusting and suggestive movements. The widely viewed performance of Ms. Cyrus, mildly discomfiting and somewhat off-putting to some viewers, is chosen here to represent analogous, and more egregious, behavior by hydrophilanthropists who do not respect and/or are not aware of societal norms in the communities in which they work. Transgressions of this type undermine positive activities and can indicate a lack of respect for a local community and their values. Hydrophilanthropic "twerks" can include inappropriate attire or speech, and actions which are in opposition to community customs, mores and traditions. Underlying these insensitive actions is often an inability or an unwillingness of the would-be hydrophilanthropist to understand and fully empathize with local values and circumstances.

Crusaders After the Holy Grail - Trying to Convert Those Who Just Want Clean Water

Some hydrophilanthropists have a second agenda in their WASH efforts, and that is to impose their religious beliefs on a foreign community. While many individuals and faith-based charities are inspired by a religious world view which positively motivates their actions, there are some who thoughtlessly shove their convictions and dogmas down the throats of those they are attempting to assist. Similar to the previous section, this activity effectively disrespects local values and perspectives, to the detriment of clean water projects.

Seal Team Six Approach - Short-term In and Out, Epitomizing a Lack of Follow Up

Many professionals, students and other individuals who donate their service and resources on WASH projects overseas have severe financial limitations and time constraints. Like the group SEAL Team Six, popularized in the movie Zero Dark Thirty which chronicled the raid on Osama Bin Laden, many volunteers feel like they are inserted into a foreign country and then extracted on a predetermined schedule. (SEAL Team Six is the United States Naval Special Warfare Development Group, NSWDG, which specializes in rapid surgical military operations). This creates a tendency to have incomplete projects with no follow through. Writing about groundwater management needs, Burke and Moench (2000) stated,

> "*needs cannot be viewed as 'problems' that, once 'solved', require little attention. Instead, current problems signal the emergence of management needs that will require long-term attention."*

Beyond groundwater management, their comments are appropriate to address shortcomings that plague the larger arena of WASH management as well. The Water, Sanitation and Hygiene Rotary Action Group of Rotary International (WASHRAG 2014) points out: *"The world is discovering that effective programs take 3 to 5 years to be sustainable – local community engagement and appropriate technologies are keys to success."*

Another strategic error made by many groups is measuring success by the number of beneficiaries, not the long term sustainability of a project. Ned Breslin (2010) writes,

> *"Despite the images that dominate the sector – pictures of children happily gulping water from a new tap or the counter-image of women collecting water from dirty puddles – the real image should be the one that plays itself out every day all over the world of the woman walking slowly past a broken handpump, bucket at her side or on her head, on her way to (or from) that scoop hole or dirty puddle that she once hoped would never again be part of her life."*

Hopefully that paradigm, of beneficiaries before sustainability, is changing.

The Bernie Madoff Ponzi Scheme - Depending on Resources That Aren't There

Bernard L. Madoff was arrested in 2008, convicted on conducting the largest securities financial fraud in history, a "ponzi" scheme where he gained investors, while at the same time no tangible investments were made or resources were available. While WASH groups do not conduct a ponzi schemes, some similarly venture into new projects with a dependence on nonexistent resources. This includes unrealistically high standards of expected transportation and shipping, unfounded trust in local availability of supplies and services, reliance on a non-existent workforce, and false confidence in projected government cooperation and easy permitting. The quixotic quest of these well-motivated hydrophilanthropists often ends abruptly or becomes mired in unforeseen complications.

The "Balrog Got Gandalf" Eventuality – Missing Oversight or Leadership

Some WASH projects either begin with poor leadership or lose a central organizing leader due to unanticipated events (e.g. illness). Like wandering people, dwarfs, and hobbits from Tolkien, the once straightforward water and sanitation undertakings can begin to meander. Out of the Mines of Moria the leaderless hydrophilanthropists can find themselves running from the wargs of lost language translational skills, the orcs of missing personal contact information, and/or the goblins of derailed logistics. Contingency planning can avoid this.

Additionally, inherent project weaknesses can be exacerbated due to the very nature of their volunteers. Breslin (2010) points out the example of engineering students implementing projects in developing countries, where they would never be allowed to implement an engineering project in their more affluent home country. But fundamental mistakes have even been made by experienced professionals without proper guidance, oversight and leadership.

The Peter Pan, Playpump People Diversion - Inappropriate Technology

Peter Pan's ardent wish to never grow up, is reflected in the PlayPump technology, where the energy from a spinning playground roundabout disk is used to pump water from a well. The image of playful children having a great time and simultaneously pumping needed water in a Developing Nation is a happy image that has engaged many donors. The reality is more moderate (Chambers 2009). In some cases, like elementary schools with abundant children and plentiful shallow groundwater, this technology may be very beneficial. However, PlayPumps are less efficient hand pumps or treadle pumps, and are ill-fitting for many target communities. This top-down, donor pleasing idea fails significantly in rural communities, where people do not ride on this contraption for what would be sickening hours, but struggle to turn these by hand. Many claim that the marketing claims have been overblown, and some charities flat-out refuse to install them. Some of their reasons are: the cost (four regular pumps could be installed for the price of one PlayPump), complex pump mechanisms that are hard to maintain and repair, dependence on child labor, the community need for water at times when children would not be playing (during school hours, during inclement weather, and in the early morning), and injury risk. The PlayPump is symptomatic of many different applications of inappropriate technology to WASH effort.

Relics of other forms of inappropriate technology litter the landscape in the developing world. Examples include: motorized well pumps that have broken down in short order and were unable to be repaired, then scavenged for parts, (where a repairable hand pump would have been more appropriate); and toilets installed in places where no toilet paper is available and the facilities quickly become blocked with refuse and overflow.

The Superman Syndrome – I Can Do It All!

Too many WASH programs do not engage the local communities in which they operate, for shared success. They swoop in, "fix" a problem, and swoop out, supplying free water or sanitary systems, and not providing a basis for community stewardship and sustainability. The stated goal of many non-government and service organizations (NGOs) is to "help the poor", but too often this does not include providing the continuing educational and entrepreneurial resources to ensure sustainability. Perhaps this dilemma is best stated by Breslin (2010):

> *"This story plays out day after day in Africa despite the compelling stories told by the NGOs and service organizations who demand more money to help the poor. The underlying message of free water systems is that communities are "too poor," "too disorganized," or (dare we say what all this truly means) "too incompetent" to actually lead their own development. The undertones are patronizing without exception. The reality is that most NGOs and almost all hands-on practitioners do not have the time,*

patience, or the real access and understanding of community development to establish the sound financial underpinnings critical to project success."

So the Superman(woman) hydrophilanthropist, who is not cognizant of his/her underlying patronizing attitude, zooms in, installs a system, and zooms out, not working with the locals. It is a quick trip with Supermen and Superwomen not drawing on the community's knowledge and abilities, and without attempting work together for sustainability. One can imagine a statement from one of these Superheroes (such as the words of the comedian Christopher Titus's anti-hero) wafting back through the air as they fly away: *"My work here is done – when your self esteem returns, so will I!"*

Suggestions for a Way Forward

There is no single approach to WASH development that fits all situations, but some basic principles create common themes for success. Taking a broad view, and anticipating future contingencies for a project is an excellent start. This includes a proper hydrogeological evaluation for future well sites. Respecting the indigenous culture and mores of societies that hydrophilantropists visit can go a long way into building good-will. Divesting practitioners of the need to impose their own separate belief systems on the populace allows trust to develop. A crucial building block is performing comprehensive, on-the-ground pre-evaluation which includes consideration of each community's abilities, resources, and potential development. That robust understanding of local resources can foster a genuine appreciation of the abilities and potential for what the community can be, tying hydrophilanthrophy into overall economic and human development. Following up WASH projects with post evaluation activities that promote sustainability is key. One example would be linking WASH projects with community education and self-education responsive to arising needs and community responsibility for stewardship. Another essential element is using appropriate technology that permits easy system repair and maintenance. Importantly, assisting the community in taking on the responsibility for future WASH success, handing the baton over, is one of the best gifts hydrophilanthropists can give. For those who serve throughout the world, you deserve admiration and support.

This has been an attempt to present, in a facetious way, the potential foibles and stumblings of professionals and nonprofessionals who engage in profoundly important WASH activities. The preceding heuristic exercise is meant to illustrate and underline some basic suggestions for WASH improvement. The author wishes to express his apologies to the historical and literary figures he has bashed about and ill-used in the quest of establishing their admittedly tenuous links with hydrophilanthropical misdeeds and ineffective action.

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SESSION II

THE FUTURE OF GROUNDWATER IN THE NATIONAL WATER SUPPLY

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ABSTRACT

Delivering a safe and reliable drinking water supply to over 80% of the population requires the abstraction, treatment and delivery of over 1,600 million litres of water each day. At present water is produced at 856 individual drinking water treatment plants, many of which have multiple sources, isolated networks and are in need of major capital upgrade. 439 of these water treatment plants utilize ground water sources, 361 of which use simple disinfection as the sole treatment processes. Many of the treatment plants were developed based on demand in the immediate area and often abstract water from unsuitable sources, or have inadequate treatment processes. The distribution networks and reservoir storage associated with small isolated water supplies offer very limited resilience and in the event of an outage at a treatment facility, whole supply zones can be left without water.

In order to fulfil our objectives under the Water Services Strategic Plan, Irish Water will review water resources at a national level, and over the next 25 years move towards a more sustainable methodology of delivering water services to our customers based on water quality, supply resilience, environmental and economic best practice.

In this evolving landscape, it is inevitable the current way in which groundwater contributes to the overall national public supply will change. However, it is envisaged that groundwater will always contribute a significant percentage of the national supply, and will become increasingly important as a strategic resource.

1. NATIONAL WATER SUPPLY PICTURE AND THE ROLE OF GROUNDWATER

Delivering a safe and reliable drinking water supply to the 80% of the population connected to the public water supply, requires the abstraction, treatment and delivery of over 1,600 million litres of water each day. Water is delivered to each tap from in a water supply zone, through a pressurised water distribution network served by a single source or group of connected sources (from - lake, river or groundwater), or from a mixture of water treatment plants. Irish Water aims to provide a consistent service in terms of water quality and supply resilience to all of our customers

At present there are 856 individual water treatment plants in Ireland feeding water into 1006 water supply zones. Of the 856 plants, 80% produce less than 1ml/d, whilst the top 15 plants in terms of output volume produce over 50% of the national supply of drinking water (see Figure 1).

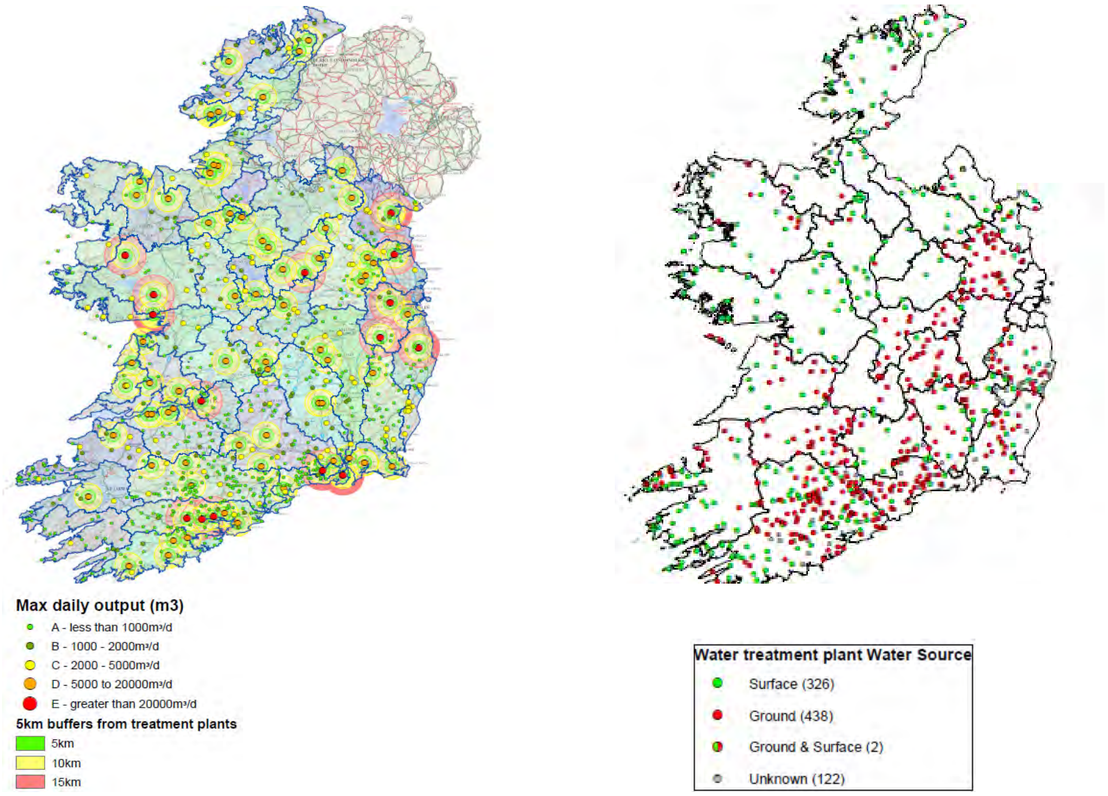


Figure1-Water Treatment Plants ROI

Ground Water Supplies represent 52% (see figure 2) of the overall number of water treatment plants; however, these 439 facilities provide just 14% of the daily deployable output, giving an average treatment plant size of 500 m³per day. Over 85% of the groundwater water treatment facilities utilize simple disinfection as the sole treatment process.

As raw water sampling is not conducted at most sources, there is an unknown level of risk with these supplies. Applying the risk based methodology, this basic level of treatment may not be appropriate where:

- Groundwater quality is variable or susceptible to groundwater influence
- Due to poor well head construction or
- Where there is inadequate source protection

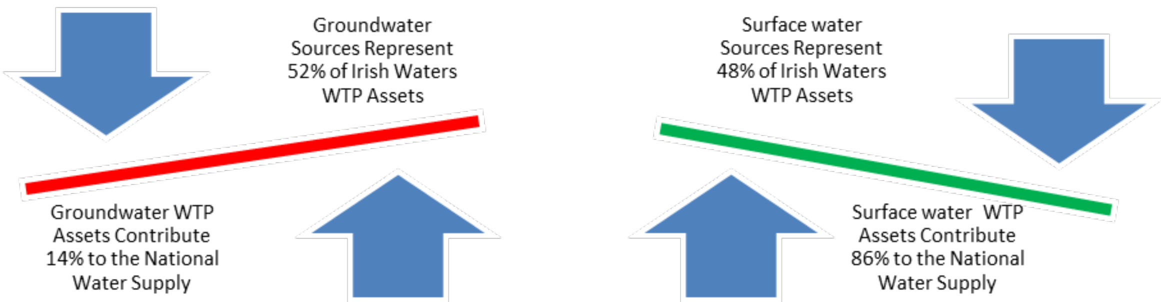


Figure 2 – Groundwater and Surface water as a Percentage of Overall supply

2 CHALLENGES WITH THE NATIONAL SUPPLY

For a country of its size, it would appear that Ireland has a very large number of water treatment plants. At present a population 3.6 million people on the public supply are served via 856 treatment plants, compared to our nearest neighbour Northern Ireland Water, where a population of 1.5 million customers is served via 24 water treatment plants. However, the population of the Republic of Ireland is extremely dispersed, so a more appropriate comparison might be with Scotland, where the public supply consists of 254 water treatment plants for a population of over 2.5 million. If we were to review these figures on the basis of number of water treatment plants per head of population, the countries would compare as follows:

- Irish Water - 1 treatment plant for 4,200 head of population
- Northern Ireland Water – 1 treatment plant for 62,500 head of population
- Scottish Water – 1 treatment plant for 10,000 head of population

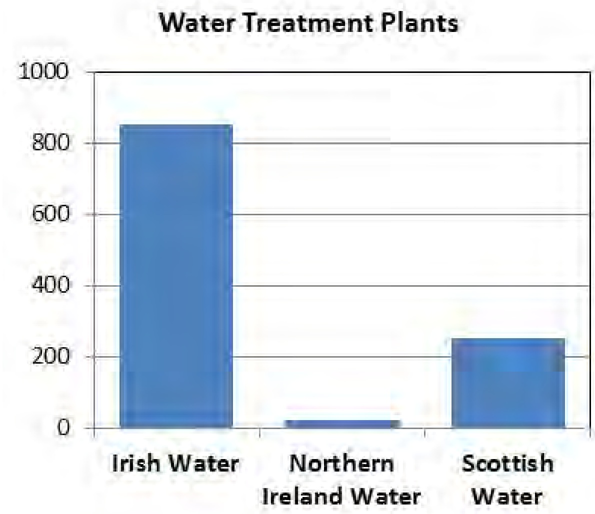


Table 1 - Water Treatment Plant numbers IW, NIW, SW

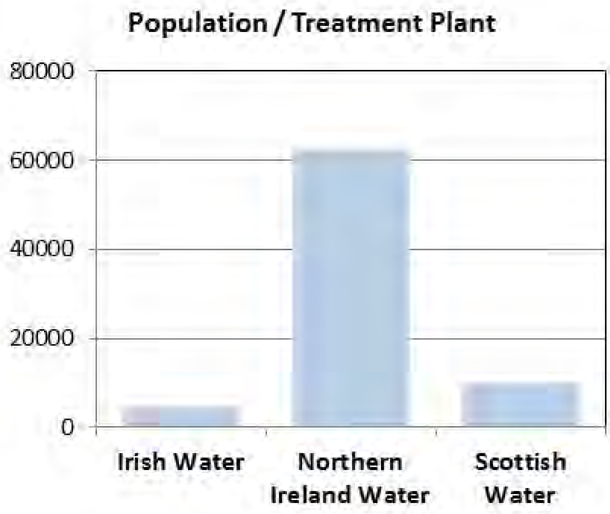


Table 2 - Water Treatment Plants

As can be seen in Table 1, even when accounting for a dispersed population, the Republic of Ireland has between 2.5 and 15 times the number water treatment plants as our closest neighbours.

This situation has evolved as a result of a number of factors including; the dispersed nature of the population, the provision of water services by 34 Local Authorities, operating autonomously within their own functional areas, and a system whereby capital funding was provided by central government whilst operational and maintenance funding remained with the local authorities.

Despite having such a large number of water sources, many of these sources have insufficient capacity to cater for demand in the short to medium term, even accounting for proposed leakage reduction targets. In addition, the fragmented nature of the supply network means that there is very little supply resilience and a pollution incident at a source, or issue at a treatment plant could result in a total loss of supply to a large area.

There are also issues with the adequacy of many of the treatment facilities. Of the 856 water treatment plants contributing to the national supply, 136 are currently on the EPA remedial action list, and over 500 have some deficiency in the water treatment process or along the distribution network. The majority of the water treatment plants require significant upgrades in the short to medium term.

The headline issues can be summarized, as follows:

- The number of small WTP presents efficiency, investment and, O&M challenges
- Many of the surface water abstractions originate from vulnerable water sources or abstract waters that are difficult to treat consistently
- Licensing is not in place for all surface water abstractions
- Many of the sources have insufficient capacity to cater for current or future demands
- There are inadequate source protection plans or set back zones around many groundwater boreholes, and the well heads are poorly constructed
- There is inconsistent catchment protection at the 856 individual sites
- Up to two thirds of water treatment plants have some process or treatment deficiency and are vulnerable in terms of ability to consistently comply with drinking water regulations
- Up to 70% of the smaller water treatment plants feed isolated networks and therefore, any pollution incident or issue with a water treatment facility, could result in total loss of supply to an entire area
- At 85% of groundwater treatment facilities, simple disinfection is the only treatment process
- Due to historical budgetary constraints many of the water treatment plants have significant capital upgrade requirements
- There have been no national standards or risk based investment planning
- Water treatment plant upgrades and implementation of appropriate treatment types will in many cases increase operational costs
- The economics of securing, operating and sufficiently maintaining 856 sites will become increasingly unviable in the future

3 ADDRESSING THE CHALLENGE -RESOURCE PLANNING

The transfer of water services functions to Irish Water has opened a unique opportunity to take a strategic view of providing water services at a national level. We have gone out to public consultation on our Water Service Strategic Plan (WSSP) which sets out the company's objectives for provision of water and wastewater services for the next 25 year period. As an organisation we will plan for water resources at a national level, with the aim of ensuring that all of our customers receive equal levels of service in terms of water quality and resilience of supply.

Following the WSSP, the first major implementation plan will be the National Water Resources Plan, which will address the deficiencies in the national water supply in terms of Treatment (Quality), Resilience, Environmental and Economic (see Figure 3).

Figure 3 – National Water Resources Plan

Through the National Water Resources Plan (NWRP), the emphasis will be placed on maximising the use of sustainable, abundant, high quality water sources. The approach will follow international best practice, an example of which is shown in Figure 4, where the Northern Ireland Water options appraisal methodology has been included for illustrative purposes.

The NWRP will commence with a review of all existing water abstractions and water treatment facilities in terms of asset condition, treatment adequacy, environmental impacts of abstraction, supply/demand balance, risk to supply, network connectivity, cost and climate change impacts.

The findings will be assessed against agreed levels of service and minimum treatment objectives. Following this, an unconstrained list of investment requirements will be compiled, with options including new resources, rationalisation of existing sources, transfer and bulk supply options.

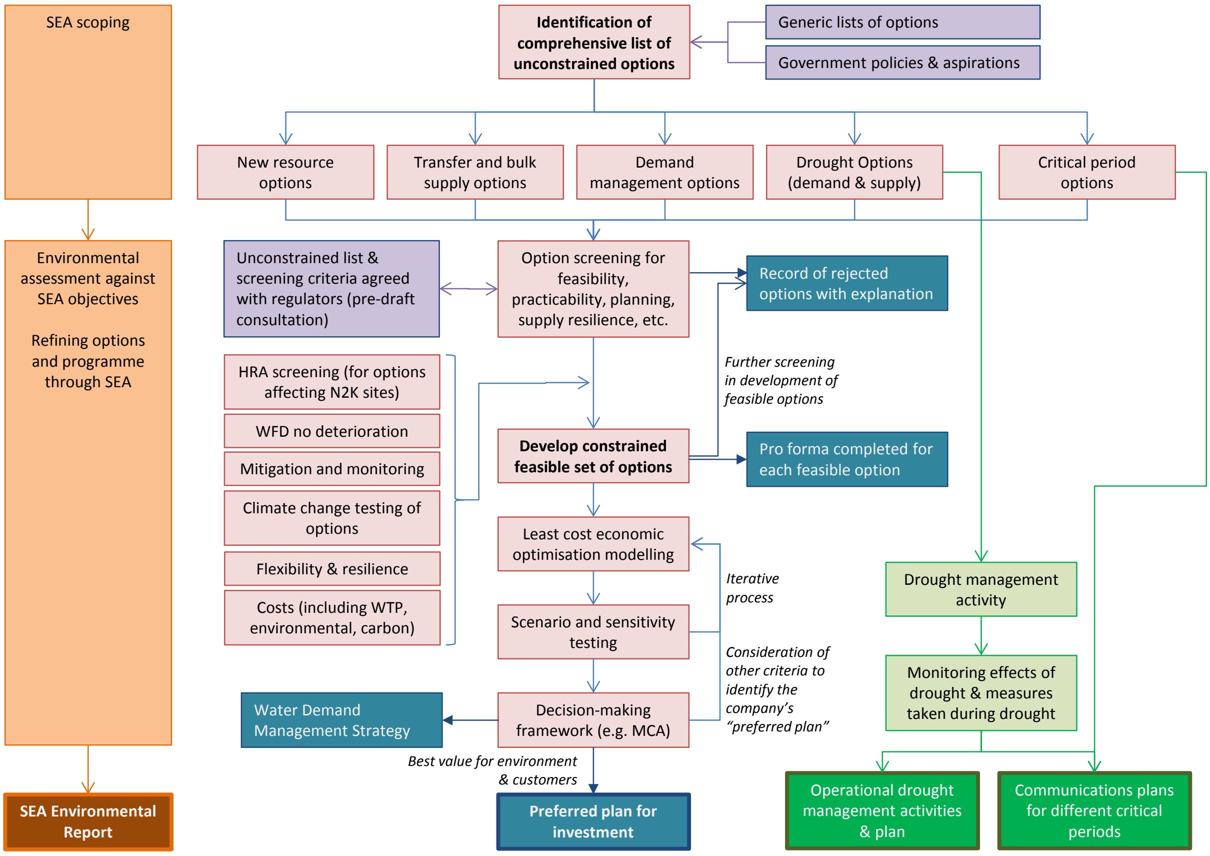


Figure 4 – Water Resource Planning Options Appraisal (Courtesy of Northern Ireland Water)

4 ADDRESSING THE CHALLENGE – ABSTRACTION

In terms of Environmental objectives, although Ireland appears to have an abundance of natural water resources, many of these are environmentally sensitive and vulnerable, particularly during dry periods or in areas of high population growth. There are finite limits to the amount of water that Irish Water can abstract from some sources, whilst others appear to be more abundant.

The WFD promotes a holistic approach to the management of the water environment where all stakeholders work together. Working with the new EPA unit, we will seek to balance the volume of our abstractions and the locations where we abstract water with the needs of the ecology supported by the water environment. We will identify opportunities for co-operation on the development of catchment management initiatives that will increase protection of drinking water sources.

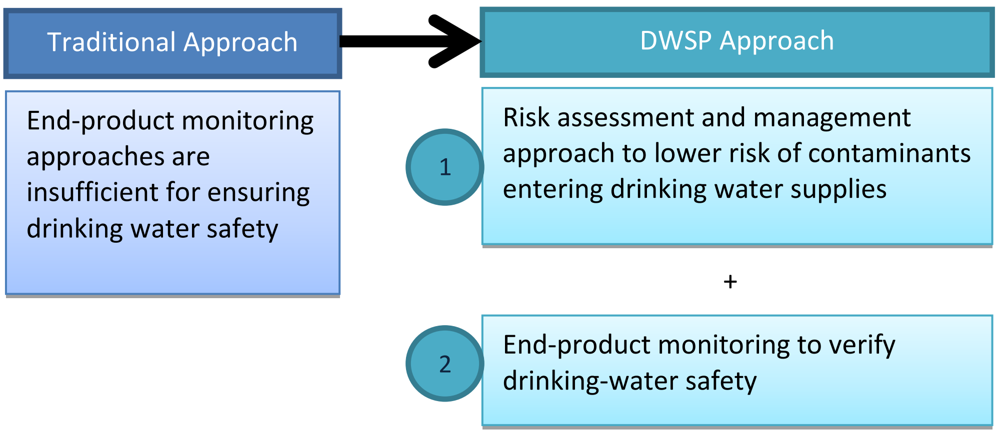
Abstraction will form a key part of the National Water Resources Plan, with the initial identification of options being completed by the end of 2017, and aligned with the WFD 2nd Cycle. We will work with the EPA and the Department of the Environment, Community and Local Government to manage the regulation of our water abstractions, on the assumption that new national legislation for abstractions for both groundwater and surface water abstraction is likely to be introduced within the next 2-5 years. In respect of any pending legislation, our paramount consideration will be to ensure that planned investment decisions account for potential changes to the regulatory landscape of water abstraction.

Key to our work in abstraction will be successful engagement with experts on the fields of hydrology and hydrogeology, including the GSI, the EPA, the third level institutions and the members of the IAH. Over the next six months Irish Water will begin engaging with stakeholders in relation to the National Water Resources Plan and will wish to include the IAH in this consultation process.

5 ADDRESSING THE CHALLENGE – WATER TREATMENT AND DWSPs

On a national basis there is currently an inconsistent approach to ensuring water quality in terms of the Source Pathway Receptor Model. There is very limited groundwater source protection in place, and treatment processes are in many cases not appropriate for the raw watertype, or the risks related to the source. In terms of groundwater and surface water, deficiencies manifest themselves in terms of Chemical and Microbiological non-compliance.

In order to address this, Irish Water has developed a national treatment strategy, specifications and design requirements based on the World Health Organisations “Drinking Water Safety Plan Approach” to water quality risk assessment, as summarised in figure 5.



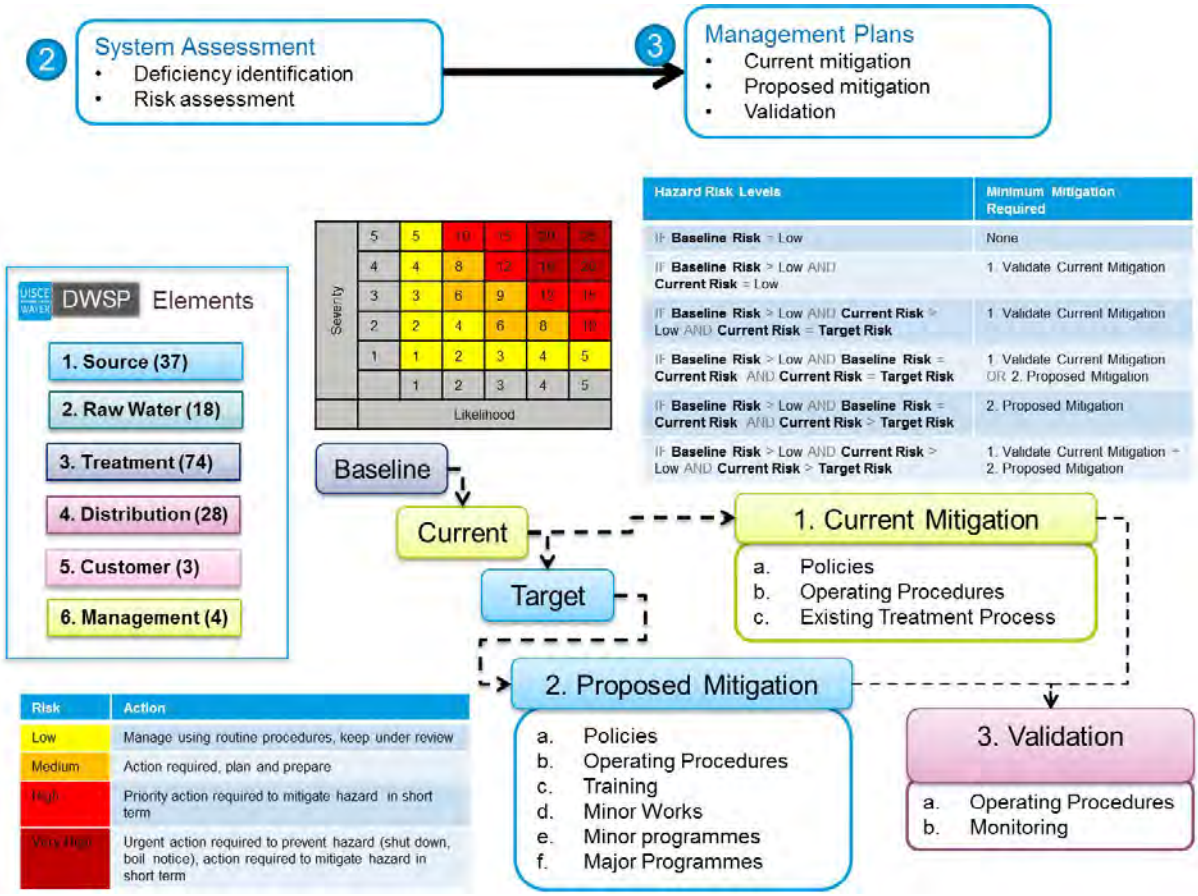


Figure 5 – DWSP Approach

The methodology addresses the water supply from source to tap on a proactive as opposed to the traditional reactive basis, where water quality issues were identified during end-product compliance sampling, a process which is reliant on the probability of detection.

For existing supplies, the DWSP methodology ensures that risks within the ground water source or surface water catchment are clearly identified, quantified and mitigated against from the source, through the treatment process, and within the distribution network.

As an intrinsic part of future resource planning, the DWSPs will allow Irish Water to investigate methods to design out risk through appropriate investigation, source protection, design and construction. With the assistance of the IAH, we have the potential to plan for a safe, a secure groundwater supply that does not involve expensive treatment processes, thus ensuring its continued viability.

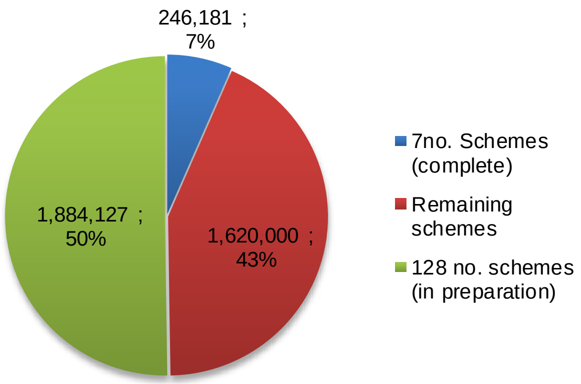


Figure 6 - Rollout DWSP

At present Irish Water proposes to implement drinking water safety plans for all of our water supply zones within the next five years. At present 7 plans have been completed (under review by Irish Water) and 135 are in progress, and due for completion in 2016. As a proportion of public water supply, this represents 57% of the population served. Due to the large number of water treatment facilities, full DWSP coverage will be a significant challenge, however, we intend to approach this in a systematic manner whereby as part of any upgrade works at a site, either in major capital, minor capital or maintenance, completion of the appropriate section of the Drinking Water Safety Plan forms part of the project. This will ensure full coverage in the least possible timeframe.

For groundwater supplies, Ground Water Protection Plans (GWPP) will be required to enable the "Source" section of the DWSP to be completed. At present the Geological Survey of Ireland has produced 148 Ground Water Protection Plans for public water supplies. In addition, GWPPs were carried out by some Local Authorities in response to DECLG Circular SP 5/03 2003. Over the next two months Irish Water will compile a detailed register of all ground water sources and protection plans relating to these. Where no protection plan is in place for a source that will be used for public water supply, a programme to produce these reports will commence in Q3 2015. It is likely the programme will extend over a three year period.

In terms of water treatment, the DWSPs will inform treatment types, but in instances where the plans are incomplete or there is no raw water monitoring in place, a default protozoa treatment credit requirement will be assigned to the source.

Table D.1: Log credit requirements for different catchments and groundwater categories

Goundwater	Surface water	Log credit requirement
Low risk (no microbiological contamination) – sealed bored well with source protection, water drawn from deeper than 30m	Not applicable	0
High risk (with microbiological contamination) – sealed bored well with source protection, water drawn from deeper than 30m	Not applicable	2
High risk (with microbiological contamination) – sealed bored well with source protection, water drawn between 10m to 30m (Groundwater default)	Upland catchment - no agricultural activity in immediate vicinity or upstream	3
High risk (with microbiological contamination) - spring or bored well, water drawn <10m, are treated as requiring the same log credit as the surface water in the overlying catchment	Upland catchment - low concentration of cattle, sheep, horses or humans in immediate vicinity or upstream (Surface water default)	4
	Lowland catchment – high concentration of cattle, sheep, horses or humans in immediate vicinity or upstream or waste treatment outfall upstream	5

Table 3 – Risk Mitigation Log Credit Requirements of Water Categories (IW Asset Strategy)

As can be seen, in all but low risk groundwater sources, there will be a log credit reduction requirement for protozoa, and where there is no information on source protection there will be an automatic 3 log credit requirement. This equates to either full filtration treatment or installation of UV treatment where appropriate.

Treatment	Log credit
Filtration (physical removal)	
Coagulation, flocculation, clarification and rapid gravity filtration	3.0
• Additional log credit for enhanced individual filtration	1.0
Slow sand filtration	2.5
Membrane filtration *	Log credit demonstrated by challenge testing and verified by direct integrity testing
Cartridge *	2.0
Bag *	1.0
Disinfection (inactivation)	
UV	Dose dependent (max 3.0)

***Denotes IW Asset Strategy Review Required**
Table 4 – Treatment Credits for Risk Reduction (IW Asset Strategy)

The implications of the DWSPs and the minimum treatment requirements will necessitate immediate investigation of the majority of groundwater supplies and/or significant upgrade requirements for the majority of these sources. However, the potential high costs involved in additional treatment requirement will drive source protection and appropriate resource planning.

6 THE NEXT FIVE YEARS AND GROUNDWATER AS A SUPPLY

Irish Water Asset Strategy is reviewing best international practice in terms of water resource planning and water treatment. In terms of overall numbers of water treatment plants, over the medium term we will move towards a more sustainable number of facilities, based on larger regional supplies with improved interconnectivity between supply zones. Given that the majority of the smaller, and in some cases, most vulnerable water treatment facilities relate to groundwater sources, there would appear to be a natural pressure to move away from ground water sources for public water supply.

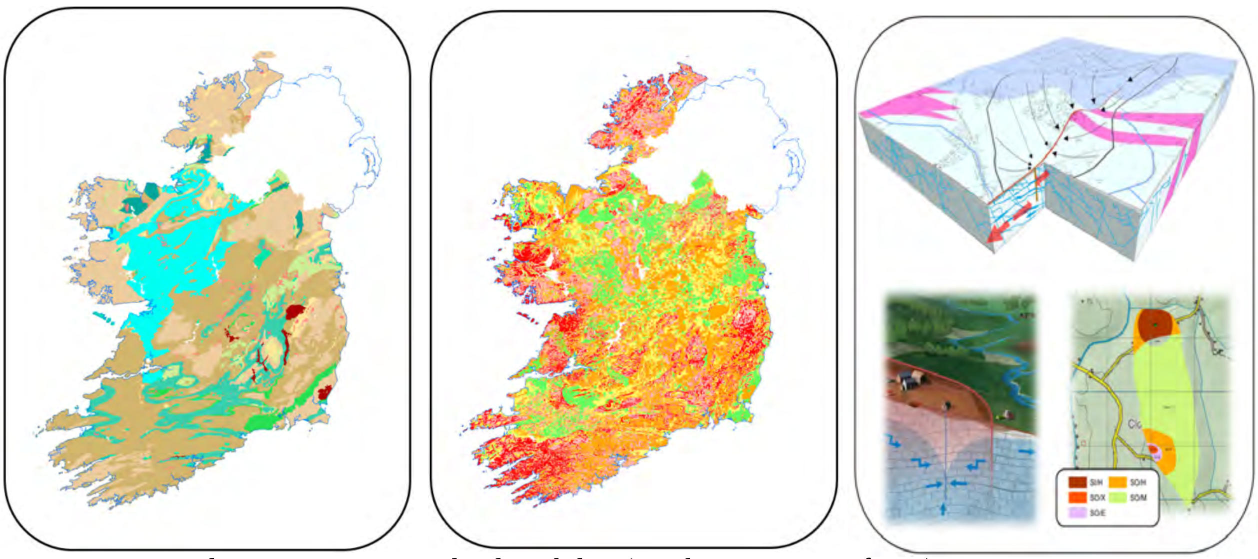


Figure 7 – Groundwater Resources and vulnerability (graphics courtesy of GSI)

However, this simplistic view, fails to recognise the significant benefits of groundwater sources to the public supply, including:

- **Availability** – Ireland has an abundance groundwater sources.
- **Cost –** Often groundwater is of better quality and less prone to sudden deterioration than surface water sources. In addition, the DWSP approach will ensure that the unit cost of groundwater supplies remain economically viable.
- **Storage –** Aquifers provide natural raw water storage, at no cost.

- **Environmental** – A correctly located groundwater abstraction can have a lower environmental impact than surface water abstraction.
- **Remote Water Supplies** – In remote areas, transporting water over long distances can cause water quality issues, therefore groundwater will always play a major part in the rural supply.
- **Source Diversity and Conjunctive Use** – When planning for long term security of supply and climate change resilience, it is anticipated that groundwater will play an increasingly important role as a strategic source, with large, well-protected sources feeding into a national grid of water treatment facilities.

7 CONCLUSIONS

Over the next 25 years Irish Water will embark on a journey towards a more rationalised and sustainable grid of interconnected water treatment plants.

However, although it is anticipated that the role of groundwater within the public water supply will change significantly over the coming years, this valuable national resource will continue to be of major importance to the rural supply network, and will become increasingly important as a strategic resource. Using the Drinking Water Safety Plans as the basic tool for water supply planning, we will work with the industry experts, EPA, IAH, 3rd level Institutions, Consultants and Drilling Contractors to ensure that groundwater remains a safe secure and cost effective water source.

We would like to invite you, as the groundwater experts to engage with us over the duration of the National Water Resources Plan to ensure the future of groundwater in the public supply.

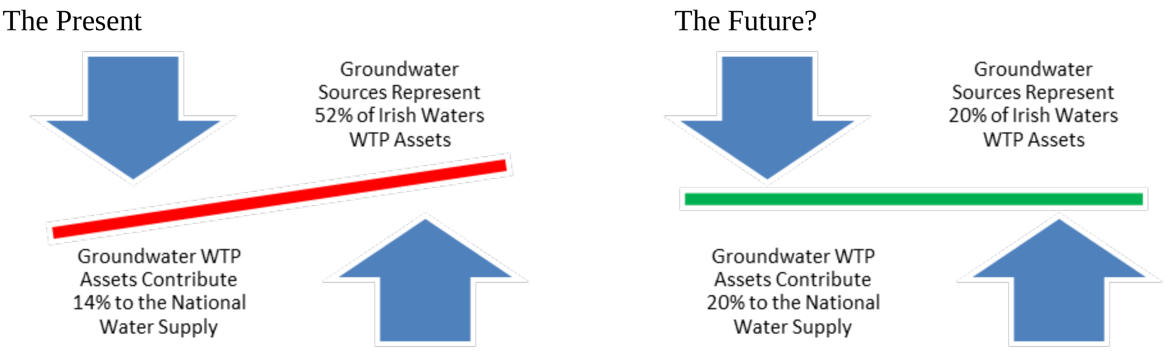


Figure 8 – Groundwater and Surface water as a Percentage of Overall supply

Acknowledgements:
Mr Victor Van Der Walt – Irish Water Treatment Strategy Specialist
Ms Taly Hunter Williams – Geological Survey of Ireland
Mr Alan Crilly – Water Resource Manager Northern Ireland Water

POOR DRINKING WATER QUALITY IN PRIVATE WELLS: THE EFFECTIVENESS OF A COMMUNICATION STRATEGY

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ABSTRACT

Significant improvements in the quality of drinking water supplied by public water supplies and community run group water schemes have been documented in successive Environmental Protection Agency (EPA) reports on the Provision and Quality of Drinking Water. These reports show a 90% reduction in incidents of E. coli contamination in public and group water schemes since 2005. These improvements have not been mirrored in private well supplies. Studies indicate that around 30% of private wells are contaminated (EPA, 2010) and that the level of illness linked to private supplies has increased (e.g. there was a 100% increase in VTEC cases between 2011 and 2012 and a further 30% increase in 2013 (www.hpsc.ie). VTEC patients were up to four times more likely to have consumed water from private wells. Private wells are unregulated in Ireland and well owners are largely unaware of the risks associated with their water supply and many are under the assumption that they are consuming "pure" water because it originates from groundwater. The EPA developed a comprehensive communication strategy involving many different stakeholders and communications methods. The effectiveness of this strategy was measured using a series of metrics measuring both awareness of the campaign and behavioral change. This paper provides an outline of the communication strategy and its effectiveness to date.

BACKGROUND

Environmental Protection Agency (EPA) publications on the *Provision and Quality of Drinking Water* have reported significant improvements in the quality of drinking water supplied by public water supplies and community run group water schemes in recent years. These reports show a 90% reduction in incidents of *E. coli* contamination in public and group water schemes since 2005. These improvements have not been mirrored in private well supplies[1].

Private well supplies are not regulated under the *European Communities (Drinking Water) Regulations 2014* and are currently classified as “exempted supplies”. This means that there is no requirement to monitor such supplies nor is there any regulatory supervision of such supplies. The sole responsibility on local authorities is an obligation to ensure that users of these supplies are advised that the Regulations do not apply to them and to give them advice on actions that can be taken to protect their health. The EPA is required to produce legally binding guidelines on how this should be implemented. EPA Advice Note No.12 was published in 2011 covering this area. Local authorities have produced and disseminated leaflets and placed newspaper advertisements advising the general public of the classification of private wells. Irish Water has no role to play in abstractions relating to private well supplies. In effect this means that the well owner is solely responsible for the quality of their well water.

[1] A private well is a well that is privately owned and provides water to a single house and does not provide water to the public through a commercial or social activity.

RISKS TO HUMAN HEALTH

In Ireland, 30% of private wells are considered to be contaminated by *E.coli*, this is based on an assessment of the national groundwater monitoring programme results[2] and is supported by findings of local spot surveys of private wells. The Central Statistics Office (CSO) census figures indicate that there are approximately 170,000 private wells in Ireland and extrapolation would indicate that 50,000 private wells may be contaminated.

According to the Health Service Executive (HSE), Ireland has the highest rate of *Veritoxigenic E.Coli* (VTEC) in Europe. VTEC is a toxin producing form of *E.coli* and is a lot more serious than an ordinary tummy bug.

Figure 1: Microscopic image of *E.Coli* (Source: Sigma-Aldrich.com)

Figures from the Health Protection Surveillance Centre (HPSC) indicate that there is an increasing trend in the number of cases of VTEC in Ireland. In 2011, there were almost 300 cases but in 2013 that more than doubled to over 700 cases. Most cases in Ireland have affected children (60%) many of whom have been hospitalized. In some people, particularly children and the elderly, the infection can cause a complication called haemolytic uraemic syndrome (HUS), in which the red blood cells are destroyed and kidneys fail. This happens in up to 8 percent of cases. Some people are left with lifelong problems, which can, on rare occasions, prove fatal.

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

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

Many well owners do not seem to be aware of the risks posed to their health from private well water. Little consideration has been given to the proper location or construction of private domestic wells. Most wells do not have any form of treatment nor are they regularly tested. A common misconception is that if the well owner has had no health problems the well water is fit for purpose, this may not be the case as the well owner may have built up immunity to the contamination. Friends, family and children may become ill as a result of consuming the well water.

[2] EPA (2010). *Water quality in Ireland 2007-2009*. Office of Environmental Assessment, EPA, Wexford, Ireland.

WELL CONSTRUCTION

Poorly constructed wells run the risk of surface water ingress either directly over the top of the borehole casing and into the groundwater (if the wellhead is below ground or flush with the ground or in an area liable to flooding) or down the side of the casing (if it has not been properly grouted and sealed after drilling) (Figure 2). In such cases, surface water contaminants such as VTEC and *Cryptosporidium* can travel directly into the water source putting consumers at risk of illness.

In 2007, the Institute of Geologists in Ireland (IGI) published "*Water Well Guidelines*", which provides guidance on drilling wells for private water supplies and sets out best practice on water well construction. Building on these guidelines the EPA in 2013 published "*Advice Note No. 14: Borehole Construction and Wellhead Protection*". The Advice Note sets out the best practice for the design, construction and protection of a drinking water supply borehole. The purpose of the Advice Note is to inform and instruct all to apply the IGI Guidelines when assessing the construction of existing drinking water supply boreholes, and also apply the Guidelines when commissioning the construction of new drinking water supply boreholes. These two documents provide best practice guidelines for water wells and should be used when constructing both public and private water supplies.

Figure 2: (a) A poorly constructed wellhead with surface water entering the top of the borehole. **(b)** An example of a sealed and protected wellhead/borehole (Source: EPA)

COMMUNICATIONS STRATEGY

While the local authorities have produced and disseminated leaflets about private wells (i.e. exempted supplies) as required by the legislation and there is published guidance on the construction of wells, there is a worrying trend in the number of VTEC cases as highlighted by the HSE. It was clear that a coordinated, national awareness campaign was required if significant changes are to be seen and the risk associated with private wells reduced.

No national body has responsibility for protection of private wells under legislation. The EPA however has delivered effective change in the drinking water supply sector since becoming the regulator in 2007 and in the interest of improving public health (and environmental protection), the EPA decided to take the lead on this issue. A comprehensive communication strategy involving many different stakeholders and communications methods was developed to reach the widest possible audience. The first element was to identify the different audiences and stakeholders and the associated key communication messages. The communication channels and tools for each stakeholder group was then determined and finally the metrics defined in order that the effectiveness of the campaign could be assessed.

Communication tools were developed to educate well owners and to make them aware of the risk and inform them of the actions they should take and they include:

- A new section on the EPA website for householders on "Protecting Your Private Well" (Figure 3). It explains the risks to private wells; advises well owners to check the location and construction of the well. It also recommends annual well water testing for microbial contamination. Well owners can find a list of testing laboratories that are offering a discount for those wishing to have their water tested – see http://www.epa.ie/water/dw/hhinfo/

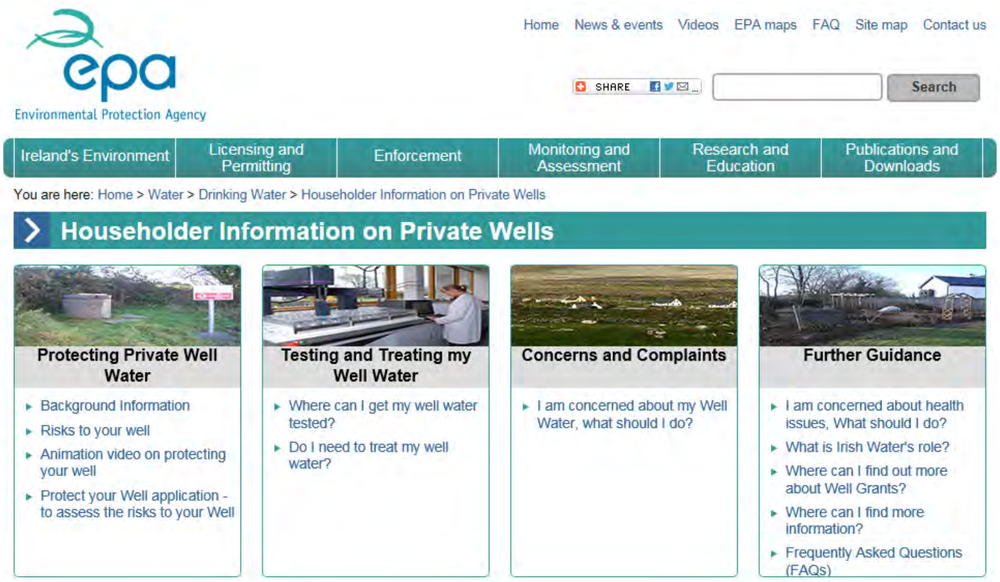


Figure 3: Householder Information on Private Well Page http://www.epa.ie/water/dw/hhinfo/

- An infographic illustrating the risk and actions to protect private wells (in Irish and English) was developed (Figure 4). It was printed as A5 leaflets and A3 posters, which were then disseminated to all local authorities, health centres and numerous stakeholder groups.
- A web application, which allows private well owners self-assess their well, was developed in-house by the EPA. The web app asks well owners a series of simple questions which then produces tailored advice that, if implemented, will improve their well water. Aggregated statistics from the app can be gathered by the EPA and used to prioritize future work and determine what the key risk factors are nationally and locally (by county) and to influence policy and research in this area.
- An animation "Protecting Your Private Well" (in Irish and English) which explains the risks to private wells and advises on the simple steps to take to protect the supply can be viewed from the EPA website and the web app.

Figure 4: Private Well Infographic leaflet

In advance of the national launch of the campaign, face to face meetings were held with a number of stakeholders including Public Health Consultants from the Health Service Executive (HSE), An Taisce, Irish Countrywomen's Association (ICA), Irish Creamery Milk Suppliers Association (ICMSA), Irish Food Safety Authority (IFSA), Sustainable Water Network (SWAN), Geological Survey of Ireland (GSI) and professional organisations such as the Institute of Geologists of Ireland (IGI), Engineer's Ireland (EI) and International Association of Hydrogeologists (IAH). During the meetings the key communication messages were discussed and requests for help to disseminate the leaflets and to highlight the risks to private wells to their members. A mail shot, which included a cover letter outlining the issues associated with poor construction of wells; a copy of EPA Advice Note 14 and a number of leaflets, was issued to all well drillers listed in the telephone directory. Drillers are unregulated in Ireland and therefore difficult to contact directly.

The strategy was launched with the HSE in June 2014, by means of national TV and radio interviews by both EPA and HSE staff and a joint press release. The national launch coincided with dissemination of information by the stakeholder groups to their membership. More than 80,000 leaflets were distributed to all local authorities; private laboratories, rural community groups, professional bodies, environmental NGOs, other state agencies and departments. Most groups also placed articles in their newsletters or E-zines and made leaflets available to members either directly or indirectly through mailshots or at AGMs and other meetings.

A number of private water testing laboratories participated in a discount scheme for private well water testing; the contact details for these labs are available on the EPA website.

There was significant interest in the subject at national and local level, eleven local radio stations conducted one to one interviews with EPA staff. An advertisement was placed in a well-known farming paper just before the ploughing championship where the EPA had a stand with information and staff available to deal with queries. Technical and non-technical articles were placed in professional newsletters, the National Federation of Group Water Schemes and the EPA newsletters as well as in Sherkin Comment, a well-known natural resource quarterly publication, which has a circulation of 24,000.

EPA staff took opportunities to explain the risks and what actions well owners can take on two national TV programs - ‘Ear to the Ground’ and ‘EcoEye’ (400,000 viewers). Presentations were given at the annual Water Event; Environmental Awareness Officers; ENDWARE and UK Private Wells meetings.

The launch in June was followed up at the end of August with a number of regional articles in local newspapers and local radio interviews.

ASSESSMENT OF EFFECTIVENESS

The communication strategy identified a number of metrics outlined below, which have been assessed to determine what worked (or didn’t) in terms of both awareness of the campaign and behavioral change. The initial effectiveness of the implementation of the strategy was measured after seven months and is presented here. It is recognized that this is a very short period for assessment as behavioral change takes sustained campaigns and time to be effective.

An EPA funded research project *Communicating Risk Based Enforcement (Relay_Risk)* (2013-W-DS-12) is currently examining ways to deliver risk based messages effectively to target audiences in order to improve knowledge and promote behavioural change. This project is also investigating appropriate metrics in order to determine the effectiveness of engagement strategies. The findings of this project will be published in 2015 and will be of value in further assessing the effectiveness of the private wells strategy and in the development of a new strategy later in the year.

Awareness of the campaign/risks to private wells

The level of awareness of the risks to private wells can be determined by the extent of exposure to the messages in the media and the activity on information platforms such as the EPA website and the web application.

Media interest
The HSE and EPA released a joint press release at the time of the launch in June 2014; this was followed up at the end of August with regional articles, which were tailored for the local and regional newspapers. A review of the print media indicates that there were at least 47 articles in seven months with national and regional coverage.

The launch included TV coverage with a piece on the News at One, Six One News and TG4. The launch attracted around 10 radio interviews including a couple with Radio na Gaeltacht and this was followed by at least 11 one to one local radio interviews at the time of the release of the regional articles.

The risks to private wells were also highlighted during TV programs, ‘Ear to the Ground’ and ‘EcoEye’ which aired in November 2014 and February 2015. The initial viewer figures for EcoEye are 400,000.

Social Media
The launch information was tweeted on Twitter by the EPA and HSE and then re-tweeted by other stakeholder groups such as An Taisce. Articles about the campaign were posted on Facebook.

Views of animation
The animation, which can be viewed through the EPA website and the well application, had more than 850 views in YouTube after seven months.

Hits on EPA website
The householder page for private wells has had over 10,000 unique page views on the main EPA website in the review period. This does not include hits on the new EPA mobile platform. There was a noticeable increase in hits directly associated with our press releases.

Web Application Usage
There has been 435 response and 6692 hits overall on this survey application, which counts the number of times the survey page has been viewed and recommendations given (or reviewed). The relatively low numbers of responses to the survey do not allow an in-depth analysis at this stage of the regional differences in usage but this will be re-evaluated as time goes by. Further efforts will be made to improve on the response rate in the 2015 campaign.

Web Application Data
The limited responses have been analyzed and some statistics are shown below in Figure 5. A worrying figure is that 59% of the supplies have not had their water tested. The well app gives tailored recommendations to the respondents and in these cases they have been advised to have their well tested as a priority. As more data becomes available it will be re-assessed and used to identify priorities (e.g. counties with higher proportion of contaminated wells, key issues identified) and to inform future communications.

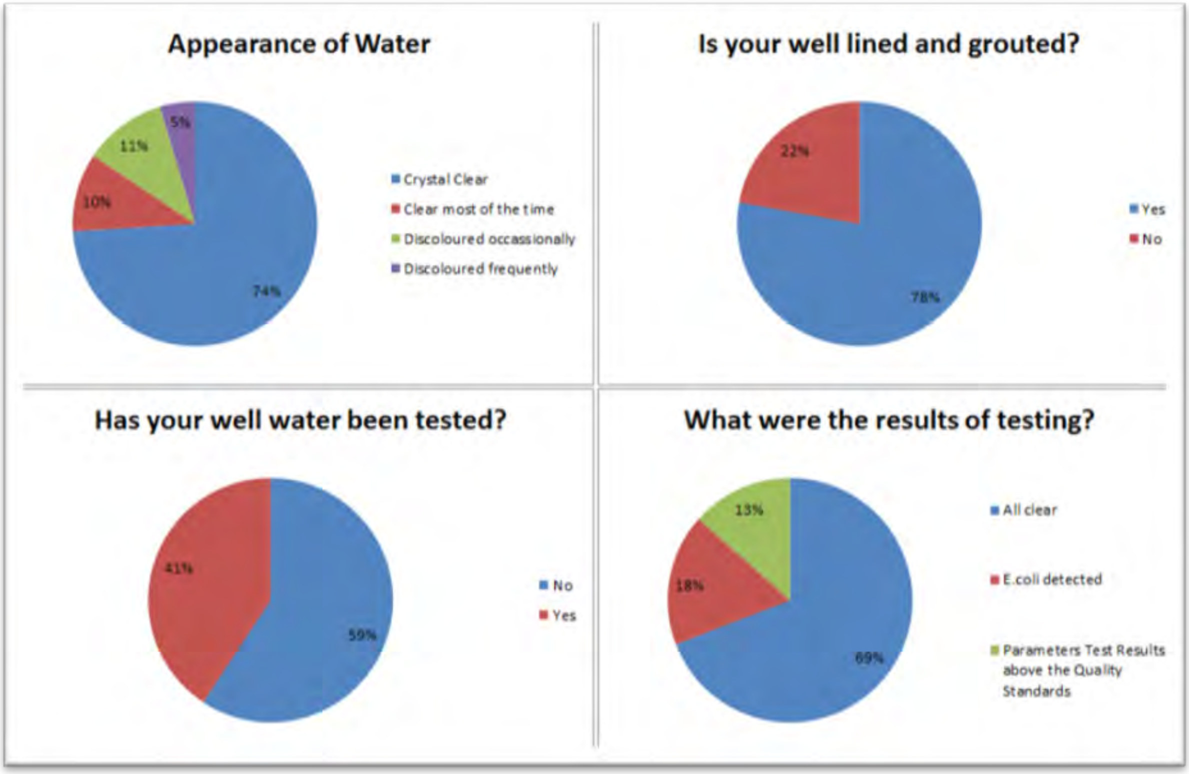


Figure 5: National statistics from the web application for a seven month period.

Behavioral Changes

Two metrics have been identified, which may give an indication of change in behavior as a result of the campaign. They relate to the rate of grant uptake and well water testing.

Level of grant uptake

In some cases where improvements are necessary to a private well a grant may be obtained from the local authority. The local authority administers the grant scheme on behalf of the Department of Environment, Community and Local Government (DECLG). These payments are only made upon completion of the work and therefore there is a time lag between the improvement and the payments made by the DECLG to the local authority.

Figures from the DECLG indicate an increase of 13% in the amount of money re-cooped to local authorities arising from well grants from 2013 to 2014.

Well water testing rates

The EPA negotiated a reduced rate for private well water testing with a number of private laboratories. A list of the laboratories participated in the scheme is published on the EPA website.

The private laboratories that have participated in the scheme have overall indicated a 23% increase in testing numbers for private wells. One laboratory noted a three-fold increase in January 2015, which they have contributed to an awareness piece on the risks to private wells on the 'Ear to the Ground' TV program.

Illness associated with water supplies

The most important metric is the number of cases of VTEC particularly those associated with private wells. This is to determine if the strategy has been effective in reducing illness in the population and therefore improved public health.

The number of VTEC cases has increased very slightly in 2014 from 702 to 713 (Figure 6). It is encouraging note that the rate of increase has been significantly reduced compared to 100% increase in VTEC[3] cases between 2011 and 2012. It will be important to analyze the data in more detail with the HPSC in order to determine the trend for the number of cases associated with untreated well water.

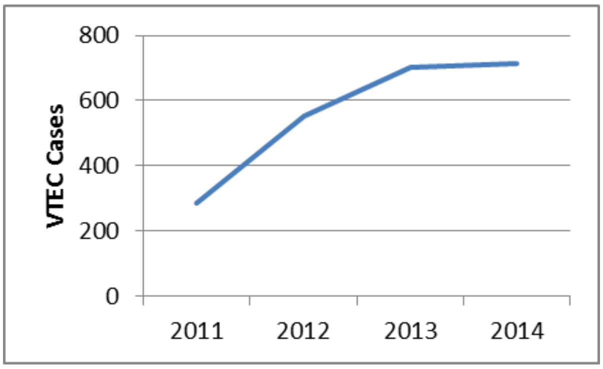


Figure 6: No. of VTEC cases as reported by the Health Protection Surveillance Centre (HPSC)

[3] VTEC are a particular group of the bacterium *E. coli.* VTEC infection often causes severe bloody diarrhea and abdominal cramps although. In some persons, particularly children under 5 years of age and the elderly, the infection can also cause a complication called haemolytic uraemic syndrome (HUS), in which the red blood cells are destroyed and the kidneys fail.

CONCLUSIONS

There has been considerable support from all stakeholder groups during the roll out of the information campaign. There has been significant coverage and dissemination of the information through the media and stakeholders. Press releases are an effective means of getting media attention and also encouraging people to look for information on the website. However, a sustained campaign is needed.

In terms of behavioral change there are early indications of a small increase in well testing and grant awards from the previous year. Tracking changes is difficult due to the lack of available structured data. This assessment has been carried out at a very early stage in the implementation of the campaign and further actions and time is needed to really assess its effectiveness on the behavior of well owners.

Nonetheless it is encouraging to note that the number of VTEC illness cases seems to have levelled off but it is still at an unacceptable level.

The findings of the *Communicating Risk Based Enforcement (Relay_Risk)* project will be used to further assess the effectiveness of the campaign and in the development of a new strategy later in the year. In the meantime every opportunity will be taken to disseminate the message and links are being made with inspection regime for domestic wastewater treatment systems.

All information can be found at http://www.epa.ie/water/dw/hhinfo/ and copies of leaflets are available from the EPA upon request. Any suggestions or support from organisations or groups not currently involved in the campaign are welcome.

OVERVIEW OF RECENTLY PUBLISHED GUIDANCE FOR EPA LICENSEES FOR REPORTING COMPLIANCE WITH THE GROUNDWATER REGULATIONS 2010

Pól Ó Seasnáin
Environmental Protection Agency

ABSTRACT

The Environmental Protection Agency (EPA) has recently published a Guideline Template Report for licensees to use when reporting a Hydrogeological Review/Technical Assessment to demonstrate compliance with the European Communities Environmental Objectives (Groundwater) Regulations (S.I. No. 9 of 2010). The guidance is designed to assist those EPA licensees who have had specific conditions related to these Regulations inserted into their licences.

LEGISLATION AND BACKGROUND

The European Communities Environmental Objectives (Groundwater) Regulations, (S.I. No. 9 of 2010) came into effect on 27 January 2010. These regulations transpose into Irish law the measures needed to achieve the environmental objectives established for groundwater by the Water Framework Directive (WFD) (2000/60/EC) and the Groundwater Directive (2006/118/EC).

Regulation 2 of the Groundwater Regulations sets out the purpose and scope of the Regulations, which include the following requirements:

- prevent [in the case of hazardous substances] or limit [in the case of non-hazardous substances] the input of pollutants into groundwater and to prevent the deterioration of the status of all bodies of groundwater
- protect, enhance and restore all bodies of groundwater and to ensure a balance between abstraction and recharge of groundwater, with the aim of achieving good groundwater status by not later than 22 December 2015
- the reversal of any significant and sustained upward trend in the concentration of any pollutant resulting from the impact of human activity in order to progressively reduce pollution of groundwater.

The Agency was obliged to examine the terms of all relevant existing licences with a view to determining whether they addressed the obligations laid down in the Groundwater Regulations. The Agency was required to declare that the licence was compliant or to technically amend/review the licence by 22nd December 2012.

As a result, since January 2013 technical amendments and reviews to a number of licences have been issued by the EPA. The conditions were inserted into licences related to:

- Domestic wastewater treatment systems with a percolation area,
- Landfills,
- Contaminated land and
- Landspreading.

Under Regulation 56 there is a particular obligation on the Agency, in relation to point sources and contaminated land, to have trend assessments carried out for identified pollutants in order to verify that:

- Plumes from contaminated sites do not expand

- That such plumes do not cause the chemical status of the body or group of bodies of groundwater to deteriorate
- And to verify that they do not cause a risk for human health or the environment.

Flowing from this, licences with landfills and contaminated land received particular conditions and are the subject of this presentation. The conditions in these licences require that an assessment is carried out in accordance with the EPA's Guidance on the Authorisation of Discharges to Groundwater (2011). Further to the assessment, any actions (including the setting of groundwater compliance points and values, if appropriate) required to demonstrate compliance with the Regulations, are to be implemented by the licensee before 22nd December 2015. The outcome is to be a report to be included in the next Annual Environmental Report (AER). The majority of these reports were due for submission by 31st March 2015.

Currently 137 EPA licences are subject to the above condition type and can be broken down into two broad groups as follows:

- 79 Landfill or waste licences
- 58 Industrial type licences other than the above

THE GUIDANCE

The EPA published guidance in the form of a Guideline Template Report and an associated process Flow Diagram in November 2014 to assist licensees required to submit a response to this new condition.

The Template Report and Flow Diagram are available at the following link http://www.epa.ie/pubs/reports/enforcement/templates/.

A related webinar was presented in December 2014 and is available at https://www.brighttalk.com/webcast/9897/135603.

The Flow Diagram summarises the assessment process in one page (see Figure).

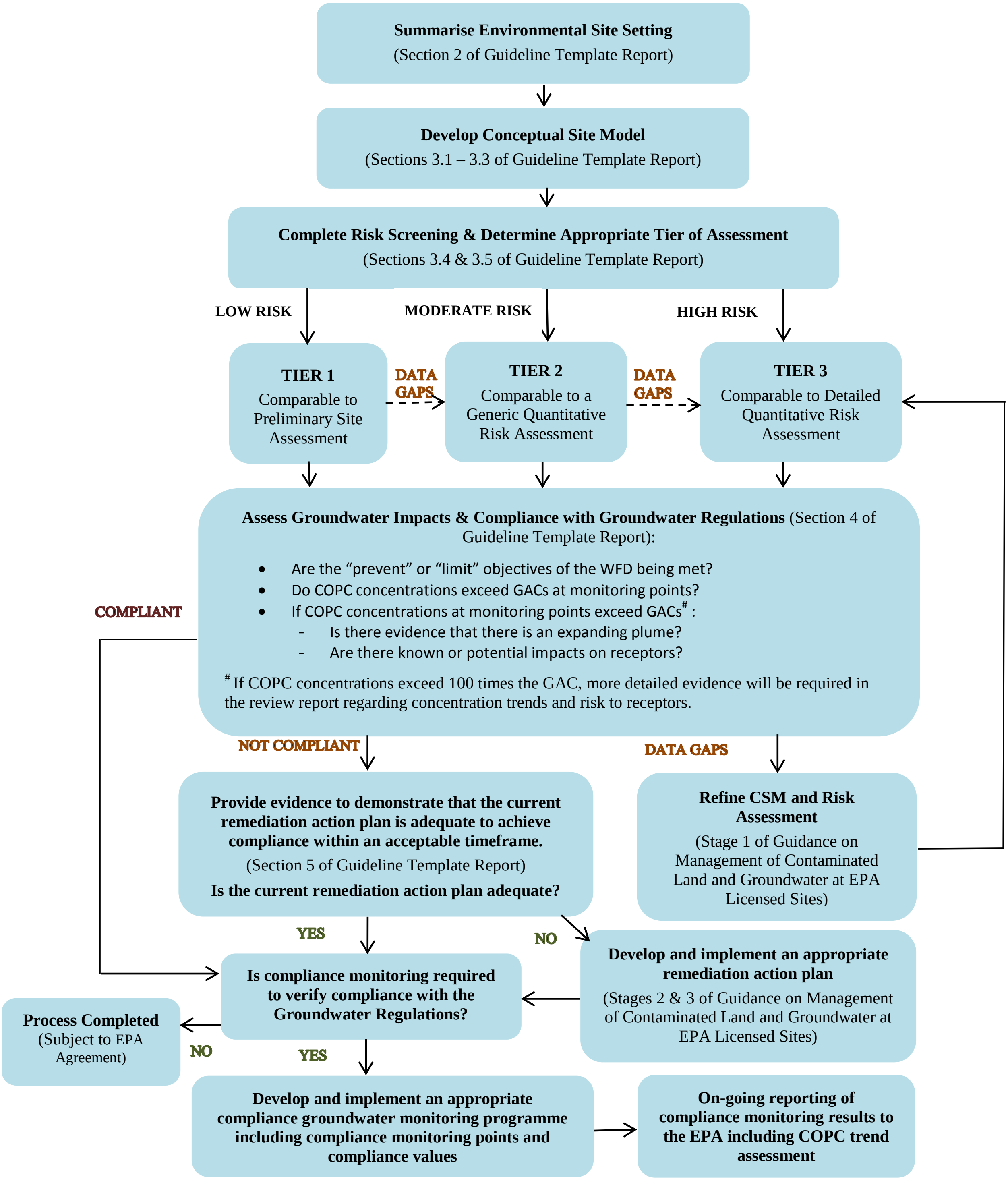
The aims of the Guideline Template Report are to:

- Set out the content and standard of work required
- Aid consistency in reporting
- Improve decision making

Both the Guideline Template Report and the associated Flow Diagram cross reference both the 'Guidance on the Authorisation of Discharges to Groundwater' (EPA 2011) and the 'Guidance on the Management of Contaminated Land and Groundwater at EPA Licensed Sites' (EPA 2013). The key steps in the Hydrogeological Review/Assessment are:

- Summarising the Environmental Site Setting
- Development of the Conceptual Site Model
- Risk Screening of key source-pathway-receptor linkages
- Completion of Tier 1, 2 or 3 Risk Assessment as appropriate
- Assessment of the Groundwater Impacts & Compliance with Groundwater Regulations
- Development of a Compliance Monitoring programme

Guideline Process Flow Diagram



The Guidance requests that licensees provide evidence to demonstrate that they are compliant with the requirements set out in the Groundwater Regulations, namely that;

1. The licensee has prevented the inputs of hazardous substances to groundwater and has limited the inputs of non-hazardous pollutants, such that they have not caused pollution.
2. The activities (past or present) of the licensees are not causing sustained upward trends in pollutant concentrations.

3. The activity is not impacting on the groundwater body (pollution or abstraction); such that there is a risk of the groundwater body being classified as being at less than good status because of the activity.

With these objectives in mind, the licensee is asked to Assess Groundwater Impacts & Compliance with the Groundwater Regulations (Section 4 of the Guideline Template Report).

Where the relevant Generic Assessment Criteria (GAC)[4] value is exceeded at a monitoring point that is representative of the groundwater body beneath/downgradient of the site activity i.e. not in the source, upgradient etc. then it is deemed that the licensee has failed to prevent or limit the input of hazardous substances or non-hazardous pollutants. Licensees should demonstrate that they have introduced measures to control the input of pollutants.

The scale of exceedance helps determine whether there is potential for failure of the trends and status objectives, in that:

- Where the pollution from the activity is impacting on associated receptors, including surface water, wetlands and drinking water sources (which includes potential use of groundwater for abstraction) such that the associated receptors are at risk of failing their environmental and health objectives, then measures are required to ensure that the objectives of these receptors are met. Evidence should be provided to demonstrate that the objectives of associated receptors are not being impaired. Where the objectives of associated receptors are being impacted upon, then actions should be proposed, indicating timelines when the objectives of the associated receptors will no longer be impaired by the activity.
- The critical plume threshold[5] for WFD status assessments is 2 km^2, whereby if a plume is greater than 2 km^2 or is expanding such that it may exceed 2 km^2 in the future; then there is a risk of failing the WFD status objective. Therefore, where concentrations are less than 100 times GAC, it is unlikely that the pollution plume would be sufficient to result in the average concentration being greater than the WFD threshold value across the whole groundwater body. As such evidence should be provided to demonstrate that concentrations are less than 100 times GAC in all representative monitoring points. Where concentrations exceed 100 times GAC, actions should be proposed, indicating timelines when the concentrations will be reduced to levels that are less than 100 times GAC.
- If the source input has been controlled such that inputs have been prevented/limited then plumes should not expand further. This can be demonstrated by undertaking trend assessments in pollutant concentrations (including breakdown products) at representative monitoring points. Where there are upward trends, action should be taken and evidence provided to show that the measures have been or will be successful, such that trends have been reversed and plumes are deemed to be stable / contracting.

Consequently, the scale of pollution dictates the remediation strategy, whereby if the prevent or limit objective has been failed, but there is little risk of the trends and status objective being failed, then in terms of preventing further inputs of pollutants, remediation measures to prevent plume expansion and ongoing monitoring to demonstrate that the situation is improving may be sufficient. However, where the conditions are such that the trends or status objective could be failed then more comprehensive remedial measures are required to ensure that these objectives are satisfied by 22nd Dec 2015. Where this deadline cannot be satisfied then licensees need to provide the Agency evidence and timelines as to when these environmental objectives will be satisfied. The evidence to the Agency should include options on what is technically feasible and also what is economically feasible in terms

[4] See Guidance on the Management of Contaminated Land and Groundwater at EPA Licensed Sites" and associated Guideline Template Reports (EPA 2013).

[5]http://www.wfduk.org/sites/default/files/Media/Assessing%20the%20status%20of%20the%20water%20environment/GWChemical%20Classification_FINAL_2802121.pdf

of remedial action in relation to the timelines proposed to satisfy the environmental objectives of the Groundwater Regulations.

This information, along with the proposed measures and timelines will be incorporated into WFD groundwater body characterisation assessments, for inclusion in future WFD River Basin Management Plans.

WIDER REGULATORY CONTEXT

The provision of advice and guidance comes under the "Better Regulation" pillar of the EPA Strategic Plan 2013 – 2015.

The work set out in this presentation advances this strategic priority by the provision of a Guideline Template Report to assist licensees in reporting compliance with the Groundwater Regulations.

Adherence to the guidance described here will facilitate licensees in complying with EPA licence conditions. Receiving the required information in a common specified format will also facilitate the EPA in assessing the information and should avoid the need for reports to be resubmitted.

In terms of strategic importance, it is aligned with other work carried out in the broader area of contaminated land & groundwater in relation to EPA licensed sites in the last number of years including:

- Publishing of 'Guidance on the Management of Contaminated Land and Groundwater at EPA Licensed Sites' and associated Guideline Template Reports in 2013 which follows a tiered risk based approach where the development of the Conceptual Site Model is key. This approach is carried forward into this guidance.
- Prioritisation of EPA enforcement effort toward waste & industrial sites which pose the most risk to groundwater.
- In terms of Ireland's obligations under the Water Framework Directive the output from this work will provide useful information that will feed into future groundwater body characterisation assessments. The output will assist in the identification of certain candidate sites that may threaten the achievement of the WFD objectives.

Acknowledgements:

- Mr. Graham Webb, Geosyntec Consultants Ltd.
- Dr. Matthew Craig, Hydrometric & Groundwater Programme, Office of Environmental Assessment, Environmental Protection Agency.
- Ms. Regina Campbell, Waste and Land Thematic Unit, Office of Environmental Enforcement, Environmental Protection Agency.
- Ms. Ann Marie Donlon, Environmental Licensing Programme, Office of Climate, Licensing, Resources and Research.

SESSION III

LEGAL PROTECTION FOR ECOLOGICALLY SIGNIFICANT GROUNDWATERS UNDER EU LAW

Owen McIntyre
University College Cork

NOTES

DEFINING HYDROLOGICAL DAMAGE IN GROUNDWATER DEPENDENT TERRESTRIAL ECOSYSTEMS

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INTRODUCTION

Wetlands as a characteristic group of ecosystems have been the subject of considerable debate in the scientific community as to exactly what does constitute a ‘wetland’. Nevertheless, it is increasingly recognized that the range of ecosystem services provided by wetlands makes their understanding and protection ever more important (Maltby, 2011), as enshrined in EU and Irish legislation. While the Convention on Wetlands of International Importance, known as the Ramsar Convention of 1971, adopted the universal definition, *“areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres”* (Davis, 1993), three features dominate the characterization of wetlands:

1. The predominant presence and dynamics of water, either at or above the surface or within the rootzone;
2. Characteristic soil or sediment conditions that differ from adjacent non-wetland (terrestrial or fully aquatic) areas; and
3. Vegetation (and generally animals) specifically adapted to permanently or seasonally wet conditions (Maltby, 2009).

Indeed, it can be argued that hydrology is the essential driver of the soil and ecosystem conditions in any wetland. In this context, several studies have identified the water balance of a wetland as the key to its functional understanding. Evaluating the hydrological inflows and outflows in a wetland is thus fundamental to the understanding of any observed or predicted ecological changes (which may be identifiable as ‘damage’ or environmental impact).

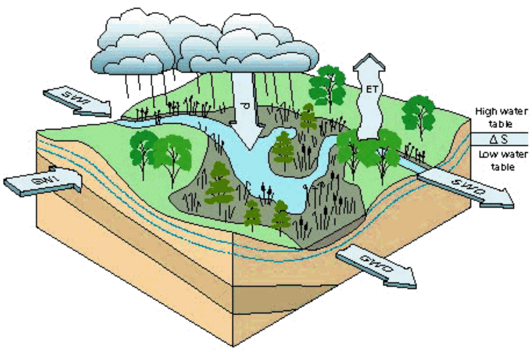


Fig. 1 Water balance of a wetland:

SWI/O Surface water in/out;
GWI/O groundwater in/out;
P precipitation;
ET Evapotranspiration;
ΔS Storage in groundwater

If the primary input to the wetland is ultimately rainfall, the wetland and its morphology can be conceptualized as a storage or resistance within the hydrological cycle. The characteristics of that ‘storage’ in terms of its ‘normal functioning’ may be represented by frequency duration curves of water level or stage. Any time series of water level within a wetland can be subjected to a similar representation. Given there may be more than one interlinked storage making up the functioning of a particular wetland, each will have its own characteristic response to the driving inflow.

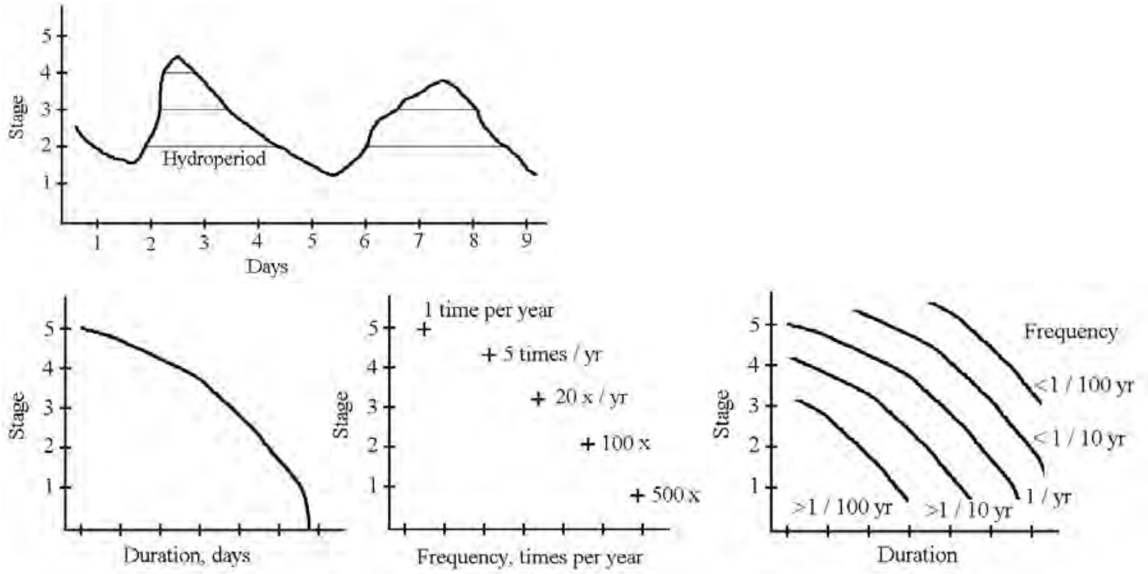


Fig. 2 The characterization of wetland storage: water level-duration-frequency (US EPA, 2008)

In this analysis, the focus is on that subset of wetlands that have groundwater either as the predominant controlling feature or as a necessary supporting condition, in other words, Groundwater Dependent Terrestrial Ecosystems (GWDTE) in the lexicon of the EU Water Framework Directive (2000). A review by Kilroy et al (2008) outlined those GWDTE wetlands common in Irish hydrogeology and their relative sensitivity to groundwater inputs (fig. 3). In the determination of potential impacts to GWDTE, much effort has been devoted to defining relevant hydrological thresholds, the exceedance of which can be deemed to be damaging the functioning of the wetland and its ecology. Under the Water Framework Directive, this designation also renders the status of the connected groundwater body as 'at risk'. Two such groundwater bodies in Ireland, shown in Fig.3, are at risk as a result of abstraction/drainage affecting connected GWDTEs. While the discussion here relates to impacts on the water supply to a wetland, the hydrological flows will also relate to hydrochemical loadings, such as in the nutrient dynamics.

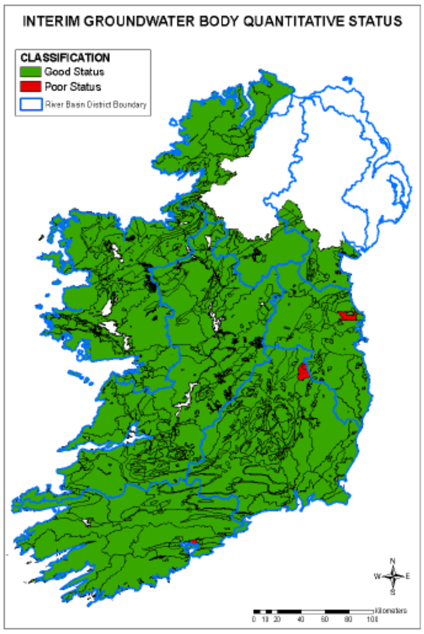


Fig. 3 Groundwater bodies 'at risk' connected to 'damaged' GWDTE including Pollardstown Fen, Co. Kildare.

The problem with fixed exceedance thresholds, for example, of water level, as an indicator of damage in a wetland is that the receptors (vegetation or animals) usually do not have a corresponding fixed response. Duration of exceedance has to be a factor in the sense that a receptor has some measure of resilience in surviving a fixed threshold. In short, the relationship between a particular protected species and the necessary hydrological conditions for long term sustainability are often very difficult to define, hence making 'damage' equally difficult to identify. Three examples of wetland damage are given here to indicate that while great progress has been made in recent years for each GWDTE type in identifying a sustainable hydrological regime, more needs to be done to be able to assess environmental impact more appropriately, to take account of the concept of resilience within overall, integrated catchment management.

GWDTE	Groundwater discharge	Groundwater contribution	Degree of mineralisation	Groundwater level	Rate of groundwater flow	Other
Petrifying springs	Direct	High	High	Minimum threshold Required	Important	Note some springs may naturally dry up, whereas others will have perennial flow
Alkaline fen	Direct	High	High	Absolute water level important		
***Cladium* fen**	Direct	High	High	Absolute water level important		
Transition mires	Direct	Mixed groundwater and rainwater input	Low–moderate	Stable		Groundwater level supports rainwater lens Groundwater supports high, stable water level in habitat Need to maintain regional groundwater flow and level
Bog woodland on raised bog	Indirect	Not groundwater dependent except in context of regional groundwater supporting the overall raised bog				
Bog woodland on transition mire	Direct	Small but vital contribution	Low–moderate			Groundwater supports surface water
Raised bog (high bog)	Indirect	Regional groundwater supports water level in bog				
Raised bog (lagg)	Direct	Mixed water contribution – groundwater, surface water and bog water				Groundwater contribution vital
Turloughs	Direct	High	Moderate–high	Dynamic groundwater fluctuations (level, timing, frequency)		Significant inundation range and duration
Machairs	Direct	High	Moderate–high	Moderate groundwater fluctuations		

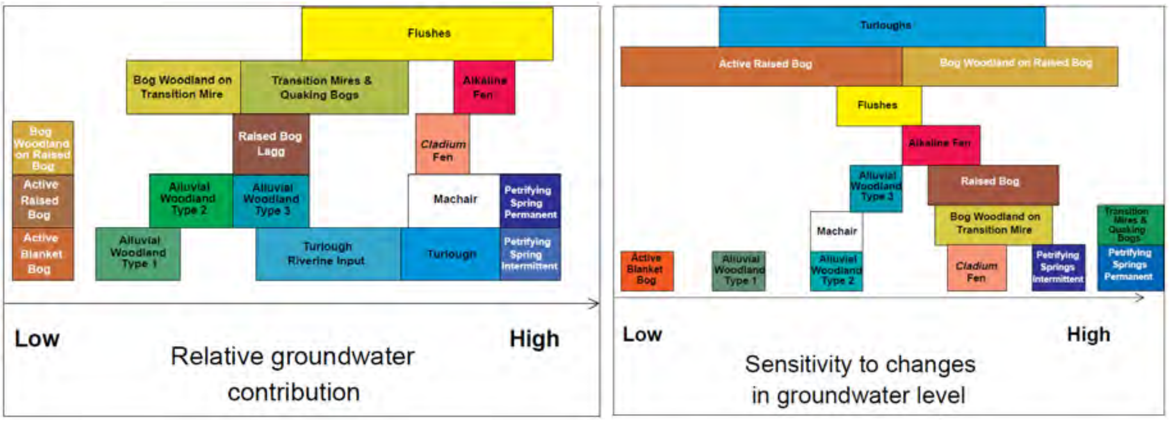


Fig. 4 GWDTE in Ireland and their sensitivities to groundwater inputs (Kilroy et al, 2008)

POLLARDSTOWN FEN

Fens are by definition largely groundwater-fed and Pollardstown is a fen on the shoulder of a large glacial outwash plain (The Curragh) where springs, mainly along the southern margin, are the source of the wetland water. However, the storage controlling the habitat of the key species (the mollusc Vertigo geyeri) is provided by thin layers of clayey peat masking the gravel at the margin of the fen (Fig.5). The slow seepage rates through this peaty layer results in the 'petrifying springs' habitat known as tufa which creates the suitable habitat for the snail. The very low seepage rates (typically 1-6 mm/day) combined with the narrow range of mobility for the snail, means that understanding the water level in the habitat in response to the rainfall and groundwater level on the Curragh was critical. This non-linear response was heavily damped compared to the regional groundwater level meaning that the ability of the habitat water level to rebound following any disturbance was limited, that is the system had poor resilience.

Although the analysis of the hydrology of the system defined a specific threshold water level at a monitoring well in the Curragh below which the sensitive habitat in the fen could not be sustained, it took no account of time or duration, e.g. instantaneous extinction would not necessarily follow an exceedance of that threshold. Nevertheless, the detailed research and an associated model of the hydrological response of the fen margin has identified a threshold which can be regarded as an alarm – such response characteristics need now to lead to an assessment of resilience in order to facilitate appropriate mitigation measures (if any).

A MICRO WATER BALANCE

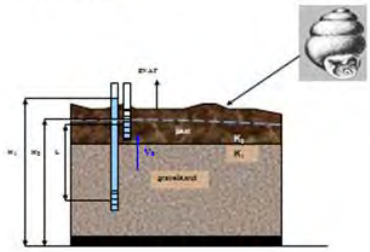
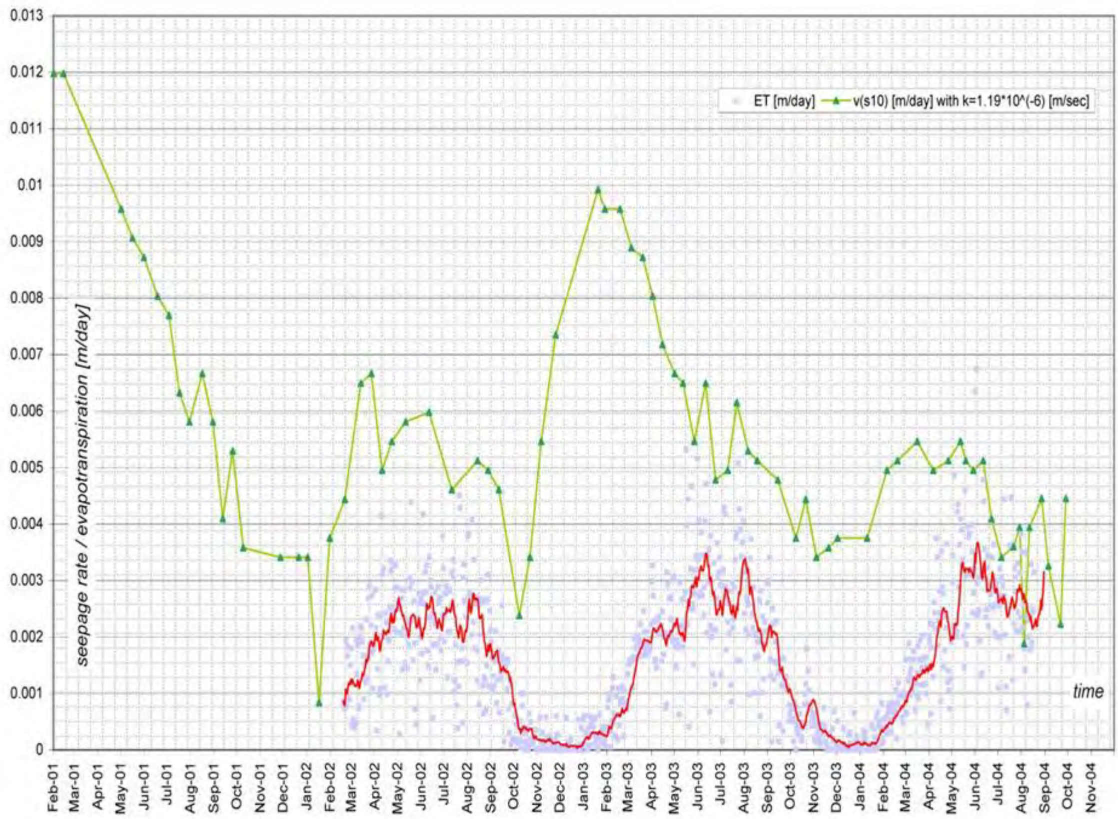


Fig. 5 POLLARDSTOWN FEN MARGIN
Seepage velocity (green) in the context of water balance. Abstraction/drainage on the Curragh was impacting on the water balance at the snail habitat.



RAISED AND BLANKET BOGS

As a result of many years' research on peatland/bog hydrology, an emerging conceptual model can be resolved into two main storages which respond to rainfall inputs very differently. The bulk of the bog peat tends to be a low permeability medium (the catatelm in a raised bog) but this in turn rests on/in a regional groundwater body which may have a variable hydraulic connection with the wetland above. The active layer in the bog is the near surface, typically <50cm in thickness, layer of growing vegetation such as the Sphagnum sp. mosses. This 'storage' has quite different response characteristics to rainfall and as the active layer in conservation terms, has attracted the research in determining criteria for sustainability. The much more heavily damped response of the deeper groundwater has received much less attention but it has far less resilience and damage resulting from disturbance to the regional groundwater can have far greater consequences (ie subsidence in the peat) than impacts on the near surface resulting from, for example, local drainage.

While long monitoring of hydrology on midland raised bogs (Clara and Raheenmore) have supported the notional threshold for sustainability of Sphagnum sp as the requirement a mean water level within 10cm of the surface, the hydrological regime is much more complex. The frequency duration curve shown in fig.6 for water levels in different ecotopes demonstrates the quite different hydrological regimes even though, for the central and sub-central zones, the mean water levels remain within the notional threshold. The frequency duration curves and the relatively rapid response of the acrotelm to incoming rainfall mean the resilience of this storage is much higher. Restoration of the storage levels is quite feasible if they have been damaged by local drainage, provided that the lower storage (regional groundwater regime) has not been impacted. Active raised bog, to maintain this water level regime in the acrotelm storage, has to be able to sustain the relevant water balance at the surface. In the many years of investigation at Clara, an appropriate metric was developed for sustainable hydraulics of the surface peat catchments involving the contributing area and the bog slope which has recently been designated the Potential Acrotelm Capacity (NPWS, 2014):

$$\mathbf{PAC = L/s}$$

Where PAC is the Potential Acrotelm Capacity (km), L = upstream flow path Length (m) and s is the local surface slope ($m.km^{-1}$). The threshold for high bog at Clara was determined to be >50 km. A modified PAC, known as the MFAC (Modified Flow Accumulation Capacity in km) was developed to be more universal in application:

$$\boldsymbol{MFAC = \sqrt{A}/s}$$

Where A is the upstream contributing catchment Area (flow accumulation area in m^2) and s is the local surface slope ($m.km^{-1}$) and the relevant threshold for high bog is >70km. In essence, this criterion means that the relevant slope for the sustainability of the bog vegetation is 0.3%, ie <30cm per 100 m. but these criteria only partly address the relevant water balance as they do not address the relevance of rainfall. It is clear that as the rainfall inflow increases, significantly greater slopes can still sustain the Sphagnum sp. as is apparent in the blanket bogs in the west of Ireland.

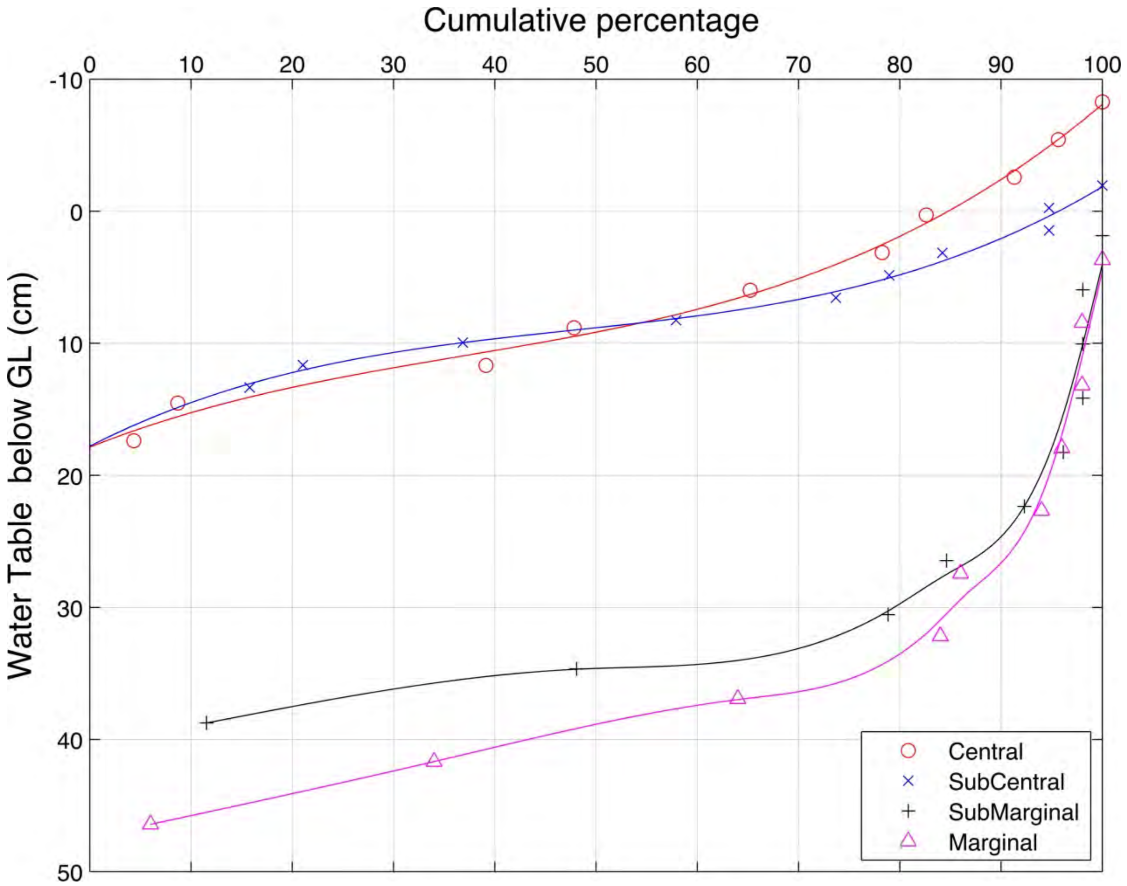


Fig. 6: Frequency duration curves of water level in the acrotelm for different ecotopes in Clara Bog

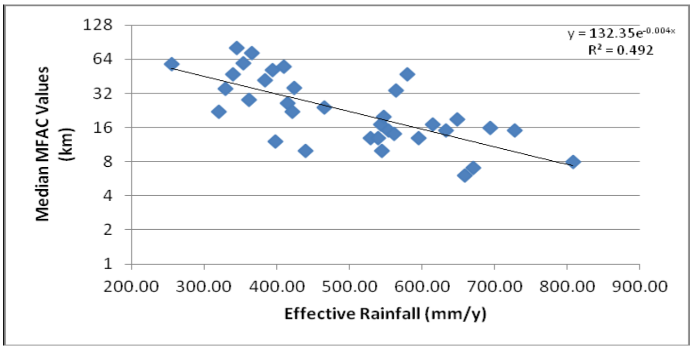


Fig. 7: Correlation between effective rainfall and Acrotelm Flow capacity for raised bogs (NPWS, 2014)

Although a correlation was developed for the acrotelm capacity and mean annual effective rainfall (Fig.7), the logarithmic regression does not properly reflect the hydraulics of the situation, the relationship between rainfall frequency duration and the corresponding flow from the bog. Blanket bogs also have a need for an appropriate criteria – significant monitoring of the hydrology on a blanket bog draining to a lake but intersected by a road (N59) and shallow drain near Recess in Connemara has shown quite different frequency-duration curves (fig.8) to those in Clara, although the annual rainfall is over 2000mm and the surface slope of the bog towards the drain is 1%. The bog is part of a Special Area of Conservation and has an active cover of Sphagnum and associated ecology. However, the monitoring of piezometric and phreatic levels has indicated that the lower storage, ie the regional groundwater under the bog is quite responsive to rainfall events suggesting also that the blanket peat itself is likely to be more permeable than is usually found in raised bogs. Such responsiveness indicated that the blanket bog may be more resilient than its raised bog equivalents but specific metrics remain to be determined.

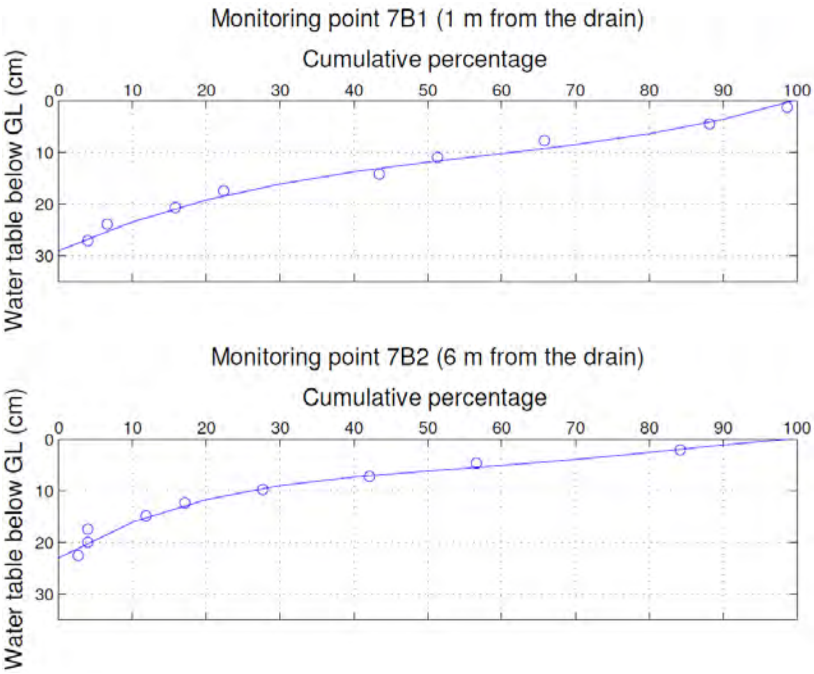


Fig. 8 Blanket bog near Recess, Co. Galway.
Frequency-duration curves for phreatic water levels at a distance from a shallow drain, 0.5m depth. Variable peat depth on the bog, up to 6m.

TURLOUGHS

Turloughs are unusual wetlands in that they respond strongly to seasonal groundwater inputs and are exclusively in karst hydrogeology. Hydrological and ecological monitoring of turloughs in the west of Ireland has shown that there is a relationship between zones of vegetation within a turlough and the frequency-duration of flooding levels. The relevant storage for the wetland in this case is the body of the turlough for which a depth-volume relationship can be determined from topographic surveying. Thus there is a direct hydraulic relationship between net inflows and the cumulative driving rainfall. Notwithstanding the effects of grazing, the diversity of species has a clear correlation with the frequency-duration curve for the inundation levels in the turlough (Fig.9). Threshold criteria for hydrological damage are difficult to determine unless frequency-duration is taken into account.

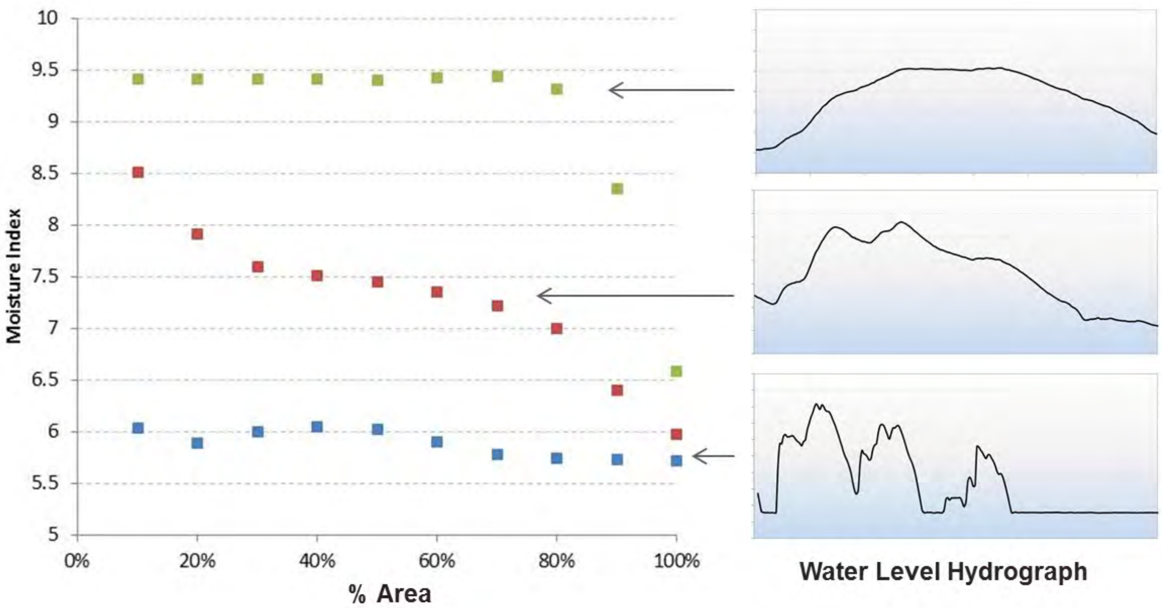


Fig. 9: The Ellenburg moisture index for different plant species against the percentage area occupied for three different turloughs having different response characteristics to driving rainfall. (Owen Naughton, Unpublished Data)

The figure shows, however, that the more responsive turlough is likely to be more resilient than the one showing a more damped response – which is shown by the more even distribution of plant species. For example, truncating the flooding level of the slow response turlough is likely to have a greater impact than a similar truncation on the rapid response turlough. While a numerical reservoir storage model of turlough hydrology has been developed (Naughton, 2012) it remains to determine a suitable metric for resilience.

CONCLUSION

Resilience is a concept that has been applied to water resources and ecological systems for some time (Walker & Salt, 2006) but is relatively new in the quantitative evaluation of wetland behaviour. A quantified measure of resilience would give a better measure of the potential for hydrological damage in a given wetland, rather than relying on fixed thresholds for identifying damage. Although criteria have been developed for sustainability of different types of GWDTE, the element of time/duration has not been incorporated which would reflect the significance of violating such thresholds. A key analysis of resilience has recently been developed for surface water hydrology by Botter et al (2013) but which has great potential for groundwater dependent wetlands. Essentially a simple representation of the driving precipitation as a Poisson process of response-producing events of a given frequency λ and magnitude α feeding a reservoir storage model yields an outflow (or water level) record having a characteristic recession constant k. The response of a wetland system is typical of any hydrological system and can be represented by a gamma function with characteristic parameters representing rate r= αk and shape parameter s= λ/k. The variability of the response (resilience) is represented by $\sqrt{k/\lambda}$, all parameters identifiable from measured hydrological data. However, an essential requirement for any impact assessment involving wetlands is the gathering of sufficient but relevant data over a sufficiently long time period. Most situations have their own unique hydrological signature but this can be determined, given appropriately focussed data gathering.

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THE FLOODS DIRECTIVE AND NATIONAL CFRAM PROGRAMME: ASSESSMENT OF GROUNDWATER FLOOD RISK

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ABSTRACT

Flood risk management has evolved over time in Ireland, from land drainage for the improvement of agricultural land to the development of urban flood protection schemes. A major review of national flood policy in 2004 set the basis for further development of this sector and lead to the development of the National 'CFRAM' Programme. The EU 'Floods' Directive, which was well aligned with the new national policy, came into force in 2007 and moved key components of the CFRAM Programme onto a legislative basis. The first step of implementation of the Directive, the Preliminary Flood Risk Assessment (PFRA), identified 300 areas of potentially significant flood risk around the country for which detailed flood maps are being prepared and flood risk management measures will be developed. Groundwater flood risk was considered as part of the PFRA process, with indicative mapping undertaken based on past events, the topography around turloughs and professional judgement, although only one area of potentially significant risk were identified. This was due to the focus in the first cycle of implementation of the Directive on community-level risk where the greatest risk exists within concentrated areas. However, the Directive is cyclical and future refinements and improvements can be achieved, including a better understanding of the impacts of projected wetter winters in the west of Ireland on groundwater flooding and in the assessment of risks in rural areas. Such improvements would enhance the understanding and management of groundwater flood risk in Ireland.

BACKGROUND

Flooding is a natural phenomenon that was historically not a major national issue in Ireland to the extent that it would have been in some countries such as the Netherlands, and a greater focus was placed on the improvement of agricultural land. This was achieved through embankment schemes to protect low-lying areas and drainage schemes, such as localised drainage schemes that form the Drainage Districts maintained by the local authorities, or, since 1945, the catchment-wide arterial drainage schemes implemented and maintained by the Office of Public Works (OPW). While the arterial drainage schemes reduce flooding in urban areas along scheme channels, it was only in 1995, with the amendment to the 1945 Arterial Drainage Act, that attention became focused specifically on localised flood protection.

Following a series of major floods during the late 1990’s through to 2002, and in line with a changing view on the most appropriate approach to flood risk management both nationally and internationally, a major review of national flood policy was initiated. This review was led by an Inter-Departmental Review Group, supported by the OPW, and led to the production of a report that was approved by Government and published in September 2004 (OPW, 2004).

The new policy promotes a pro-active and catchment-based approach to the assessment and management of flood risks, with greater use and development of non-structural measures, such as prevention (through sustainable planning) and community preparedness and resilience, to work alongside capital structural protection works.

A number of specific recommendations were also made, including a national flood mapping programme and the development of catchment-based Flood Risk Management Plans (FRMPs) that would set out long-term sustainable strategies for flood risk management. To implement the above mentioned specific recommendations, the OPW developed the Catchment-based Flood Risk Assessment and Management (CFRAM) Programme. Pilot CFRAM Projects were initiated in 2006 in the River Lee Catchment in Co. Cork and the River Dodder Catchment running down from the Dublin Mountains through Dublin to the River Liffey, and then subsequently in the Fingal - East Meath Area to the north of Dublin City.

THE 'FLOODS' DIRECTIVE

These Pilot CFRAM Projects were well underway when the EU Directive on the Assessment and Management of the Flood Risks (the EU 'Floods' Directive - 2007/60/EC) came into force late in 2007, which was subsequently transposed into Irish law by SI No. 122 of 2010. The principal requirements of the Floods Directive are:

- Undertaking of a Preliminary Flood Risk Assessment (PFRA) to determine areas of potentially significant for flood risk
- Preparation of Flood Hazard and Risk Maps for the areas identified in the PFRA
- Preparation of Flood Risk Management Plans, including defining objectives for the management of flood risk, and then setting out measures aimed at achieving the objectives defined for the areas identified in the PFRA

There is clearly a strong degree of alignment between the requirements of the Floods Directive and the National CFRAM Programme in terms of the production of flood maps and FRMPs. In addition to the three key stages above, Member States are also required to:

- Co-ordinate with the process and implementation of the Water Framework Directive (WFD)
- Ensure co-operation between Member States in transboundary river basins
- Promote public and stakeholder participation and dissemination of outputs

It is important to note also that the 'Floods' Directive is cyclical, with reviews of the three key stages required at six-yearly intervals.

THE PRELIMINARY FLOOD RISK ASSESSMENT

The objective of the PFRA is to identify areas where the risks associated with flooding might be significant. These areas (referred to as Areas for Further Assessment, or ‘AFAs’) are where more detailed assessment will then be undertaken to more accurately assess the extent and degree of flood risk, and, where the risk is significant, to develop where possible measures to manage and reduce the risk. The more detailed assessment, that will focus on the AFAs, will be undertaken through Catchment Flood Risk Assessment and Management (‘CFRAM’) Programme.

In Ireland, the PFRA has been undertaken by:

- Reviewing records of floods that have happened in the past
- Undertaking analysis to determine which areas might flood in the future (predictive flood mapping), and what the impacts of such flooding might be, and,
- Consulting with the Local Authorities and other Government departments and agencies

The ‘Floods’ Directive does not provide a definition for ‘significant’ flood risk. A highly prescriptive definition is not suitable given the preliminary nature of the PFRA, but guiding principles were set. It should however be remembered that, while flooding of one home will be traumatic to the owner or residents of that home, the PFRA needs to consider what is a nationally or regionally significant flood risk. On this basis, it was decided that the first cycle of the PFRA should focus on the risk at a community-level where the risk tends to be greatest and most concentrated.

This assessment has considered all types of flooding, including natural sources, such as that which can occur from rivers, the sea and estuaries, heavy rain and also groundwater, and the failure of built infrastructure. It has also considered the impacts flooding can have on people, property, businesses, the environment and cultural heritage. The Overview Report of the National PFRA (OPW, 2012) and a range of technical reports provide further details on the PFRA, and are available at the website of the National CFRAM Programme (www.cfram.ie).

The outcomes of the PFRA were taken to public consultation, after which 300 AFAs were designated nationally, as presented in Figure 1. Of these, most relate to flood risk from rivers, 90 are coastal communities, 2 relate to pluvial flood risk (flooding from intense rainfall events). One AFA was designated on the basis of Groundwater flooding; namely, the area around Doughiska Turlough, Galway City.

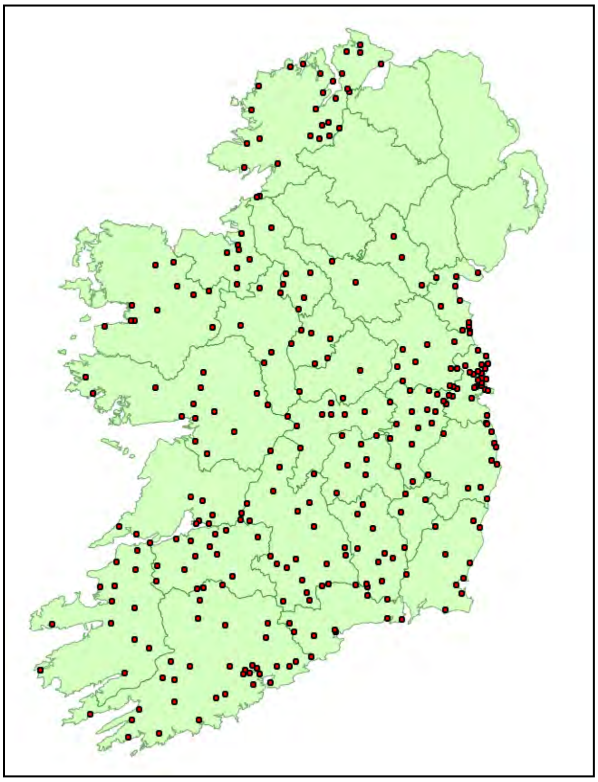

Figure 1: The 300 Designated AFAs in Ireland

FLOOD MAPPING

The second stage of the implementation of the 'Floods' Directive, and one of the core outputs of the National CFRAM Programme as initially developed, was the production of flood maps for the AFAs. The Directive requires Member States to produce flood extent maps for two, and optionally three, flood event probabilities with information on levels or depths and, optionally, flows or velocities, and also flood risk maps showing the potentially affected number of inhabitants, IED installations and some areas protected under the Water Framework Directive, and the types of economic activity potentially affected. In the first cycle, these need only be produced for the current scenario (i.e., without taking account of the potential impacts of climate change).

The CFRAM Projects had been specified to develop a significantly greater degree of detail and, as a consequence, number of maps than those subsequently specified by the Directive. Maps are been produced for up to eight flood event probabilities (depending on the type of map) for flood extents and depths (see Figures 2 and 3), for overland flow velocities and 'risk to life' (a function of depth and velocity), for flood zones (specifically for the purposes of planning and development management), for defence failure scenarios and for seven types of risk. Maps are also being prepared for two potential future scenarios, taking account of potential impacts of climate change, as well as for the current scenario.

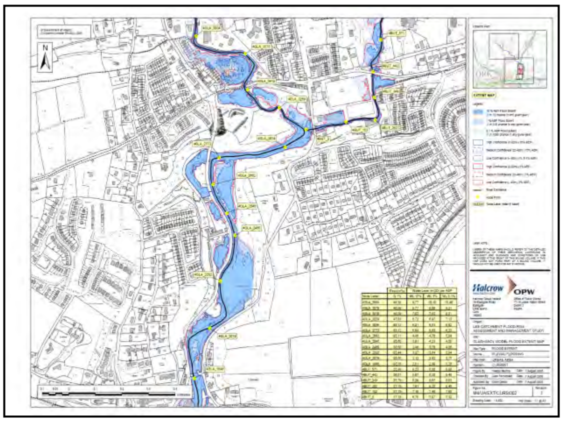

Figure 2: Flood Extent Map

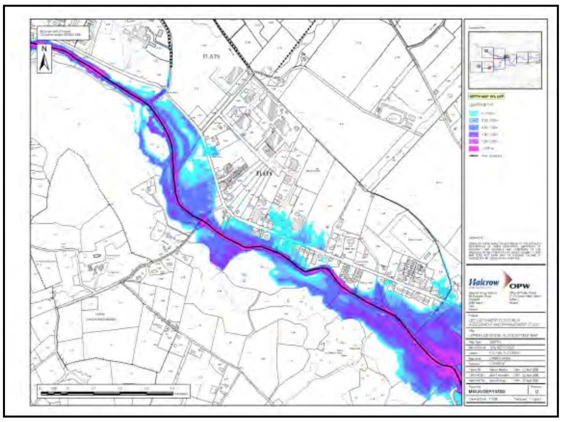

Figure 3: Flood Depth Map

These maps have been produced using hydrodynamic modelling, with dynamically linked 1-dimensional - 2-dimensional models for rivers and their floodplains, and 2-dimensional modelling for the inland propagation of extreme sea levels and coastal waves.

The maps are a stepping stone to the identification and assessment of flooding and flood risk that will help in the development of appropriate flood risk management solutions, but are also of significant value in their own right. They will promote and facilitate sustainable development with due consideration of flooding, as set out in the Guidelines on the Planning System and Flood Risk Management (DECLG/OPW, 2009), to help avoid the costly mistakes of the past and an ever-increasing national vulnerability to flooding. They will also inform flood event emergency response planning, and can help raise public awareness of flood risk to build individual and community resilience.

The flood maps, at the time of writing, are being exhibited at over 200 local consultation days around the country, and will shortly be taken to formal national public consultation.

FLOOD RISK MANAGEMENT PLANS

The final stage of the 'Floods' Directive, and the second of the core outputs of the National CFRAM Programme, is the preparation of the FRMPs.

The first step in this process is the identification of objectives, that define what we are intending to achieve. In Ireland these have been primarily defined in terms of the reduction in flood risk to people and a range of economic, social and environmental assets or functions. The objectives were taken to public consultation in October 2014 and have now been finalised.

Having identified the objectives, the next step is to develop measures aimed at achieving those objectives. This involves the consideration of a wide range of potential methods to reduce flood risk, the development of options based on potentially appropriate methods and then the appraisal of the options in terms of their performance against the defined objectives, and also economically through a cost-benefit analysis, to identify preferred measures. The preferred measures, after consultation, will be set out in a prioritised programme in the FRMP.

Examples of the FRMPs are available for the pilot projects from the National CFRAM Programme website (www.cfram.ie). The draft FRMPs for the country should be available for consultation early in 2016.

THE 'FLOODS' DIRECTIVE AND GROUNDWATER FLOODING

THE PFRA FOR GROUNDWATER FLOOD RISK

The vast majority of extensive, recurring groundwater floods originate at turloughs (groundwater-fed, seasonal lakes that reflect a groundwater environment that has developed in certain karstified limestone formations). A total of 482 turloughs were identified at the time of the PFRA; the majority of which occur in the west and north-west of Ireland, and consequently it is in these regions that most groundwater floods occur. Land around and to the north-west of the town of Gort in southern County Galway is particularly vulnerable to extensive groundwater flooding.

The methodology used to undertake the groundwater PFRA comprised three inter-linked stages, which differ from each other in terms of the availability of historic flood images and the amount and quality of existing information.

The **first stage** was based on the analysis of digital images of six historic floods, namely those in February 1990, the winter of 1994/1995, and on 24/02/01, 30/11/09, 02/12/09 and 04/12/09. The images are for relatively small, scattered areas in the west and north-west of Ireland. Most of the areas identified are associated with known turloughs, which validates the inference that the floods shown on the images were caused by groundwater rather than surface water. However, local more detailed assessment found this not to be the case for the one area identified as being of potentially significant flood risk.

Historic images of floods are, however, unavailable for much of Ireland. The **second stage** defines maximum groundwater flood outlines around those turloughs that lie outside the coverage of the available images and for which there is little or no other information. Flood outlines were drawn by assuming flood levels 4.0m above the base elevations of the turloughs (derived as the median difference between the base elevations of 85 turloughs that lie within the coverage of the historic flood images and the corresponding flood levels shown on the images). The flood outlines have been drawn electronically by following contours shown on a Digital Terrain Model. Some outlines proved to be unrealistic and these have been adjusted using a set of pragmatic constraints. Sensitivity analysis confirmed that the outlines based on the median difference are reasonable.

The **third stage** was based on evidence in 37 historic flood reports given on www.floodmaps.ie that contained information relevant to turlough flooding in the west, and on a visual examination of aerial photographs given on http://maps.osi.ie for the relatively few turloughs in the east. This information was used to corroborate or adjust the flood outlines derived during Stages 1 and 2.

Groundwater Emergence Maps and Groundwater Susceptibility Maps, as used in the UK, were not applied to the Irish situation because both require detailed groundwater level data. There are very few locations where groundwater level data are collected routinely and the records of these are of short durations that do not include the years when most of the severe groundwater floods have occurred. Furthermore, in karstic environments groundwater levels measured at one location may be unrepresentative of levels nearby and so were deemed likely to be of limited value in the Irish situation.

A paper on the Groundwater PFRA methodology was presented at the IAH Conference of 2011 (Hardistry et al, 2011). The detailed report on the Groundwater PFRA methodology is available from the National CFRAM Programme website as noted above (Mott MacDonald Group, 2010).

The areas identified as prone to flooding from groundwater were mapped and these are available on-line (www.cfram.ie/pra), and are shown here in Figure 4.

As noted previously, only one groundwater-related AFA was identified in the PFRA, which was the area around Doughiska Turlough, Galway City. Trinity College Dublin were subsequently commissioned to further investigate the flooding in this area, and in a number of other areas of concern that had not been designated as AFAs but where groundwater flooding had been observed as a risk to property. This study concluded that the flooding in the Doughiska area was not in fact related to the turlough, but was rather due to inadequate capacity of the surface drainage systems following heavy and prolonged rainfall events and/or when soils are saturated and unable to take further infiltration, i.e., pluvial events (Naughton, 2013).

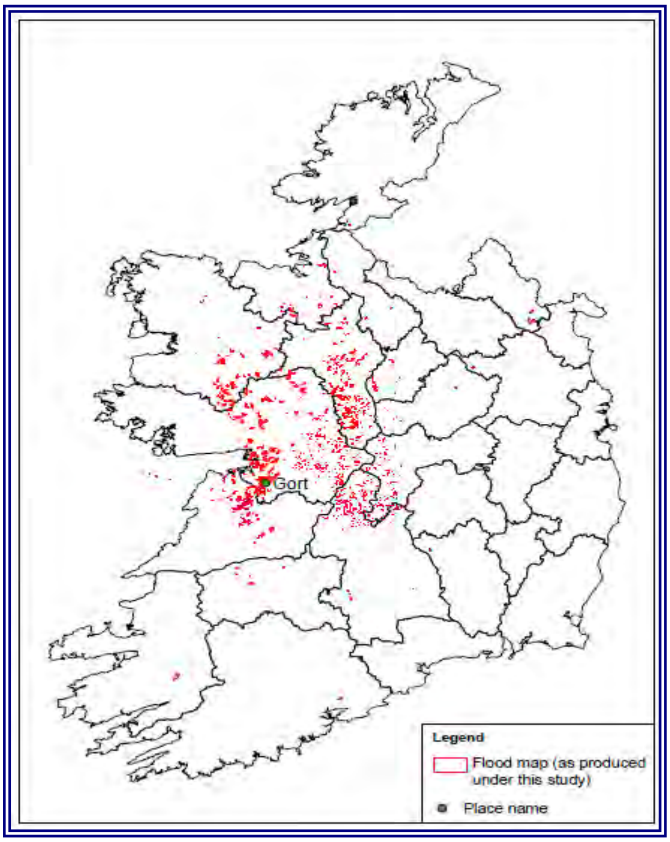

Figure 4: PFRA Groundwater Flood Map

As this area has been determined in fact not to be at significant risk, detailed predictive groundwater floodmaps have not been developed for this area, and there is no significant risk requiring flood risk management measures. As such, there will be no groundwater specific measures set out in the FRMPs. However, broader policy measures to be set out in FRMPs, such as sustainable planning and development, will apply to areas prone to groundwater flooding as well as those prone to flooding from rivers, the sea, etc.

NEXT STEPS

The National CFRAM Programme is bringing the management of flood risk in Ireland forward by a generation. The flood maps provide detailed information on flood hazard and risk that will inform sustainable planning and effective flood emergency response planning, as well as providing the platform for building community awareness of, and resilience to, flood events. The FRMPs will set out a holistic and sustainable strategy for flood risk management for 300 communities within a catchment context that integrates non-structural measures with the more traditional capital flood protection schemes.

Groundwater flooding from turlough systems has caused extensive flooding in the west of Ireland; most notably in 1995 and 2009. However, while the flooding has affected large areas of agricultural land and a number of properties, only one AFA related to groundwater flooding was initially designated in the first cycle of the PFRA, and this was later found to be in error after more detailed, local investigation. This outcome is primarily a result of the need to focus in the first cycle of the implementation of the 'Floods' Directive on the areas of most significant risk, which is typically concentrated at a community-level in our villages, towns and cities, rather than rural areas with dispersed populations which are those that tend to be affected by groundwater flooding.

However, the 'Floods' Directive is cyclical, and a review of the PFRA will need to be completed by the end of 2018 and every six years thereafter. There is a recognition across the EU that it is not possible to cover all risks in exhaustive detail in the first cycle of implementation of the Directive, but that future cycles do offer the opportunity to refine and improve the work previously done.

While much has, and is, being achieved in the current cycle of the implementation of the 'Floods' Directive, the OPW recognises that more can be done. Consideration will be given as to whether improvements can be achieved in the predictive groundwater flood mapping within the context of the PFRA. Other areas where refinements could be realised include:

– Improvements in the understanding of the potential impacts of climate change, including the response of different catchments to changes in rain patterns, such as the wetter winters that are projected for the West of Ireland.
– Improvements in the assessment of risks in rural areas, including damages to agricultural land and effects on isolated properties.

The above factors are relevant to developing a better understanding of groundwater flood risk, and new AFAs related to groundwater flooding may be designated in the future, which would then benefit from detailed flood mapping and the assessment of flood risk management measures. Our understanding and management of groundwater flood risk in Ireland is improving, but there is more to be done.

ACKNOWLEDGEMENTS

The author wishes to thank Sarah Beeson and Rachael Hardistry of Mott MacDonald Group for their work in undertaking the Groundwater Preliminary Flood Risk Assessment, and also Dr. Owen Naughton and Prof. Paul Johnston of TCD for their work in undertaking local assessments of groundwater flood risk areas.

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SOILS OF IRELAND: THE IRISH SOIL INFORMATION SYSTEM

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INTRODUCTION

The Irish Soil Information System project was established in 2008, following a comprehensive inventory of Irish soil data compiled by Daly and Fealy (2007) which highlighted that soil data coverage of Ireland was incomplete in both detail and extent. This realisation led to the establishment of the Irish Soil Information System, co-funded as part of the STRIVE programme of the Environmental Protection Agency and coordinated by Teagasc, in collaboration with Cranfield University (UK) and University College Dublin. The objectives of this project were: (1) to develop a new soil map for Ireland at 1:250,000 scale; (2) to identify new and existing soils; and, (3) to provide a detailed description and classification system for all the soil types present in Ireland.

DEVELOPMENT OF THE SOIL INFORMATION SYSTEM

The Irish Soil Information System project has utilised existing data and maps from the previous National Soil Survey (NSS) conducted by An Foras Talúntais (forerunner organisation to Teagasc). The NSS produced: mapping at 1:126,720 scale for 44% of the country; identifying over 450 soil series with varying properties and different environmental and agronomic responses. This data was used as the basis of a General Soil Map of Ireland and a National Peatland map, both at 1:575,000 scale and other miscellaneous large scale mapping of experimental farms. In addition, more recent map products have been included such as the Indicative Soil and Subsoil mapping (Fealy et al., 2009) with national coverage using GIS and remote sensing techniques.

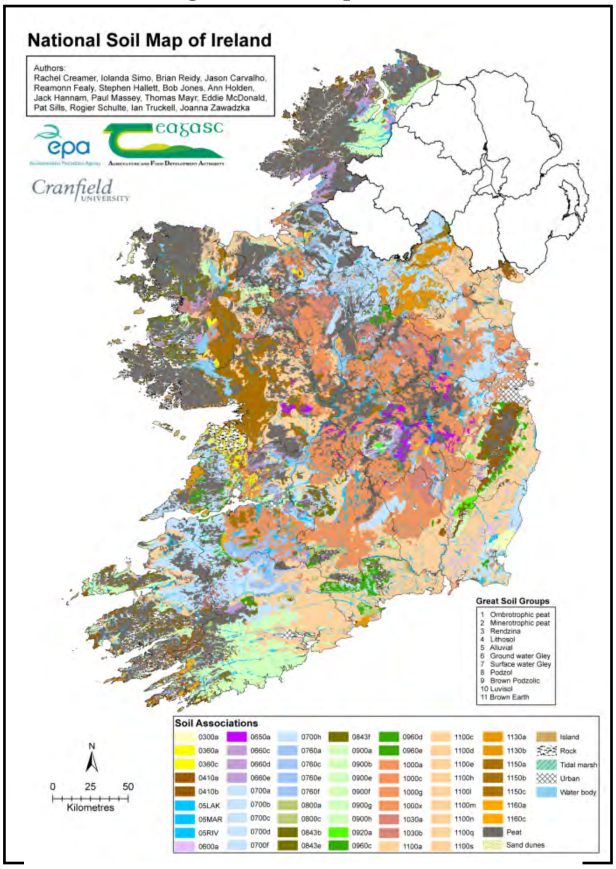

Figure 1: Irish Soil Map (3rd Edition)

Comparison of soil information at a European scale has led to the requirement for the harmonisation and coordination of soil data across Europe. Harmonised geo-referenced soil data across Europe at a scale of 1:250 000 will allow for the exchange and comparison data across member states. In light of the demands for soil protection on a regional basis within member states there is a growing need to support policy with a harmonised soil information system. Following the INSPIRE Directive implemented in 2007, there has been a large emphasis on provision of soils data at a recommended scale of 1:250,000, in addition to harmonisation of soil classification laboratory methodologies and meta-data production to facilitate comparison of data and maps between countries. The European Soil Bureau Network

(ESBN) Technical Working Group dealing with Soil Monitoring and Harmonisation recommended a soil map of Europe at a scale of 1:250,000 as an economically feasible intermediate scale that can identify specific problems at regional scale (Montanarella and Jones, 1999).

The project adopted a combined methodology of utilising novel predicted mapping techniques in tandem with traditional soil survey applications at a national scale. Building upon the detailed work carried out by the An Foras Talúntais (AFT) survey (known as *Terra Cognita*), the Irish Soil Information System project generated soil-landscape models at a generalised scale of 1:250,000 for the counties of Carlow, Clare, Kildare, Laois, Leitrim, Limerick, Meath, Offaly, Tipperary South, Waterford, Westmeath, Wexford, West Cork, West Mayo and West Donegal. These soil-landscape models (also referred to as soilscapes) were used as the baseline data for statistical models (random forests, Bayesian belief networks and neural networks) to predict soil map units in counties where there was no map available (referred to as *Terra Incognita*). In order to validate the methodology, an intensive field survey was carried out over 2.5 year, in which 11,000 locations were evaluated for soil type, using an auger bore survey approach (Simo et al., 2014). These data were used to check the predicted soil mapping units (associations) for counties: Cavan, Dublin, East Cork, East Donegal, East Mayo, Galway, Kerry, Kilkenny, Louth, Monaghan, Roscommon, Sligo, Tipperary South and Wicklow, where a detailed soil survey map was not available. In addition to the auger bore campaign, a second field campaign was initiated based upon the findings of the auger bore survey. Where new soil information was generated, due to previously unknown combinations of soil-landscape units, profile pits were selected at representative locations across the country. These profile pits were excavated and sampled to a depth of approximately 1m. All horizons were sampled for a full pedological, chemical, physical and biological characterisation. These 225 pits, described and sampled in detail, were used to generate a new soil classification system for the country (Figure 2).

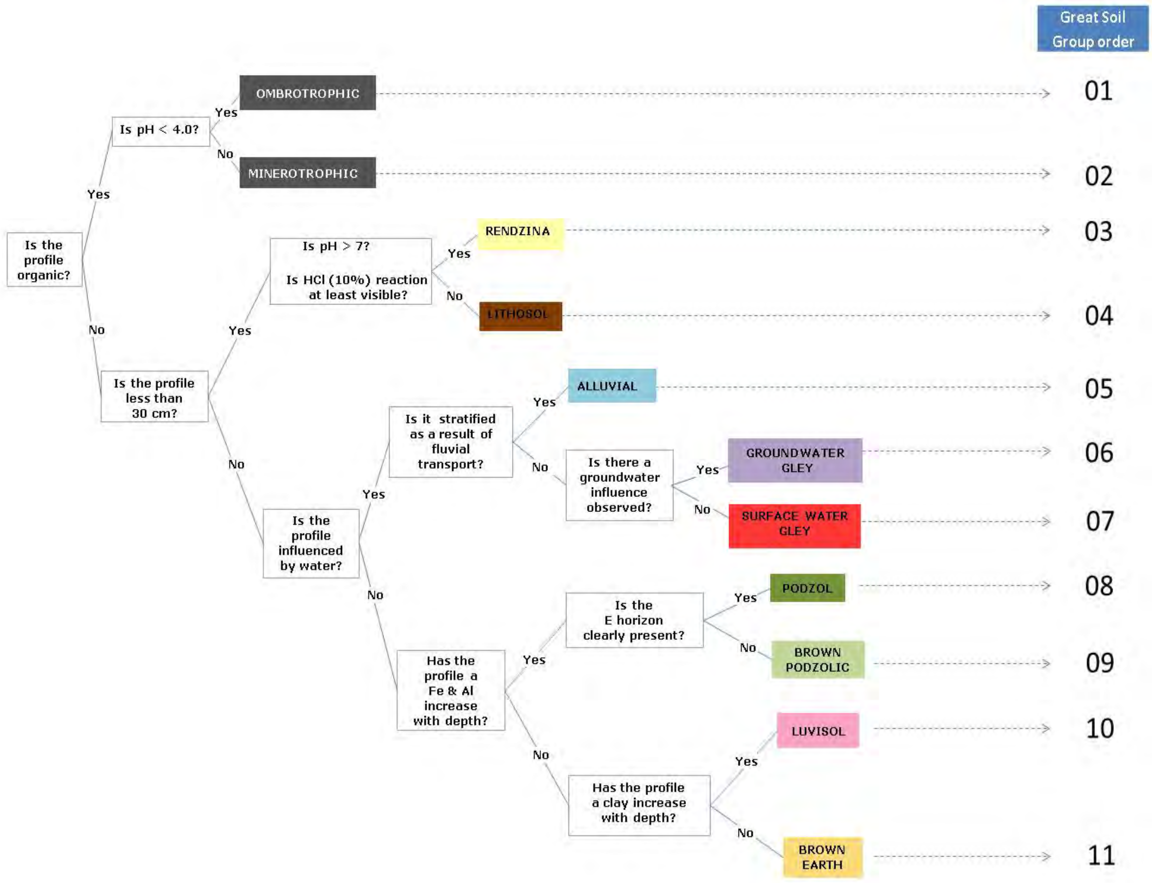

Figure 2. Irish Soil Classification System – Identification of Great Soil Groups, 2014

The final product is a unique combination of new and traditional methodologies and soils data from both the AFT and the Irish Soil Information System project. The final soil association map of Ireland (Fig. 1) consists of 58 associations (excluding areas of alluvium, peat, urban, rock or marsh) that are made up from 213 soil series. Associated representative profile information is available in the online soil information system. Details of the project can be found at (http://gis.teagasc.ie/soils). Creamer et al. (2014) provides a full summary of this project and there are 17 technical reports available for download from http://erc.epa.ie/safer/.

CONCLUSION

A key component of this project has been the development of a soil and land information system and associated public web site. This system has been designed to hold the complete set of information deriving both from the field programme and modelling activity, as well as the previously existing legacy soils information available for Ireland. This soil information system, which provides data behind the soil map of Ireland, is freely available, as it is intended that this system will add to the capabilities of soil survey, rather than take from it, providing a modern and clear soil classification system for Ireland. Drawing on this information system, the web site is designed to hold and disseminate this information online both in cartographic and tabular form to stakeholders. Prior to this development, there was no harmonised computerised system in place to hold and manipulate national Irish soils data. The information system therefore addresses the pressing need and requirement for a publicly-accessible, integrated IT framework based upon contemporary informatics standards to serve the many and varied stakeholders having an interest in soils information in Ireland.

ACKNOWLEDGEMENTS

This project was co-funded by the EPA (Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007-2013) and Teagasc. Many thanks to project partners at Cranfield University and University College Dublin, and the project Steering Committee.

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EARLY CAREER HYDROGEOLOGISTS' NETWORK

THE IAH EARLY CAREER HYDROGEOLOGISTS' NETWORK (ECHN): WHAT ROLE CAN EARLY CAREER HYDROGEOLOGISTS PLAY AS GROUNDWATER ADVOCATES?

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ABSTRACT

The Early Career Hydrogeologists' Network (ECHN) of the International Association of Hydrogeologists (IAH) was formally accepted as a network of the IAH in 2011. Attracting early career hydrogeologists typically with less than 10 years' experience, the membership has grown rapidly to 378 registered members on LinkedIN in 2015 and via the establishment of three national ECHN Branches in South Africa, Western Australia and the UK. This short essay aims to outline the formation of the ECHN, its present involvement in IAH activities and planned future activities. It is hoped that this introduction will clarify the purpose of the ECHN and serve as an invitation to new members to join our effort in promoting the role of early career hydrogeologists (ECHs) in IAH matters.

Keywords: Early Career Hydrogeologists' Network; ECHN; young hydrogeologists; network

1. The recent rise of Young Professional and Early Career Networks

A healthy and well functioning professional society in any field can only be sustained by ensuring that new members continue to be interested and engaged in the group's purpose and activities. The International Association of Hydrogeologists (IAH) is no different. Particularly, as highly-experienced groundwater professionals reach retirement, it is vital that a concerted effort is made to ensure that this invaluable knowledge and informed foresight is not lost. In this endeavour early career hydrogeologists can reap the benefit of decades of accumulated information and know-how from willing senior scientists and professionals. They are also exposed to more senior members of the IAH, where they are supported in their career development, and can be encouraged to take on more formal roles within the organisation.

For such reasons an early career network was envisioned by the IAH in its *Forward Look Initiative* in 2009 inspired, in part, by other similar professional societies. In recent years these groups have also identified the need for increasing the membership and involvement of young or early career scientists within their organisations. Several examples are worthy of note, perhaps the foremost being the

International Water Association (IWA) which provided a well-developed, multi-faceted Young Water Professionals scheme. The International Association of Hydrological Sciences (IAHS) has employed similar measures to establish a Young/Early Career Hydrologists' Meeting. One of the incentives established by such associations, including for instance the International Association for Engineering and Environmental Geologists (IAEG), is the offering of tailored awards and acknowledgments for early career members and their work.

2. The establishment of the ECHN

Following encouragement from the IAH Council and Secretariat, two early career hydrogeologists, Mark Cuthbert and Sophie Vermooten, (supported by John Chilton, Executive Manager of IAH, and the local organising committee including ECH Anna Kuczynska) planned a tentative meeting for early career hydrogeologists at the IAH conference in Poland in September 2010. The meeting attracted over 50 participants and a lively and informal discussion led to a better understanding of the needs of ECHs and possible ways forward for better supporting them professionally and encouraging their involvement in IAH. A small working group was set-up (Judith Flügge as chair; Mark Cuthbert and Jay Thakur as co-chairs) to take forward and implement the outcomes of the meeting. Opting for the reference model of the Young Water Professionals Group of the IWA, a network was developed and is now known as the Early Career Hydrogeologists' Network (ECHN). The ECHN was formally accepted as a network of IAH in 2011.

A second meeting, the first annual general meeting (AGM) of ECHN was held in Pretoria, South Africa, at the joint Ground Water Division (GWD) of the Geological Society of South Africa (GSSA) and IAH conference in September 2011. Subsequent ECHN AGMs have continued to take place at each IAH conference. The second was held with the newly elected Steering Committee: Judith Flügge as chair, Viviana Re and Matthys Dippenaar as co-chairs. With third and fourth meetings being held in Perth, Australia and Marrakech, Morocco, in September 2013 and 2014 respectively. Judith Flügge stepped down as chair in 2013 and was succeeded by Vivana Re. Matthys Dippenaar and Gillian Hurding, have contributed as co-chairs since this time. The current steering committee is also supported by an annually reviewed Task Group composed of 11 members from 10 different nations.

3. Why have an ECHN?

The overarching aim of the ECHN is to support hydrogeologists at the start of their professional careers and to promote their involvement in IAH affairs. A paper entitled '*What role do Early Career Hydrogeologists play as Groundwater Advocates?*' was presented during the Groundwater for Decision Makers session of the IAH conference in Niagara Falls (2012). The paper focussed on the advantages of ECHs promoting the sustainable use of groundwater whilst being actively involved in groundwater awareness. The goals were twofold, chiefly: (1) enhancing information sharing possibilities for its members to discuss and develop ideas and schemes, and (2) to enhance the social and professional network of the ECHs (Flügge et al. 2012). Social and professional networking was emphasised as vital in involving ECHs in IAH activities and ensuring their interest and involvement in the long term. To meet these aims the following objectives were developed:

- To promote information sharing possibilities for early career hydrogeologists.
- To provide support networks for members to discuss and develop ideas or schemes, through web-based forums, meetings, etc.
- To preserve hydrogeological competence and experience via productive exchanges between junior and senior hydrogeologists.
- To provide technical training via short-courses and master-classes at conferences and online sessions.
- To enhance the social and professional networking opportunities of early career hydrogeologists, e.g. by specific events at conferences.

- To strengthen the status of early career hydrogeologists within IAH by networking at conferences, congresses and within its National Chapters, Commissions and Networks.

The network also encourages initiatives to increase the participation of ECHs as co-convenors of symposia and workshops at IAH conferences and to help increase the prominence of poster sessions. It is expected that members, especially those on the steering committee, envisage active future involvement in national chapters and commissions within the IAH.

4. The ECHN Structure

The structure of the ECHN (Figure 1) centres on a steering committee guided by a chairperson and two co-chairs. Past members of the steering committee are offered the opportunity to join an advisory panel, the rationale for which is twofold: (1) due to the objectives of the ECHN, the steering committee changes quite frequently to allow new members to become active and to enable existing committee members to grow into other IAH roles, and (2) to allow consistency in ECHN objectives and functioning despite changes in the steering committee. Members of the advisory panel reduce their involvement in ECHN matters and take no direct part in the steering committee decisions, but contributions and participation within meetings are welcomed.

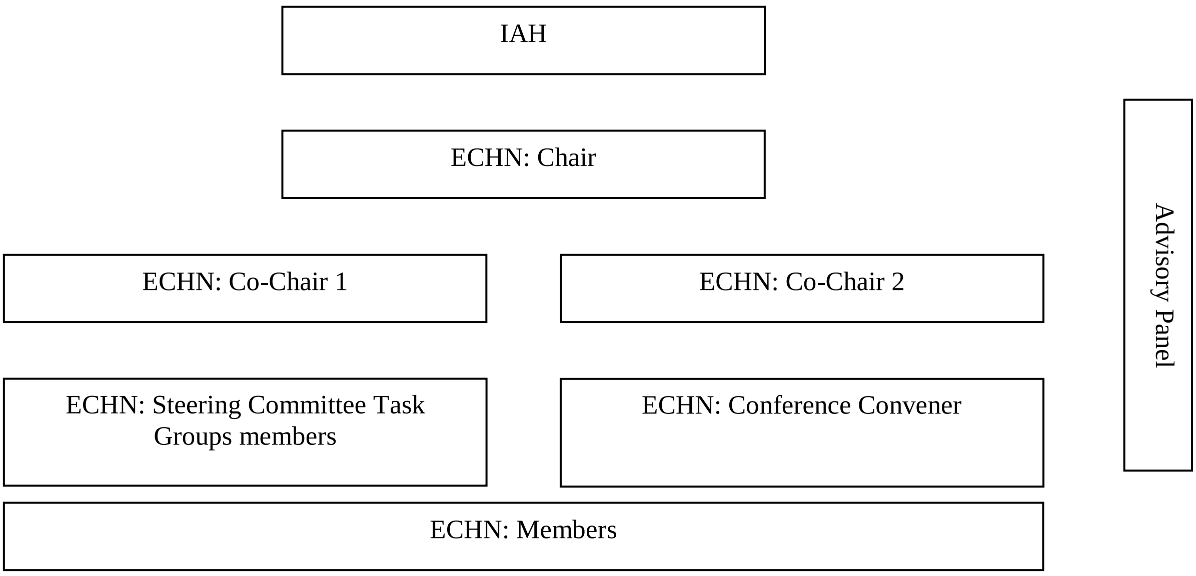

Figure 1. Present structure of the ECHN

An ECHN member is elected annually as conference convenor to represent the ECHN in the planning phases of the next congress and to ensure a prominent presence of the ECHN at the congress. This member is usually from the country where the congress is to be held to ensure that he/she is available to attend all meetings and to make arrangements directly.

5. Where are we now?

5.1. ECHN at the IAH Congress

Since 2011, the ECHN has continued to contribute to IAH activities such as the upgrading of the IAH homepage and creation of the new ECHN website. It has also consistently delivered specific activities for early career hydrogeologists at the annual IAH conferences beginning at the 39th Congress in 2012 where approximately 400 out of the 900 delegates identified themselves as ECHs. During the 40th IAH Congress celebrations in Perth, the ECHN invited Hydrogeology Journal Executive Editor, Clifford Voss, who presented his '*tips for writing a knock-out paper'* to ECHN members during a specific lunch-time session. Whilst at the 2014 Marrakesh Congress, Bruce

Misstear (IAH Vice President), joined by Karen Villhoth (IAH Outreach Commission), offered his advice at the ECHN session under the title of: "Being effectively succinct: Tips from the experts on presenting your research in 15 min or less". Lively ECHN social functions also form part of the ECHN AGMs to bring current and potential members together in a relaxed environment and to provide opportunity for ECH feedback. Thanks to the collaboration with Hydrogeologists without Borders-UK at the 2014 AGM, early career hydrogeologists were encourage to become "Hydro Heroes" by working in teams to propose a solution for a real hydrogeological case-study in Myanmar.

5.2. ECHN National Branches

In 2012 and 2013 the first ECHN Branches, ECHN South Africa and ECHN Western Australia were established. Locally focused and run branches have subsequently been replicated in the UK and can offer local fieldtrips and tailored events without prohibitive travel costs. Branch start-up guidelines have been developed by the ECHN Steering Committee and are available on request from echn.iah@gmail.com. The sustained and consistent delivery of ECHN activities relies on such Branches forming strong ties with their local IAH Chapters.

5.3. The ECHN On-line

In order promote the role of early career hydrogeologists as groundwater advocates and to encourage a fruitful discussion with the international hydrogeological community, the ECHN is also active on popular social media namely Facebook (https://www.facebook.com/ECHN.IAH) and Twitter (@ECHN_IAH). Such platforms are viewed as particularly useful for live updates and active participation during the IAH conferences and in offering free communication with members throughout the course of the year.

5.4. Coolest Paper Award

In 2013, the ECHN launched the first edition of the Coolest Paper' Award aimed at encouraging early career hydrogeologists to express their views on recent hydrogeological papers. The competition was conducted online using the ECHN website, with crowd-sourced nominations and voting. The definition of 'cool' was deliberately left open to interpretation to encourage a wide range of nominations. The process was designed to be open and democratic. The winner of the first edition of the Coolest Paper, Dr. Sebnem Arslan, was awarded during the IAH Annual General Meeting held in Morocco in 2014. Nominations are now open for the second edition of the Coolest Paper Award:
http://echn.iah.org/2014-coolest-paper

5.5. Mentoring Scheme

ECH mentoring helps to preserve competence by supporting interaction between junior and senior hydrogeologists. IAH supports this activity through its newly developed mentoring scheme. Mentors can provide:

- Scientific advice and technical knowledge.
- Guidance on career options and pathways including guidance on job types, interviews, networking or educational and training options.
- Practical experience and information, for example, about specific regions of the world or specific aquifer types.

The IAH mentoring scheme operates at different levels of support which are:

- Web/online meetings, discussions etc (e.g. IAH or IAH-ECHN LinkedIn groups).
- Side meetings, seminars etc. at IAH congresses and meetings.
- A one-to-one partnership.

The IAH mentoring scheme is still being established, and both providers and receivers of advice are encouraged to share their ideas and help develop the scheme.

5.6. Membership break-down

The inclusion of members as ECH is broadly based on the individual having less than 10 years' experience. Queries were initially aired regarding the exclusion of more senior hydrogeologists, as well as the suggestion than ECH applies only to inexperienced hydrogeologists or students. Members of all ages with varying ability are, however, welcomed to the network. The current ECHN membership falls into two main groups. In the first, membership comprises mainly full-time students, often at masters, doctoral or post-doctoral level within academic institutions. These members are typically in their late 20s to early 30s and tend to remain within research or academic institutions. The needs of these members differ from the second main group of young scientists who often hold a professional degree (which implies studying for 4 – 5 years) and broad professional experience from immediate introduction into the work force in their early 20s.

Full-time students and academic or research institution staff generally make up the bulk of the ECHN members on LinkedIN as well as those attending conferences. Professional early career hydrogeologists generally attend conferences hosted by their own national chapter only due to the lack of research grants for funding, the lack of research in a project-driven consulting environment and the financial losses represented by their time off work. Those who do attend from professional spheres are often associated with conference sponsorships or exhibitions and attend only certain parts of the conferences relevant to their employment.

6. The Future of the ECHN

The continuing success of the ECHN is necessitated by the imminent and continued need for inclusion of ECHs in IAH activities. This can be achieved through the involvement of ECH members in their respective IAH national chapters and in establishing better links and involvement in IAH commissions and other networks. The ECHN logo (Fig. 2) depicts the flow and continuity required by the ECH members – and notably the steering committee – to be replaced seamlessly and effortlessly and to go on to contribute directly in IAH activities. The ECHN strives to accomplish this objective through establishing, maintaining and developing these fundamental links with the IAH and the groundwater community.

Figure 2: Flow and continuity depicted in the ECHN logo.

The ECHN has already established close links with the IAH Commission on Groundwater Outreach and strives for interaction with the IAH Burdon Network and UNESCO-IHP. Presently, the network is focused on ensuring ever-more tailored and interactive ECHN events for Rome 2015 and supporting the start-up of local ECHN branches, strongly linked to their corresponding IAH Chapters. Equally, there is a focus on increasing traffic to the new ECHN website and sparking interaction amongst members via the LinkedIn, Facebook and Twitter accounts. A pilot *Hydro-Holiday* is also intended for September 2015. This initiative is planned to be delivered via the University of Strathclyde in Scotland and will replicate the University's Hydrogeology MSc annual fieldtrip for a small fee for up to ten ECHN members. For more information please contact echn.iah@gmail.com.

With many new members joining the network and strong support of the IAH, it is hoped that the present achievements of the Early Career Hydrogeologists' Network will be long-lived and fruitful in meeting ECHN and IAH objectives now and in the future.

Acknowledgements

Thanks to the IAH, notably Ken Howard, Willie Struckmeier, John Chilton, Andrew Stone, Shammy Puri, and Kellie Nicholson for their continued faith in our efforts. John Chilton is thanked particularly for proofreading original drafts of this essay back in 2012 and recommendations made to improve its value. Thanks to all past and present members of the ECHN steering committee and the founder members in particular (Robert Hoogeveen, Anna Kuczynska, Jay Thakur and Sophie Vermooten). Thanks also to the congress organisers at Krakow, Pretoria, Niagara Falls, Perth and Marrakesh for their efforts in showcasing the ECHN, as well as Antonio Chambel as the new Programme & Science Coordinator and Ian Acworth as the past Australia and the Pacific Vice-President.

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QUANTIFYING HYDROGEOLOGICAL INFLUENCES ON PEATLAND ECOLOGY: CURRENT AND FUTURE ISSUES

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ABSTRACT

Although once covering over 300,000 ha, over 98% of Irish Raised Bogs no longer accumulate peat (host-degraded vegetation communities). Sites that have experienced degradation since declaration as protected areas must be restored according to the EU habitats Directive. Restoration requires appropriate hydrological conditions. Hydrological modelling has demonstrated that complete restoration is not possible at some sites and measures must be implemented elsewhere, including active engineered intervention.

Current restoration measures such as drain blocking and tree clearance aim to increase the area of active (peat accumulating) raised bog. These measures aim to raise the water-table to the surface or near to the surface to promote the development of peat accumulating plant communities and creates water-logged conditions that slow rates of organic matter decay. This research investigates the hydrogeological conditions present on raised bogs through continuous monitoring and comparing the water-level regime in areas of accumulating and non-accumulating peat over the hydrological year.

The research will also to replicate the water-table fluctuation observed on site by creating a water-table model using climatic data such as rainfall and evapotranspiration rates.

Results generated to date highlight clear differences in regime, with the water-table remaining within the top 15cm of the bog in areas of active raised bog, while damaged bog showed fluctuations to a depth of 55cm below ground level. Analysis of seasonal variation displayed little contrast in regime across the bog during winter. By contrast significant differences occur during the summer. Water-level modelling has generated good fits to field data, however current research is on-going to refine the model and account for empirical parameters.

The results generated to date quantify the target conditions required for restoration, which has led to the development of E-Levels (environmental levels), this is the water-level that is required to maintain a healthy wetland ecosystems which is necessary for development of successful restoration programmes. Furthermore water-level modelling will allow for assessment of potential future effects of climate change.

GROUNDWATER NITROGEN DYNAMICS ALONG FOUR INSTRUMENTED AGRICULTURAL HILLSLOPES: INFLUENCE OF HYDRO-GEOLOGICAL SETTING AND AQUIFER GEOCHEMISTRY.

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ABSTRACT

At the catchment scale, a hierarchy of landscape, hydro-geological and physico-chemical characteristics combine to affect the distribution of groundwater (GW) nitrogen (N). Denitrification is a microbially facilitated process whereby nitrate (NO_3^-) is sequentially reduced. Depending upon a complex interaction of environmental parameters, the product of this reaction varies from benign di-nitrogen gas (N_2) to nitrous oxide (N_2O). While GW denitrification may serve as a viable NO_3^- sink, it also represents a potential N_2O (harmful greenhouse gas) source. Extensive monitoring (shallow to deep GW pathways) was carried out along four agricultural hillslopes in two ca. 10km^2 catchments. Both catchments are dominated by well drained soils, but exhibit contrasting subsurface lithologies (Devonian sandstone vs. Ordovician slate), and landuse (grassland vs. arable). The capacity for GW denitrification was assessed by examining the concentration and distribution patterns of N species (total nitrogen, nitrate, nitrite, ammonium), dissolved organic carbon (DOC), dissolved oxygen (DO) and redox potential (Eh) in monthly samples from a network of shallow and deep piezometers (n=37). Excess N_2 and N_2O were measured seasonally using gas chromatography and membrane inlet mass spectrometry. The slate catchment was characterised by uniformity, both laterally and vertically in aquifer geochemistry. The four year spatio-temporal mean groundwater NO_3^--N concentration was 6.89 mg/l, demonstrating low spatial and temporal variability (temporal SD: 1.19 mg/l, spatial SD: 1.185 mg/l). High concentrations of DO (mean: 9.75 mg/l) and positive Eh (mean: +176.5mV) at all sample depths indicated a setting with little denitrification potential. This non-reducing environment was reflected in a low accumulation of excess N_2 (mean: 1.57 mg/l) and N_2O (mean:1.61 µg/l). A mean N_2O emission factor (EF_5g) of 0.00034 was an order of magnitude lower than the most recent Intergovernmental Panel on Climate Change (IPCC, 2006) default value of 0.0025. GW in the sandstone catchment had a similar mean NO_3^--N concentration to that of the slate site (6.24 mg/l). Spatial variability (SD: 3.63 mg/l) was substantially greater than temporal (SD: 0.9 mg/l). Gaseous production in the sandstone GW contrasted that of the slate with excess N_2 ranging from 0.16-8.77 mg/l and N_2O from 0.07-66.42 µg/l. Mean dissolved oxygen concentration and redox potential were 5.6mg/l and 67.5mV respectively. The near stream zones in particular were marked by favourable denitrifying conditions: a shallow unsaturated zone, hydraulic conductivity (<2m/day), Eh (<50mV) and DO (<5 mg/l). The mean sandstone EF_5g was 0.0035, higher than the current IPCC default value. Significant exceedances (range: 0.027-0.106) occurred primarily at intermediate Eh/DO concentrations, reflective of incomplete denitrification. Seasonal recharge had a flushing out effect, increasing NO_3-N, DO and Eh, while decreasing excess N_2/N_2O. The evolution of groundwater geochemistry along a subsurface flow path is a function of residence time. While both catchments are considered productive, the slate catchment exhibits greater permeability, particularly at depth. Longer travel times in the sandstone catchment, coupled with low permeability zones, facilitated the onset of NO_3^- reducing zones. Large temporal and spatial variability in N dynamics, both laterally and vertically emphasizes the importance of fine scale monitoring in developing process based understanding.

QUANTITATIVE ANALYSIS OF FAULT AND FRACTURE SYSTEMS AND THEIR IMPACT ON GROUNDWATER FLOW IN IRISH BEDROCK AQUIFERS

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ABSTRACT

Faults and fractures are the most important store and pathway for groundwater in Ireland's bedrock aquifers either directly as conductive structures or indirectly as the locus for the development of dolomitised limestone and karst conduits. Through quantitative analysis in a range of Irish bedrock types, we have developed generic conceptual models of depth dependency, lithological control and scaling systematics for the different fault and fracture systems, linked to observed groundwater behaviour. Quantitative characterisation of the main post-Devonian fracture systems in over 80 outcrop, quarry, mine and cave locations shows that their geometry and nature varies with lithological sequence and with spatial controls, such as depth and regional variations in deformation style and intensity. The nature of fracturing and faulting directly controls aperture distribution, size and geometry, which in turn influences karst conduit geometry in limestones. Determining these attributes is, therefore, key for groundwater flow parameter estimation. We briefly describe how the most conductive structures (Tertiary strike-slip faults), and the most common structures (joints) can be linked to critical groundwater parameters, such as transmissivity, storage and connectivity, at both regional and local scales. We show that structural parameters critical to groundwater flow (including orientation, spacing and aperture) can be used to compute ranges of hydrogeological parameters (fracture porosity and permeability), which in combination with hydraulic data (groundwater levels, volumetric flow and recharge) can be used to provide constraints on permeability anisotropy and heterogeneity at different scales.

USING LANDSCAPE POSITION TO DETERMINE THE RELATIVE IMPORTANCE OF SOIL AND GROUNDWATER TIME LAGS

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ABSTRACT

Time lag (t_T) is the intrinsic delay in the response of a waterbody to agricultural mitigation measures, as a result of the transport of contaminants, first through the unsaturated zone (soil) (t_U), and then through the saturated groundwater zone (t_S), to a receptor. This time lag can impair the ability of waterbodies to attain water quality improvements within expected timescales. Typically, the contribution of t_u has been underestimated and neglected; however, it may be the controlling factor on t_T, within a landscape. Numerical models can simulate t_u, using soil hydraulic parameters derived via a range of methods, with increasing accuracy moving from generic to site-specific physical measurements. The relative importance (t_r) of t_u is calculated as t_u as a percentage of t_T, and can be used to indicate whether low or high complexity data should be employed in modelling.

For three groundwater scenarios (0.5, 5 or 10 year t_s), the t_r of nine real Co. Waterford soil profiles was assessed, using t_u values estimated using generic (textural class), moderate (particle size distribution) or complex (soil water characteristic curve (SWCC)) soil data. The Hydrus 1D numerical model was used to estimate t_u. For all profiles, where t_s was brief (0.5 years), t_r was high (av. 76%, excluding the shallowest two profiles). As t_s became greater, average t_r decreased, to 25% at t_s of 5 years, and 14% at t_s of 10 years. At t_s of 0.5 years, the difference in t_r between the three methods of t_u estimation was on average 11%. This decreased to 7% and 4%, at t_s of 5 and 10 years, respectively. Low complexity, generic data consistently underestimated t_r, compared to the complex approach. Consequently, where the profile is near a receptor and t_s is therefore short, high complexity data becomes critical. However, where the receptor is more remote, and t_s is greater, the difference between methods of t_u assessment is smaller. This may justify a reduction in complexity, allowing textural data from soil mapping to be employed, rather than time consuming and expensive site-specific analysis. In conclusion, the position of the soil profile through which the contaminants are transported, relative to the receptor indicates the degree to which the soil controls total time lag, and can be used to determine the optimum complexity of input data for assessing t_u using Hydrus 1D.

SESSION V

THE IRISH CENTRE FOR RESEARCH IN APPLIED GEOSCIENCES (ICRAG) – A MAJOR NEW INVESTMENT IN RESEARCH BY SFI AND INDUSTRY.

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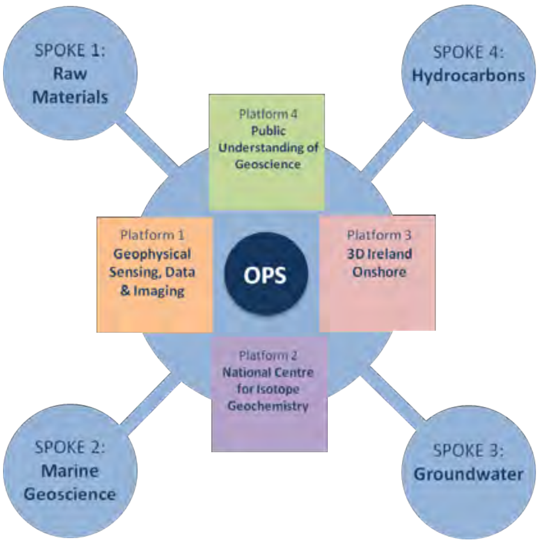
ABSTRACT

iCRAG is a newly formed national research centre which will transform applied geoscience research in Ireland, performing research which is designed to deliver economic impact for a broad range of application areas and industries. The Centre brings together Ireland's leading geoscience experts focussing on a range of issues all of which underpin economic development - from safe and secure groundwater supplies through to the discovery of mineral/aggregate deposits, and from the de-risking of oil and gas exploration to ensuring that the Irish public is educated and informed on these issues. Supported by Science Foundation Ireland (SFI) (€17.8M) and industry partners (€8M) for the next 6 years, iCRAG is one of only 12 SFI Research centres, and the first national geosciences initiative to be supported by SFI's flagship funding scheme. iCRAG is a collaboration between 150 researchers within UCD, TCD, NUIG, UCC, NUIM, DIAS and more than 50 industry partners who will work in partnership with government agencies (GSI and EPA) involved in the geosciences sector.

iCRAG's research programme consists of four cohesive topics or 'spokes' in the areas of raw materials, marine geoscience, groundwater and hydrocarbons which are built around four enabling technology and equipment based 'platforms' which focus on geophysical sensing and imaging, geochemistry, 3D geological modelling and public perception and understanding. The spokes are selected to build on demonstrable islands of scientific excellence and to leverage the maximum economic impact for Ireland. iCRAG will promote the exchange of ideas, data and methodologies between and within spokes and platforms, with cohesion derived from shared analytical and modelling techniques and pervasive cross-cutting themes. It will capitalise on Ireland's unique geological resources, including its world-class base metal deposits, its unusually extensive and highly prospective offshore basins and its world-class lowland karst and fractured bedrock aquifers. The principal goal is to embed the outcomes of high quality research within industry practice in Ireland and overseas.



USING GIS AND NATURAL TRACERS TO EVALUATE GROUNDWATER DISCHARGE TO LAKES

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ABSTRACT

Groundwater discharge is recognised as a major pathway for the delivery of freshwater and nutrients to surface water bodies, which sustains lake levels and supports biological communities. Contaminants from a variety of sources at and below the surface may also be transported via groundwater and since most lakes generally receive groundwater inflows through their bed or loose water via seepage to the aquifer; groundwater-lake interactions could have a disproportionally greater influence on water quality and ecology potentially sufficient to threaten risk of failure to comply with WFD objectives. In recognition of the significance of groundwater as a potential pollution pathway and the challenges to localising and assessing inputs that are diffuse and highly variable, here we present an overview of both robust and cost effective qualitative (national scale) and quantitative (local scale) methodologies for assessing groundwater-lake connectivity to help inform requirements for future monitoring programmes in support of WFD objectives. This research endeavours to take significant steps towards filling the knowledge gap that presently exists in Ireland with respect to field-based information on groundwater-surface water interaction.

INTRODUCTION

The Water Framework Directive (WFD) was adopted in 2000 to establish an integrated approach to the protection, improvement and sustainable use of all water bodies. The Irish Environmental Protection Agency (EPA) is implementing a national programme of water body monitoring in compliance with the WFD (EPA, 2006). This is conducted primarily through surveillance and operational monitoring programmes which provide an assessment of overall surface water status as well as identifying water bodies "at risk" of failing to meet WFD environmental objectives. While individual monitoring programmes are in place assessments of groundwater-surface water interactions are not undertaken as part of the general monitoring procedure in Ireland. This is because groundwater discharge is often patchy and diffuse and very difficult to estimate using traditional techniques including seepage metres and piezometers (Lee and Cherry 1978).

As both ground and surface water components represent an interconnected system, an improved understanding of the connection between ground and surface water across a catchment is increasingly viewed as a critical prerequisite to more effectively managing water resources (Sophocleous, 2002). Water resource managers internationally, recognise the importance of incorporating management strategies that require quantifying groundwater fluxes since the fluxes and how they respond to change dynamically affects water levels and ecosystems (Jacobs and Holway, 2004). However, determining where in the first instance across a water catchment groundwater discharge is occurring and subsequently deriving localised quantitative estimates of groundwater fluxes, is an extremely challenging task.

In recognition of the significance of groundwater as a potential pollution pathway and the many challenges to localising and assessing inputs that are diffuse and highly variable, the EPA STRIVE funded CONNECT project (2012-W-MS-13) aims to further develop techniques that identify (map), characterise and evaluate the potential occurrence and impact of groundwater discharge to surface water bodies. The purpose of the project is to examine the connectivity between ground and surface water at a national and local scale by combining three key approaches. Firstly a qualitative assessment of the potential for groundwater discharge nationally was undertaken using GIS techniques incorporating available hydrogeological and geological datasets to classify surface water bodies in order of “likelihood” to receive significant groundwater inputs. Secondly, remote sensing of surface water temperatures was undertaken to identify thermal anomalies and localise potential groundwater seepage points. Following completion of the GIS and remote sensing analyses, a subset of target regions was derived and flagged for prioritisation. Subsequent verification of the remote sensing and in-situ evaluation of groundwater inputs is presently being completed through fieldwork incorporating geochemical tracing as the final approach.

DESKTOP GIS ANALYSIS OF GROUNDWATER - LAKE CONNECTIVITY

OVERVIEW

A desktop GIS analysis was undertaken to serve as a rapid preliminary assessment of the potential for lakes to receive groundwater discharge nationally. The objective was to categorise each lake in order of “likelihood” to receive significant groundwater discharge, to help determine which lakes should be prioritised for the remote sensing analyses of lake water temperatures. Additionally, the results from the remote sensing analyses were used to validate the “likelihood” categorisation by determining whether the higher likelihood categories were associated with larger thermal anomalies.

ANALYSES AND OUTPUT

“Likelihood for significant Groundwater Discharge” or LGD, was determined following analysis of a number of key national spatial datasets. The analysis is based on groundwater body units (GWBs) as opposed to catchments because surface water catchments are defined based on surface water hydrology and topographic divides which may not coincide with groundwater catchments. The starting point for the categorisation is the national aquifer classification developed by the GSI and regarded as the fundamental control on potential for groundwater discharge. As the initial process of categorisation (Scale 1), a division into “more likely” and “less likely” (to receive significant groundwater inputs) lakes was undertaken using the WFD classification of GWBs (Figure 1). This means that lakes lying partly or entirely in productive groundwater bodies composed of karstic, fractured, sand and gravel aquifers (i.e. Rk, Rf, Rg, Lk, Lm, Lg) are classed as “more likely” and those lying entirely in groundwater bodies composed of poorly productive aquifers (Ll, Pl, Pu) are classified as “less likely”. The objective of the second (Scale 2) approach was to further examine the “more likely” water bodies to determine which lakes within them were the most likely locations for groundwater discharge. The outcome is a subdivision of “more likely” water bodies into “very high”, “high” and “moderate” likelihood categories. Similarly, the “less likely” water bodies identified at Scale 1 were further assessed to determine which lakes were the least likely locations for groundwater discharge (Figure 1). The outcome was a subdivision of “less likely” water bodies into “less” and “least” likelihood categories.

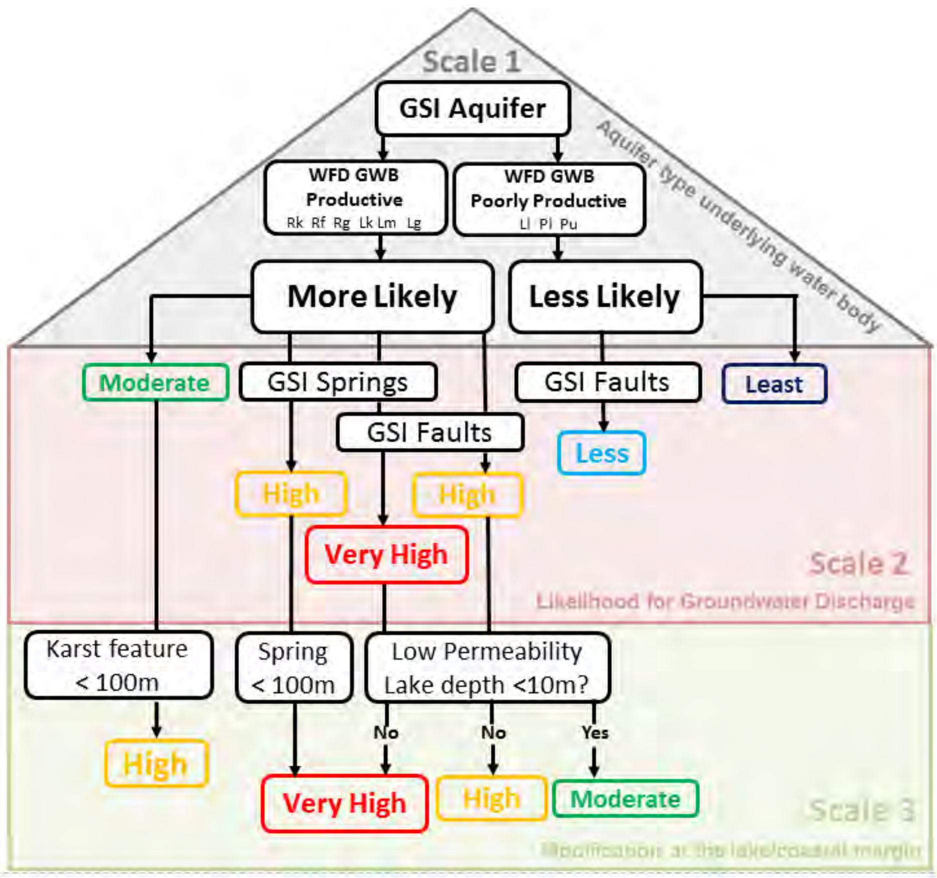


Figure 1 Schematic illustration to summarise the methodological approach for defining "likelihood" to receive groundwater discharge (LGD). Likelihood is described by the categories *Very High*, *High*, *Moderate, Less* and *Least* and corresponds to analyses undertaken across three scales (Scale 1, Scale 2 and Scale 3).

The GSIs national faults and springs database was used to help further categorise the "more likely" lakes. For instance, lakes intersected by a fault or within a 1km region (spatial buffer) of a fault were awarded a higher category of likelihood. While the absence of faults might result in a lower likelihood it did not mean elimination from the more likely list. This is because we could not assume that the national faults database is all encompassing and moreover because groundwater seepage may occur in the absence of any faults in the vicinity. Furthermore, it is also possible that faults may impede the passage of flow depending on their orientation. The GSIs national fault database was also used to help further categorise the "less likely" lakes and two groups were distinguished. Lakes underlain by "less likely" aquifers AND intersected by a fault OR have a fault within a 1 km buffer distance (and groundwater discharge potentially more likely) were defined as "less" likely. Lakes underlain by "less likely" aquifers NOT intersected by NOR within 1 km of a known fault (in which groundwater discharge potentially less likely) were defined as "least likely".

The number and presence of springs within a productive groundwater body was also used to further categorise the lakes. This relates not only to springs directly feeding into the water body but refers to presence of springs, regardless of whether they are directly connected to a lake or shoreline, as an indicator of the potential for groundwater discharge to a lake. For example, the number of springs within a 1km buffer of a lake was used to place a higher likelihood on lakes with springs over lakes with no springs within the same groundwater body. While the absence of springs resulted in a lower likelihood it did not mean elimination from the "more likely" list. This is because firstly it could not be assumed that the national springs database is all encompassing and secondly that, groundwater seepage may occur in the absence of any springs in the vicinity. Moreover, a substantially greater amount of research on springs has been conducted in karst areas. This means that a disproportionately higher number of mapped springs would be expected in karst areas over non-karst areas.

The lakes were further examined at Scale 3 (Figure 1) to determine the cumulative effect of having relatively more favourable conditions for groundwater discharge within a groundwater body as illustrated in the flow chart and a final categorisation was produced (Figure 2).

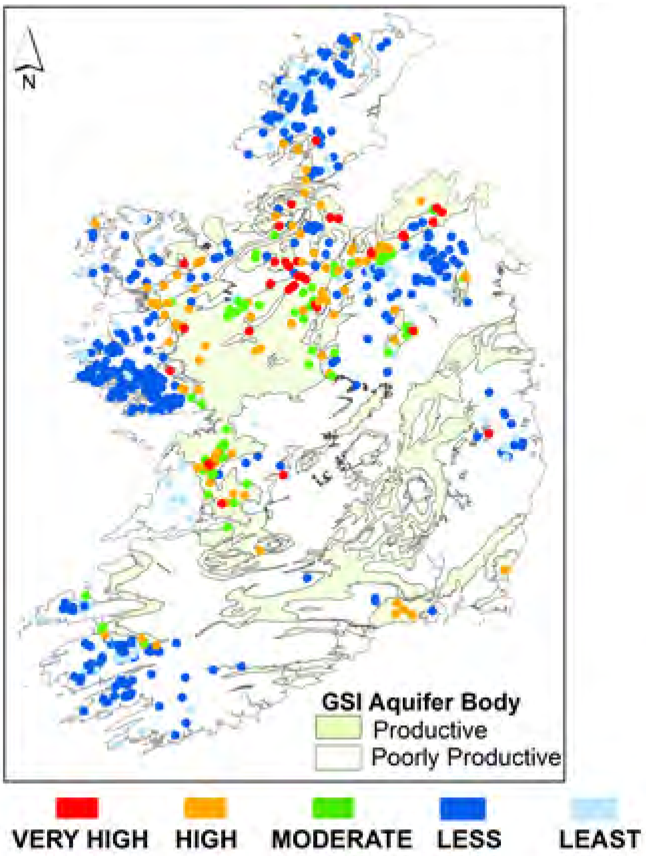


Figure 2 Final national characterisation of lake water bodies by Likelihood for Groundwater Discharge (LGD)

NATIONAL ASSESSMENT OF GROUNDWATER DISCHARGE TO LAKES USING REMOTE SENSING

OVERVIEW

In this second approach a national assessment of groundwater discharge to lakes is undertaken using remotely sensed measurements of surface water temperature i.e. heat as a tracer. The remote sensing results are presented against the output from the desktop analysis to determine the extent to which the GIS derived categorisation of likelihood for groundwater discharge aligns or agrees with satellite derived observations of temperature.

DATA ACQUISITION AND ANALYSES

The success of the remote sensing component hinges upon data availability and a total of 16 mostly cloud free Landsat thermal images of Ireland were obtained. The imagery was pre-processed to correct for the effects of the atmosphere and water surface temperature values were generated using commercially available image processing software (ERDAS Imagine Advantage). The methodology for retrieval of surface temperature from Landsat thermal data is presented in detail in Wilson and Rocha (2012) to which the reader is referred.

The major objective was to use remote sensing to localise potential groundwater inputs to lakes. To identify where anomalous temperature patterns indicative of potential groundwater discharge entry points are occurring and to allow comparisons across image acquisition dates, thermal anomaly maps were generated from the temperature maps.

Thermal anomaly (TA) is defined for the purposes of this work as the difference between the surface temperature of each pixel in the image and the average temperature value recorded across the water body:

$$TA = Tp - \check{T} \tag{1}$$

where *TA* denotes thermal anomaly (°C), *Tp* is the temperature value specific to each water body pixel (°C), and $\check{T}$ is the average temperature value for the water body (°C).

The obtained image dataset spans a range of acquisition dates and the absence of in-situ temperature data at the time of satellite over pass means that the satellite derived temperature measurements cannot be validated. These limitations however can be overcome by generating a standardised set of fully inter-comparable temperature maps that allow a comparison of surface temperature values from imagery acquired on different calendar dates.

To calculate a value for standardised temperature anomaly (STA), TA values (Eq.1) were divided by the standard deviation of temperature as follows:

$$STA = \frac{TA}{\sigma} \tag{2}$$

where *STA* is standardised temperature anomaly and σ denotes the standard deviation.

RESULTS

Satellite derived surface water temperatures and thermal anomalies were mapped for a total of 122 lakes and the summary of results (Table 1) clearly reveals that the desktop GIS categorisation defining the likelihood for groundwater discharge has been successful. The largest average anomaly (STA) values are associated with lakes within the highest likelihood categories (Very High and High) and the size of the anomaly decreases sequentially from the Very High, High, Moderate, through to the Less and Least likelihood categories.

Table 1 Average Standardised Anomaly Value by LGD class for a total of 122 mapped lakes.

LGD Class	Average Anomaly	Maximum Negative Anomaly Value	Total No. Lakes (% total)
Very High	-1.8	-3.0	19 (16 %)
High	-1.7	-2.5	47 (39%)
Moderate	-1.5	-2.4	24 (20%)
Less	-1.4	-2.0	20 (16%)
Least	-1.3	-1.5	12 (9%)

The results suggests that we should expect to find larger (i.e. more negative) thermal anomaly values in high LGD category lakes over lower LGD category lakes. In terms of aquifer type, overall lakes underlain by sand & gravel on average yielded the largest negative anomaly (-1.9), followed by Karstic (-1.7), Productive Fissured (-1.6) and Poorly Productive (-1.4) aquifers.

VERIFICATION AND IN-SITU EVALUATION OF GROUNDWATER DISCHARGE USING GEOCHEMICAL TRACING

OVERVIEW OF THE APPROACH

To validate the classification developed as part of the desktop GIS analysis while at the same time verifying the results from the remote sensing and providing in-situ evaluation of groundwater inputs and processes, 8 lakes were selected for fieldwork on the basis of four test scenarios (Table 2, Table 3, Figures 3 and 4).

Natural tracers of groundwater including radon-222 and conductivity are used to groundtruth the thermal signals observed from the remote sensing analyses to confirm the presence of groundwater discharge. Continuous surveys of each of the lakes is undertaken by boat and background sampling is undertaken on shore to verify and evaluate the thermal signals observed as groundwater discharges as a qualitative assessment of groundwater inputs to the lake. A mass balance approach is employed to calculate advective fluxes of radon as a proxy for subsurface groundwater discharge rates.

Table 2 Site selection rationale illustrating the link between test scenario and GIS and remote sensing outputs.

Test Scenario	LGD	Thermal Anomaly
1A	More Likely	Plumes evident - large negative anomaly
1B	More likely	No plumes evident - weak negative anomaly
2A	Less Likely	Plumes evident – large negative anomaly
2B	Less Likely	No plumes evident – weak negative anomaly

Table 3 Final set of target lakes illustrating LGD, underlying aquifer type and maximum negative standardised thermal anomaly.

TEST Scenario	Lake Name	Area (Km^2)	Aquifer Type	LGD	Max Negative Anomaly	WFD EU_CD
1A	**Gur**	0.79	**K**	**High**	-1.8	IE_SH_24_99
	Sheelin	18.16	**K (Lk)**	**High**	-1.8	IE_SH_26_709
1B	**Carrigavantry**	0.12	**PF**	**High**	-1.4	IE_SE_17_8
	Killinure	0.21	**SG**	**Moderate**	-1.0	IE_SH_26_750d
2A	**Ennell**	11.56	**PP**	**Less**	-1.6	IE_SH_25_188
	Ramor	7.13	**PP**	**Least**	-1.5	IE_EA_07_275
	Dan	1.03	**PP**	**Less**	-1.2	IE_EA_10_29
2B	**Tay**	0.50	**PP**	**Least**	-1.5	IE_EA_10_25

Figure 3 Lough Ennell, Co. Westmeath selected under scenario 2A. Maps display surface water temperature (left) and standardised thermal anomaly (right) generated from a Landsat Thermal image acquired 18th April 2014. Surface water inflows and fault lines are also shown and the lake is set against the backdrop of the WFD defined "poorly productive" groundwater body type.

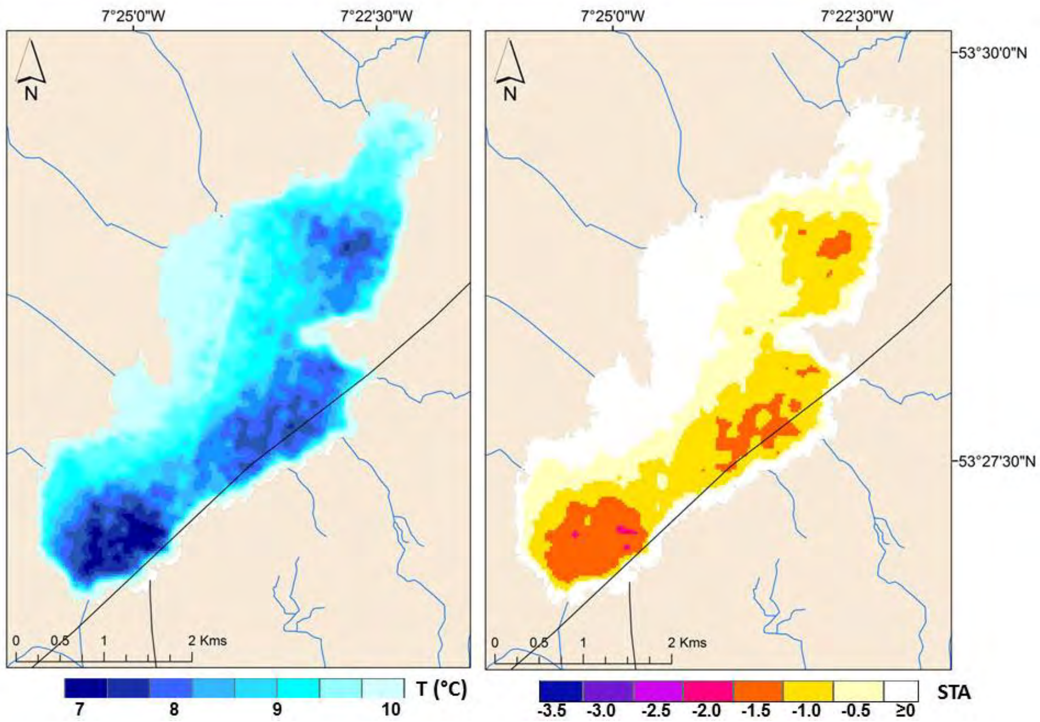
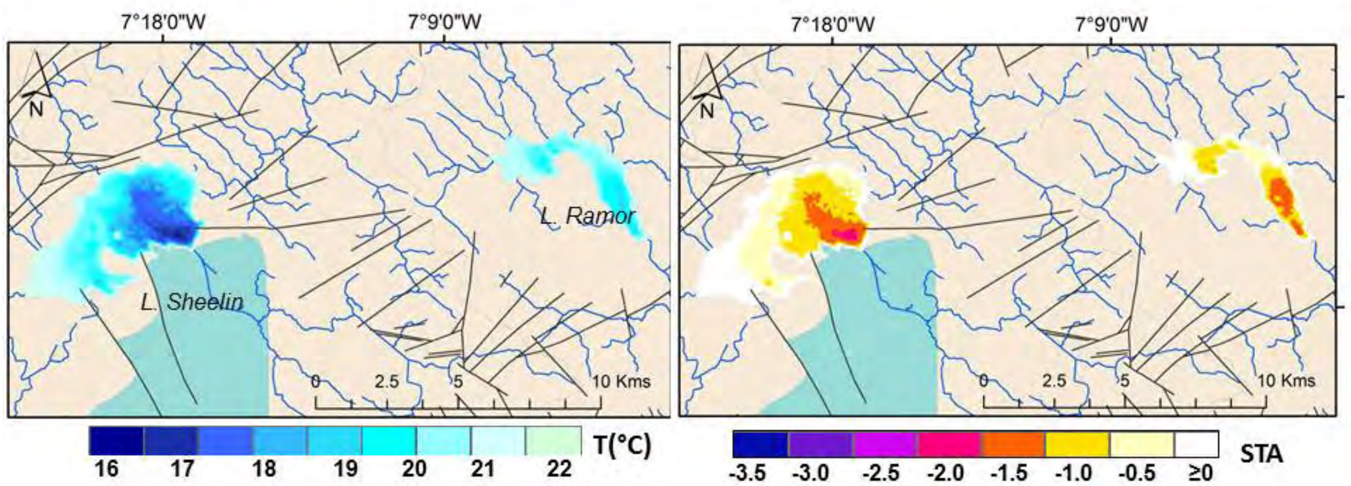


Figure 4 Loughs Sheelin and Ramor, Co. Cavan selected under scenarios 1A and 2A respectively. Maps display surface water temperature (left) and standardised thermal anomaly (right) generated from a Landsat Thermal image acquired 9th June 2013. Surface water inflows and fault lines are also shown and the lake is set against the backdrop of the WFD defined groundwater body types illustrating karstic (green) and poorly productive aquifer types.



Specifically we are:

1) Recording and mapping the spatial distribution of radon activity (Radon-222) to confirm the presence of groundwater and to identify any radon "hotspots" i.e. groundwater sources.
2) Recording and mapping the spatial distribution of conductivity as a secondary tracer to support the radon measurements.
3) Recording and mapping physical measurements of the water column including water depth (bathymetry) and temperature to determine whether the lake is stratified.
4) Gathering sediment samples from the lake bottom to evaluate radon emanation rates by diffusion in the laboratory;
5) Gathering background data on radon activities in the atmosphere.
6) Gathering and recording radon activities in lake subsidiary streams and surface water inputs in general, alongside data on their discharge rates. These are used in conjunction **4)** and **5)** within a mass conservation approach to determine the groundwater supported advective fluxes of radon into the lake (i.e, subsurface groundwater discharge rates).
7) Gathering water samples from the lake for subsequent nutrient analyses to determine if the observed groundwater signals are accompanied by nutrient signals.

This work is currently ongoing, the results of which are presently being compiled for publication.

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ACKNOWLEDGEMENTS

We would like to acknowledge the Irish Environmental Protection Agency (EPA) for funding this work through a STRIVE Research Fellowship (project code 2012-W-MS-13) hosted by the Biogeochemistry Research Group, Department of Geography, School of Natural Sciences, Trinity College Dublin, Ireland. We also wish to thank the projects Steering Committee for their continued input and support.

KARSYS APPROACH – AN EXPLICIT CONCEPTUAL 3D MODEL FOR KARST HYDROGEOLOGY

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ABSTRACT

For the purpose of applied studies on karst hydrogeological systems, three main questions remain often difficult to answer: (i) where does the water of a karst spring come from, (ii) through what underground routes does it flow and (iii) where are the underground resources and what are their importance? Most of the classical approaches are dedicated to time description (i.e. hydrograph analyses, chemographs, isotopes) and are therefore unable to answer the previous questions.

The KARSYS approach aims to represent karst hydrogeological systems in an explicit 3D model. This model involves (i) geological and hydrological data and (ii) karst hydrogeological concepts that help to understand the general setting of the studied system.

The result of the approach is a clear identification of (i) the geological setting, (ii) the major hydrological feature (i.e. springs, swallow holes, turloughs), (iii) the groundwater body geometries, (iv) the underground water flow pathway and (v) the catchment and sub-catchment area. Based on the KARSYS 3D hydrogeological model, these results can be generated as a function of the hydrological situation (low to high or even extremely high water).

Introduction

How can karst be described? The answer can fall in a large range of scientific specialities: geomorphology, geology, speleology, speleogenesis, hydrology, hydrogeology or even natural hazard. Over the last 20 years, several scientific studies were conducted in order to depict the behaviour of a karst system ranging from transport processes (e.g. Genthon et al. 2005; Hauns et al. 2001; Martin & White 2008), to technical investigation techniques (e.g. Goldscheider & Drew 2007), or spring analyses (Birk et al. 2002; Geyer et al. 2007; Grasso et al. 2003). The core problem remains that none of these studies are producing a spatial solution for the investigated system and are therefore often not applicable to applied problematics.

Involving a suite of karst related concepts, the KARSYS approach (Jeannin et al. 2013) results in a model, that explicitly displays in a 3D environment (i) system geological boundaries, (ii) infiltration type depicted over the whole catchment area, (iii) geometry of the aquifer, (iv) geometry of the karst groundwater body, (v) sketch of the conduit network or the main hypothesized flow path.

KARSYS approach

The KARSYS approach is composed of four major steps (Figure 1): (i) data collection, (ii) geology, (iii) aquifer zonation and (iv) hydrogeology. Principles, involved concepts and related necessary data for each step are discussed in the following sections.

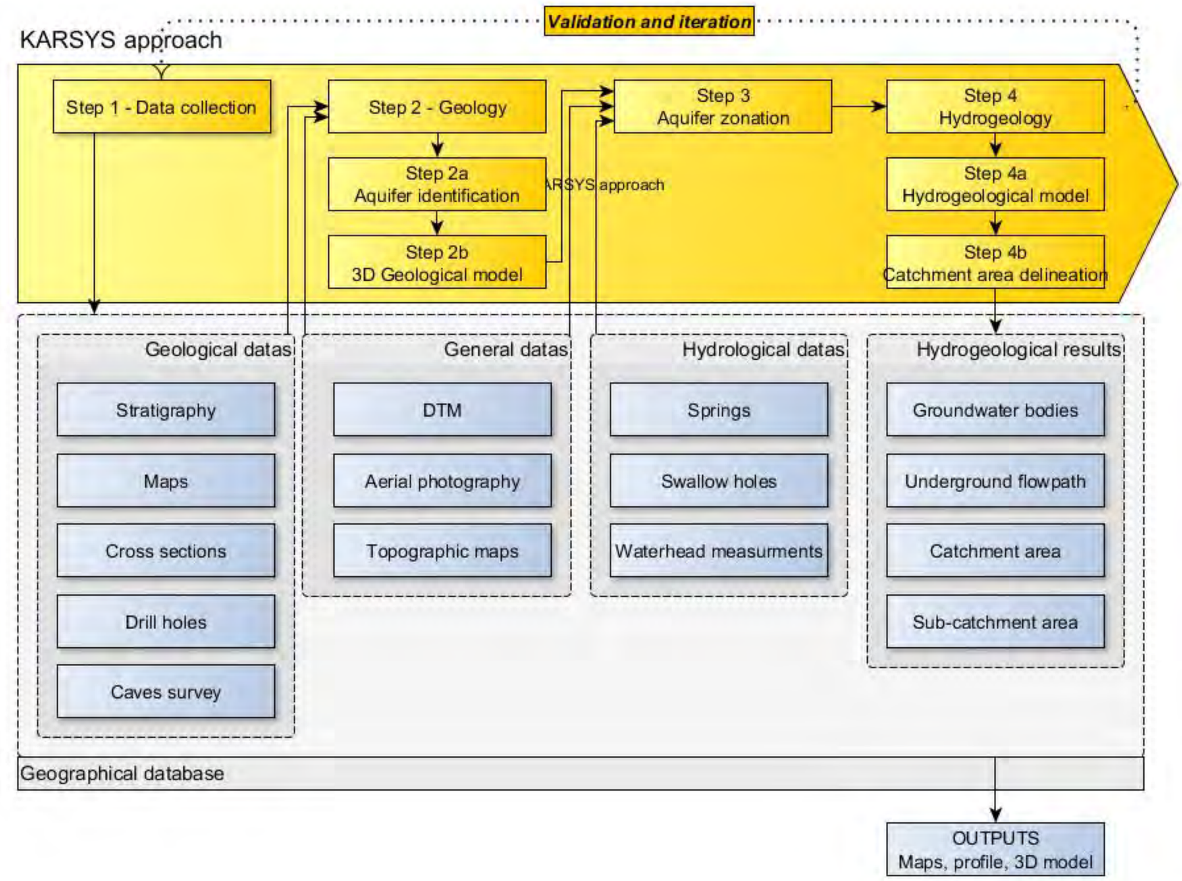

Figure 1 Workflow of the KARSYS approach

Step 1 – Data collection

As any other investigation, the first step of the KARSYS approach is to collect all the existing data related to the study area. Priority is given to geological, hydrological and speleological information. For the optimisation of the modelling approach, a GIS database is built. This database stores all the possible information required to run the model, as well as produced model results. Elevation (z) values are of particular importance, and storing these values simplifies the 3D import/export processes (Figure 3A).

Step 2 – Geology

The geological step aims to obtain a 3D geological model representing the geological features which play a role in the karst speleological and hydrogeological processes (i.e. aquifers, aquicludes, boundaries and faults). This step is split into two: (i) aquifer identification and (ii) 3D geological modelling.

Aquifer identification

The concepts involved in the aquifer identification are the following:

- Karst aquifer property of a rock is a function of its soluble mineral content
- Karstification can be localized along particular stratigraphic beds due to contrast (i.e. lithological, mineral, porosity) with the surrounding lithology (Filipponi et al. 2009).

Based on lithological descriptions of the stratigraphic pile stored in the database the aquifers are identified. Location of data such as caves, sinkholes, springs and swallow holes help to identify more precisely the geological formation where karstification occurs (so called inception horizons).

At the end of this step, a clear correspondence between all geological related data and the hydrogeological log must be achieved (Figure 2).

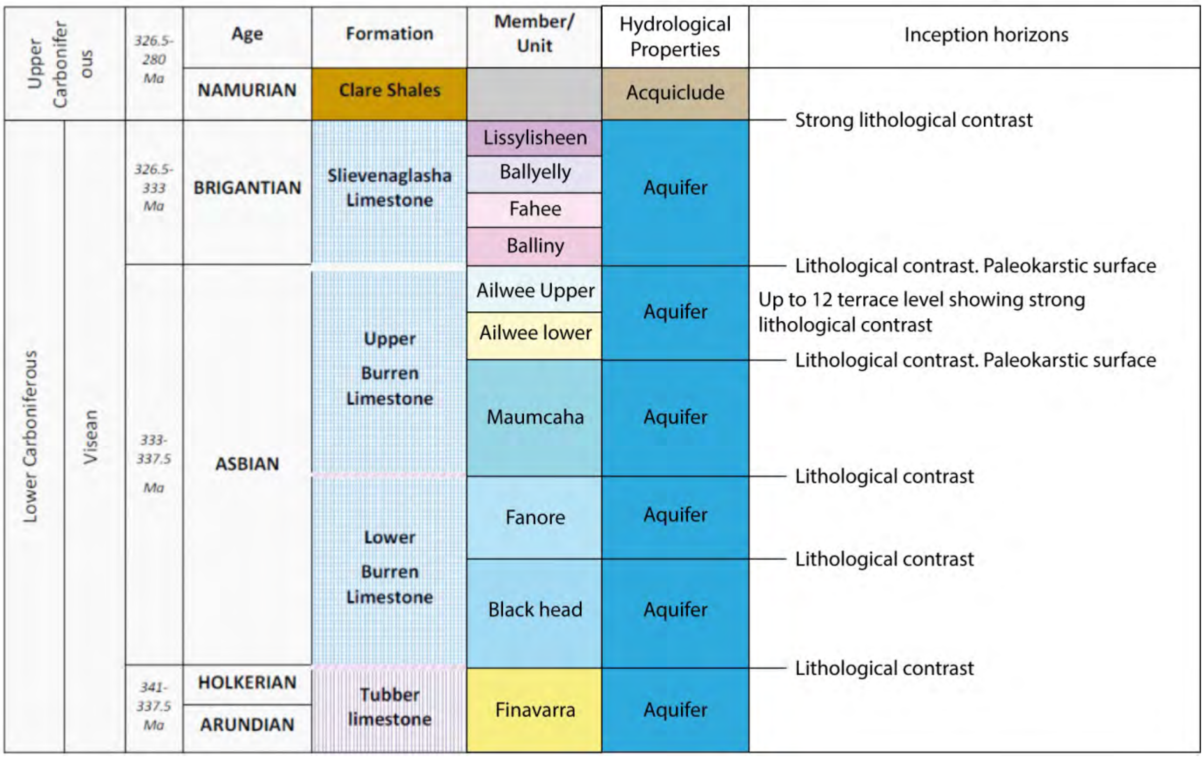

Figure 2 Stratigraphical log with corresponding hydrogeological properties and inception horizon description for the Bell Harbour karst system (The Burren, Co. Clare). Modified from Perriquet, (2014).

Geological 3D model

Using a combination of digital terrain models, geological maps, geological cross sections and drill logs, a 3D geological model is constructed using the appropriate software (i.e. 3D Geomodeller, MOVE, GoCAD). An example is presented in Figure 3B. As it implies interpretation, interpolation and simplification, users must keep in mind that the resulting 3D geological model must basically be considered as wrong. Despite that, the aim of the 3D geological model is not to figure out exactly the 3D geological structure but to depict the general geological setting that play a role in the hydrogeological behaviour of the karst system. In that sense, the resulting 3D geological model can be used in the following steps of the KARSYS approach.

Step 3 – Aquifer zonation

The aquifer zonation step aims to delineate the groundwater bodies. The 3D geological model is combined with the hydrogeological log produced in the second step. The concepts involved in this step are the following:

- The aquifer volume is saturated beneath the altitude of the lowest permanent spring (Kiraly 1973).
- Due to the very high hydraulic conductivity of the karst conduits, the hydraulic gradient in the karst groundwater body is very low (Bögli 1980; Worthington 1991; Worthington & Ford 2009).

These two rules make it possible to delineate the groundwater body at low water stage. Applying an almost flat plane with its base located at the karst spring, the intersection between this plane and the aquiclude volumes gives the geometry of the groundwater body in a low water situation (Figure 3C).

The water head data stored in the data base can be used as a basis for the delineation of the groundwater bodies at different water stage. The gradient of the groundwater body can be inferred based on water head measurements in boreholes or caves as well as the altitude and location of temporary springs. Based on the resulting gradients, the groundwater bodies can be delineated at different water stage. Therefore, underground relationship and connection between groundwater bodies can be identified as a function of water stage.

Step 4 – Hydrogeology

The aim of the hydrogeology step is (i) to understand the underground water flow path network and (ii) to deduce from it the catchment area of each of the permanent springs. For the generation of underground flow path, the following concepts are used:

- The efficient recharge on non-karstified rocks is directed toward the karst aquifer following the surface topography;
- The efficient recharge on karstified rocks is directly directed toward the karst aquifer;
- Throughout the unsaturated zone of the karst aquifer, the underground circulation is vertical. In case this vertical circulation crosses a strong inception horizon which dipping differ strongly from vertical, the underground circulation can partially or totally follow the inception horizon dip;
- At the bottom of the aquifer in the unsaturated zone, the underground circulation follows the dipping orientation of the aquiclude (Butscher & Huggenberger 2007);
- Within the saturated zone, the underground circulation follows the gradient of the groundwater body toward the spring.

Based on these concepts, the following processes are run: Geological maps are used to determine the area where infiltration is immediately directed toward the karst aquifer. The areas which feature outcropping of non-karstified rocks are defined as allogenic recharge zones. For the karstified surface a conduit network is generated following the previous rules based on aquifer/aquiclude, inception horizons and groundwater body 3D geometries (Figure 3C).

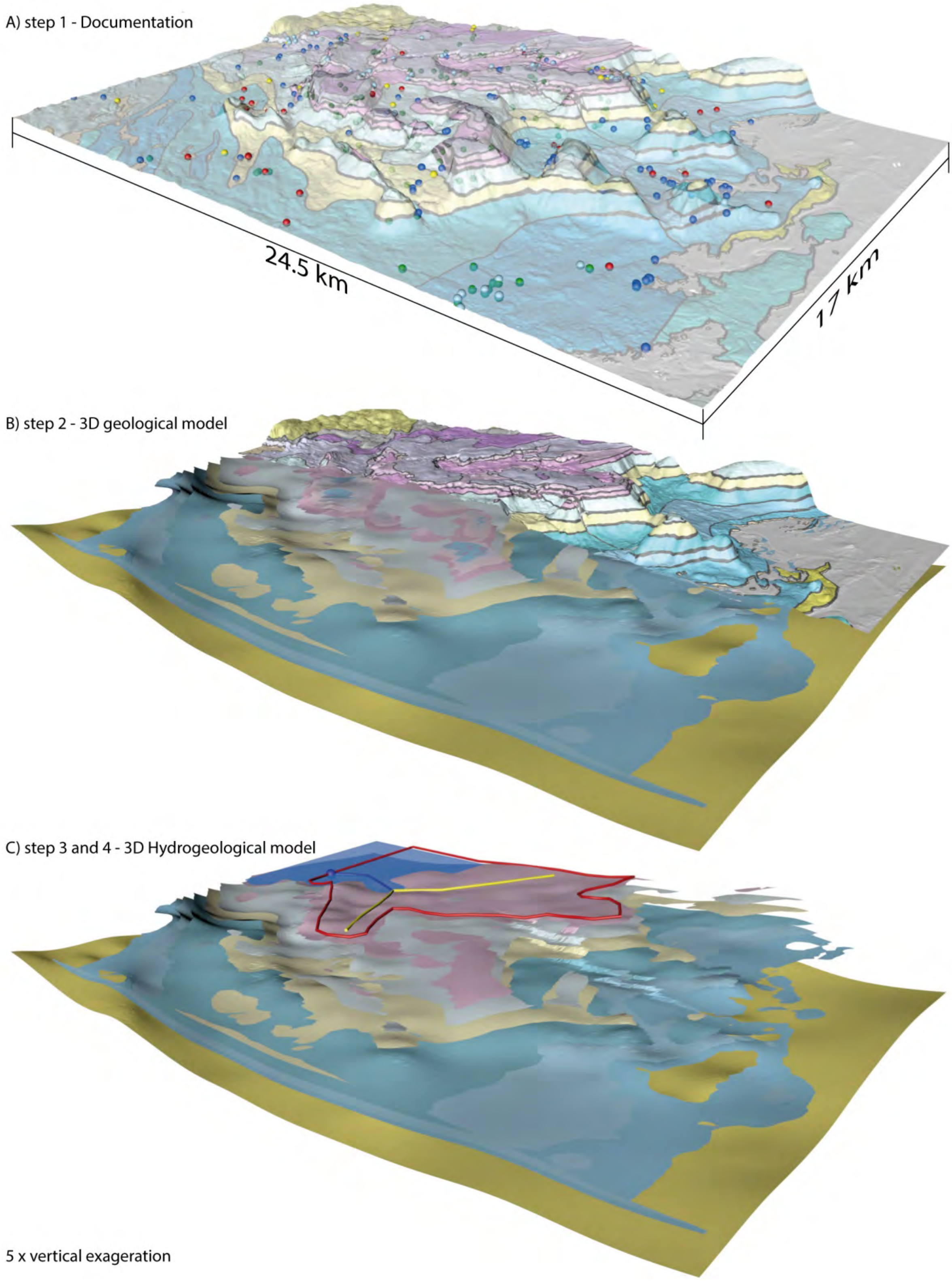

Figure 3 3D view of the 4 steps of the KARSYS approach for the Bell Harbour area. A) Blue sphere as spring, green sphere as enclosed depression, yellow sphere as swallow holes, red sphere as turloughs, white sphere as caves. DTM and geological map from GSI. B) Colour code based on Irish geological maps (see Figure 2). C) Red line as catchment area, yellow line as unsaturated underground water flow pathway, blue line as phreatic water flow path, blue sphere as Fergus spring.

Validation and iteration

The KARSYS 3D hydrogeological model provides an underground water flow path for each part of the catchment area. Dye tracer experiments can be used to test and validate the model with the help of an already existing concept of the behaviour that the dye tracer must follow in the system. Study sites can be chosen in order to solve uncertainties on the model.

The KARSYS approach is meant to be iterative (Figure 1). Based on newly created data such as boreholes, dye tracer experiments, or water head measurements, the model can be re-run and provide a newly adapted picture of the karst system.

Experiences and Application fields

In the framework of the 61th Swiss national research program (PNR61 2015) which focused on sustainable management of water, The KARSYS approach has been designed to document every karst systems in Switzerland. Objectives were to (i) identify the main karst outlet, (ii) for each of them to assess their related groundwater resources (iii) the related underground water flow path and (iv) the corresponding catchment area. At the moment, one third of the karst areas in Switzerland have been documented (Figure 4). Results have already been successfully used for project such as protection zone delineation, pollution remediation, tunnelling, flooding and sinkhole hazard assessment, underground hydropower and geothermal plant design.

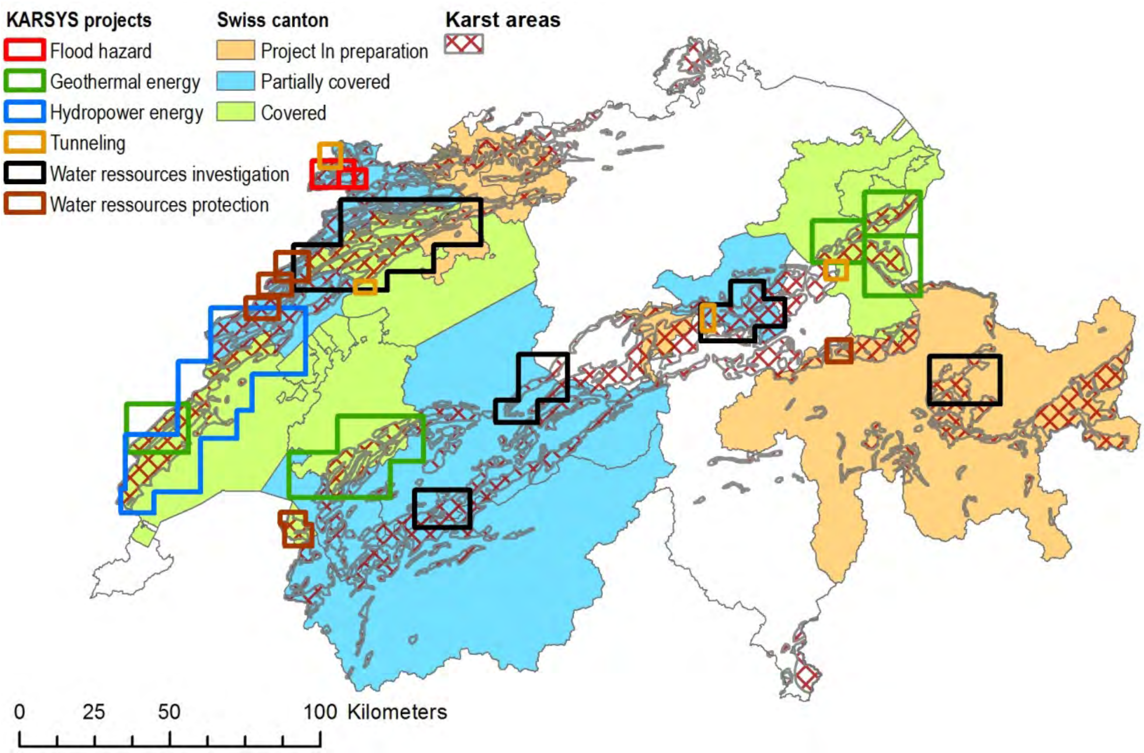

Figure 4 Areas where KARSYS approach has already been applied in Switzerland

The KARSYS approach can be used as an initial study for most of the applied problems related to karst hydrogeology. Basically, the results of this approach can be considered as the minimal necessary knowledge before carrying out any kind of study in a karstic setting. The results provide an answer to the following basic questions:

- Where does the water of a karst spring come from?
- Through what underground routes does it flow?
- What are the groundwater reserves and where are they?

Current projects

In collaboration with GSI and TCD, SISKA is currently improving the KARSYS approach in order to apply it on an Irish geological setting. This collaboration focuses on two field sites, the Bell Harbour catchment in the North Burren and the Shanballymore and Mountnorth catchments in North Cork.

Bell harbour karst system

The project aims to apply the KARSYS approach on a lowland Irish karst system. Bell Harbour has been chosen by GSI and TCD as this site is already well documented (Perriquet 2014). As this project is the first application of the KARSYS approach on a lowland karst system, this previous knowledge will help to improve its applicability in such a hydrogeological karst setting.

Shanballymore and Mountnorth karst system

Based on the experience gained in the framework of the Bell Harbour project, the KARSYS approach will be applied on a second site in the North Cork area. The chosen sites suffer from issues related to groundwater protection. Several dye tracer test have already been conducted for the purpose of delineating protection zones for public supply wells, however results have thus far been inconclusive. (Tobin & Drew 2010; Tobin 2012). The objective for this second project is to evaluate the efficiency and the confidence of the KARSYS approach in an Irish karst setting. This project thus aims to identify the groundwater bodies, the underground water flow paths and the catchment area of the public supply wells in order to support the delineation of the protection zones.

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SESSION VI

THE CAPABILITIES OF MODERN GEOPHYSICAL BOREHOLE LOGGING EQUIPMENT AND ITS INTEGRATION WITH GEOLOGICAL LOGS AND SURFACE GEOPHYSICS

Fridtjov Ruden/ Balazs Rigler
RudenAS

NOTES

RECENT DEVELOPMENTS IN SURFACE GEOPHYSICAL SURVEYING RELEVANT TO GROUNDWATER EXPLORATION AND PROTECTION

Peter O`Connor / Shane O`Rourke
APEX GEOSERVICES LTD.

ABSTRACT

Geophysical methods are well-established as techniques which can significantly contribute to the understanding of the subsurface for use in groundwater exploration and protection. Of the various geophysical methods, electrical and electromagnetic methods have the most applications which include mapping of overburden type and thickness, outlining lateral and vertical variations in rock type and formation, delineating fault and fracture zones, and the mapping of weathered layers and karst zones.

The incorporation of a geophysical survey into an exploration program can significantly improve the overall geological ground model which is usually poorly defined due to glacial cover, sparse borehole coverage and the limitations of borehole methods. This is well recognized in the minerals and geotechnical sectors in Ireland but less so in hydrogeological investigations. Both groundwater exploration and source protection studies can benefit from a properly informed application of geophysical methods.

Of the electrical and electromagnetic methods, Electrical Resistivity Tomography (ERT) has developed strongly in terms of the quantity, quality and speed of data acquisition, but there is still significant scope for improvement in the interpretation of this data and its correlation with existing direct probe, borehole and well data. It is often the case that the detailed lateral and vertical changes seen on the ERT sections are not reflected in the borehole logs or geological maps. As these changes are a function of the subsurface geology a more detailed analysis of the borehole data and soil and rock properties is required.

Downhole geophysical logging provides a set of high resolution data which is representative of the changes in physical properties with depth and can be easily incorporated into the interpretation of surface geophysical results. In appropriate cases these measurements can also be used both to check and constrain the inversion of the geophysical data, as well as significantly adding to the well log information, particularly in the case of boreholes drilled with percussive methods.

ERT FOR LOCATING FAULTS/FORMATIONS IN IRELAND

BEDROCK RESISTIVITIES

A GIS-based analysis of near surface bedrock resistivities in Ireland (O`Rourke, 2009) has assigned the following median resistivity values (Table 1) to bedrock types in Ireland. This analysis was further used to assign median resistivity values to some common formations in Ireland such as 552 Ohm-m for a combination of Lucan Formation/Calp Limestones, and 2038 Ohm-m for Wausortian Limestones. Figure 1 shows the distribution of median resistivity values from surveys carried out within the Lucan/Calp Formation as outlined in 2009.

Bedrock Type	Median Resistivity (Ohm-m)
Namurian Mudstones, Shales & Siltstones	140
Shaly Limestones	507
Intermediate muddy Limestones	1108
Massive/Oolitic Limestones	1882

TABLE 1: Median Resistivities assigned to bedrock types in Ireland. (from O`Rourke, 2009)

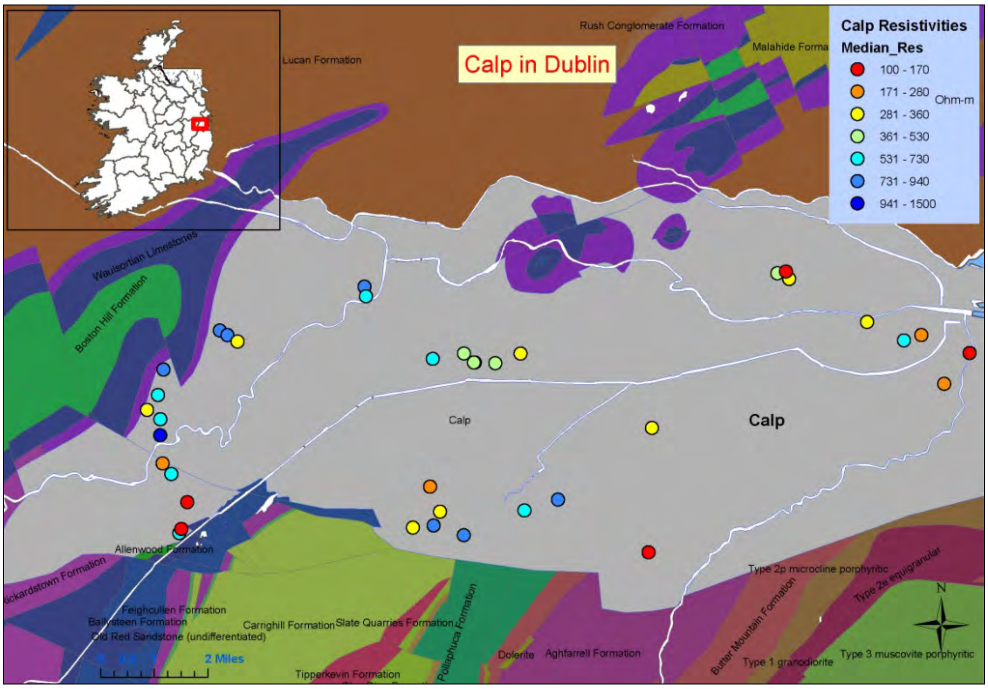

FIGURE 1. Calp Limestone Resistivities for the Dublin Area (from O`Rourke, 2009).

LOCATING GEOLOGICAL BOUNDARIES

Figure 2 shows the area of a site survey in Co. Meath in 2007. The boundary between dark limestone and shale of the Lucan formation and Namurian shale & sandstone shown on the GSI 100k bedrock geology map was 300m to the east of the survey area. After completion of ERT profiling, the resistivity results (Figure 3) showed the geological boundary to run through the middle of the survey area, with the dark limestone of the Lucan formation having a resistivity of 200-750 Ohm-m and Namurian mudstone having a resistivity of 75-350 Ohm-m.

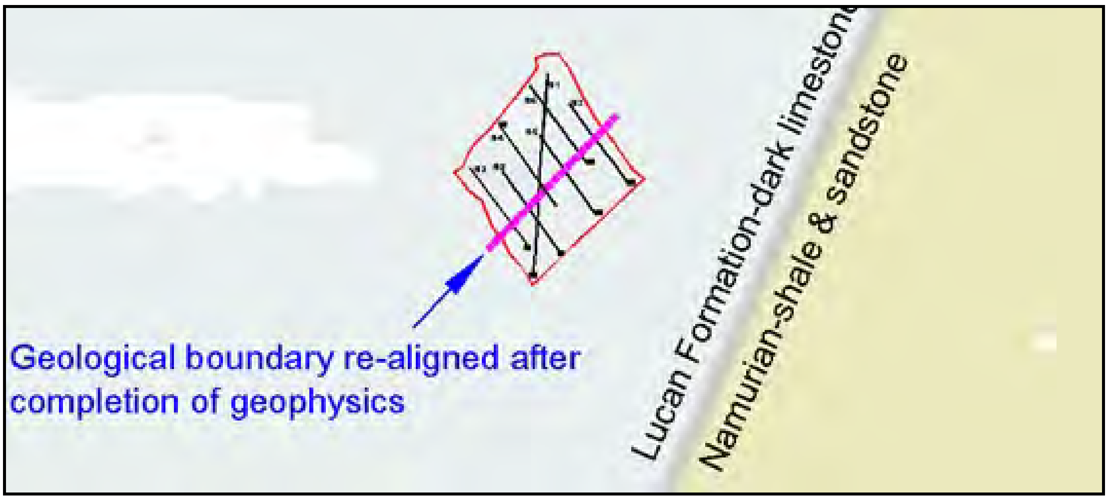

FIGURE 2. Survey in Co. Meath, showing the re-located geological boundary.

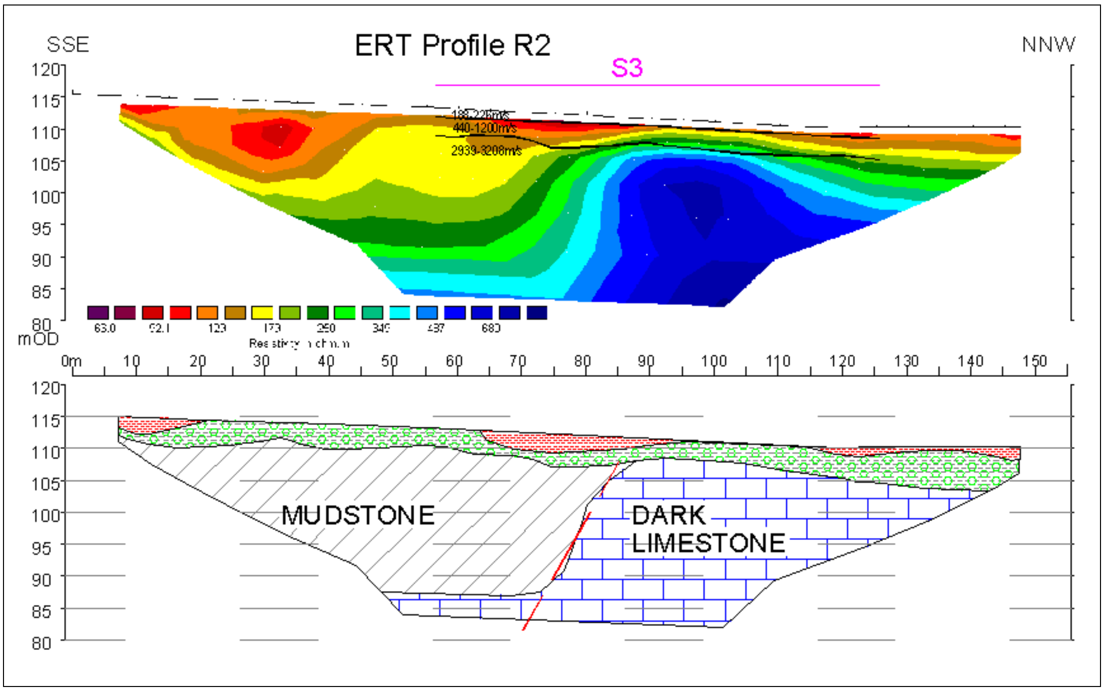

FIGURE 3. Profile R2 from the Co Meath survey, showing the transition from the low resistivity mudstone to the higher resistivity dark limestone.

Figure 4 outlines the route of the proposed Tralee By-Pass, along which ERT was carried out by Apex Geoservices Ltd. in 2007. The route crosses from unbedded Cracoean reef limestone in the south to Namurian sandstone & shale in the north, with the Cracoean classified as a "Regionally Important Aquifer - karstified, diffuse"; and the Namurian classified as a "Locally Important Aquifer – bedrock which is moderately productive only in local zones".

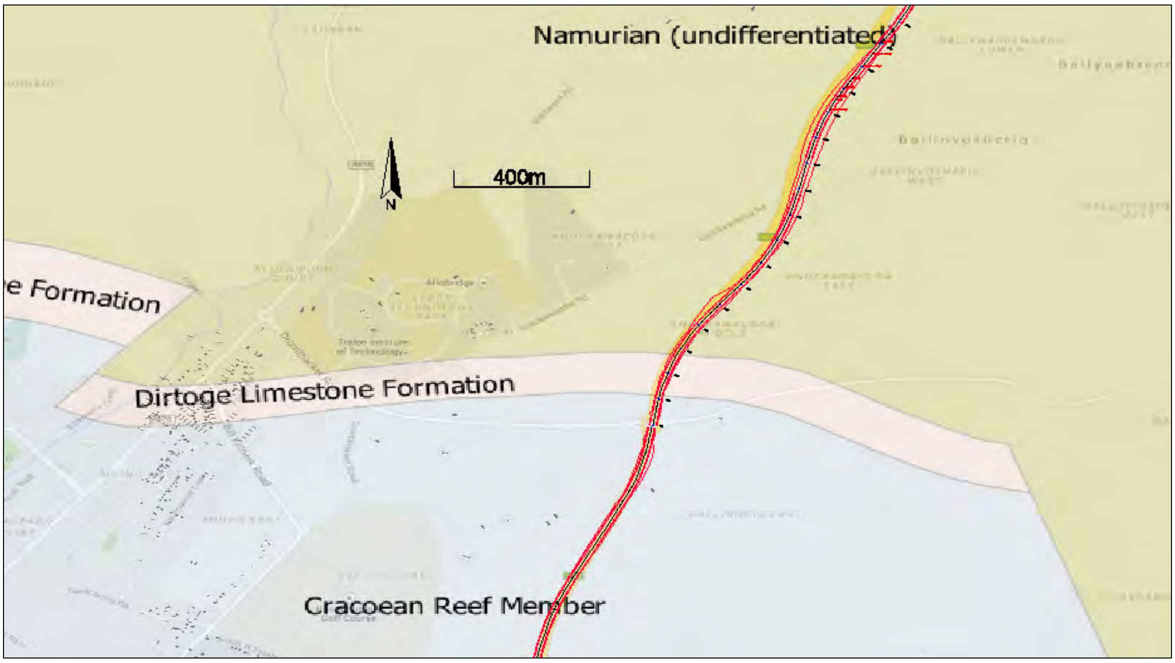

FIGURE 4. Route of the proposed Tralee By-Pass.

Figure 5 shows the results for ERT profiling across the geological boundary between the limestone and shale, with a large sub-vertical drop in resistivities at the limestone-shale contact. Accurate mapping of the location of the profiles shows that the actual position of the contact is seventy-five metres to the north of the contact as shown by the Geological Survey of Ireland map. Both the Meath and Tralee surveys show that the ERT method can be used to accurately differentiate between potential water-bearing and non-water bearing formations in an Irish setting.

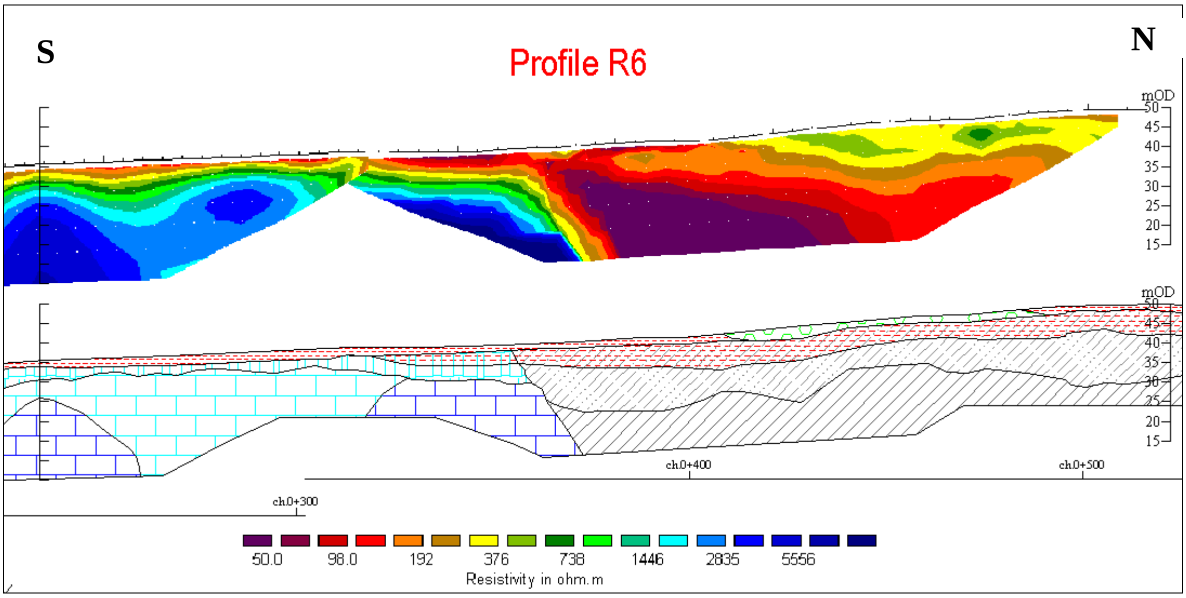

FIGURE 5. ERT results along the limestone-shale boundary.

LOCATING FAULTS

ERT may also be used to accurately locate fault zones, which are often highly permeable. Figure 6 shows the location of ERT profiling carried out across a faulted contact in the midlands, with greywacke, siltstone and grit of the Hollyford Formation to the south and dark muddy limestone and shale of the Ballysteen Formation to the north. Figure 7 shows the results for ERT profiling across the fault, with the fault zone clearly outlined in the centre of the profile.

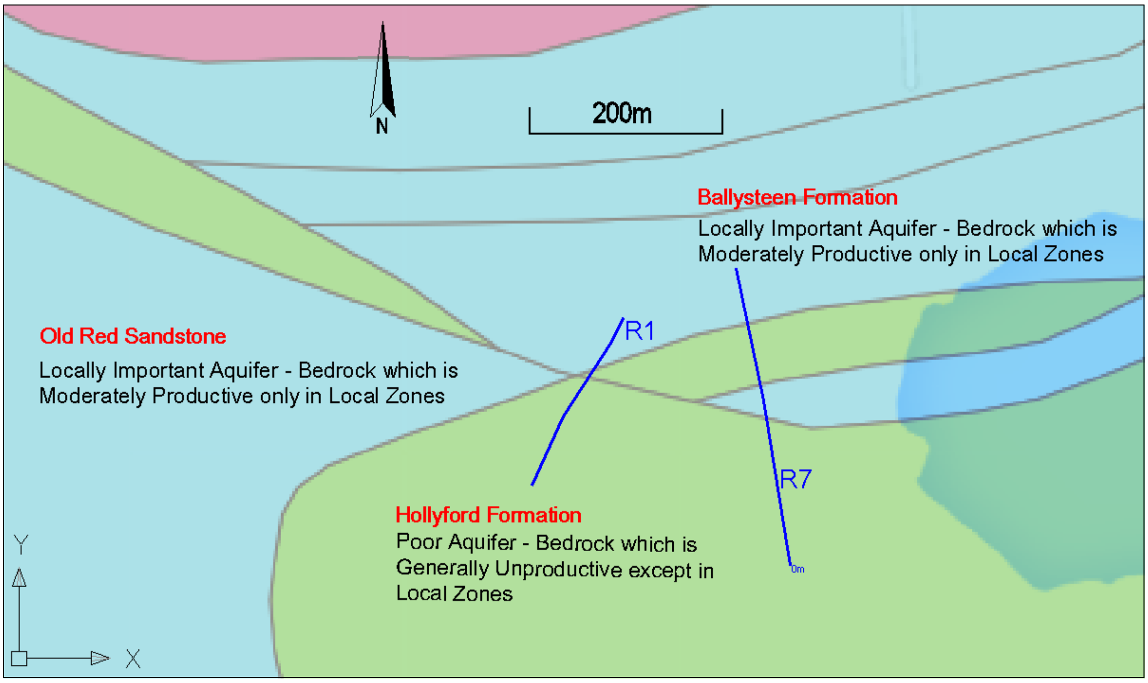

FIGURE 6. ERT at site in Midlands.

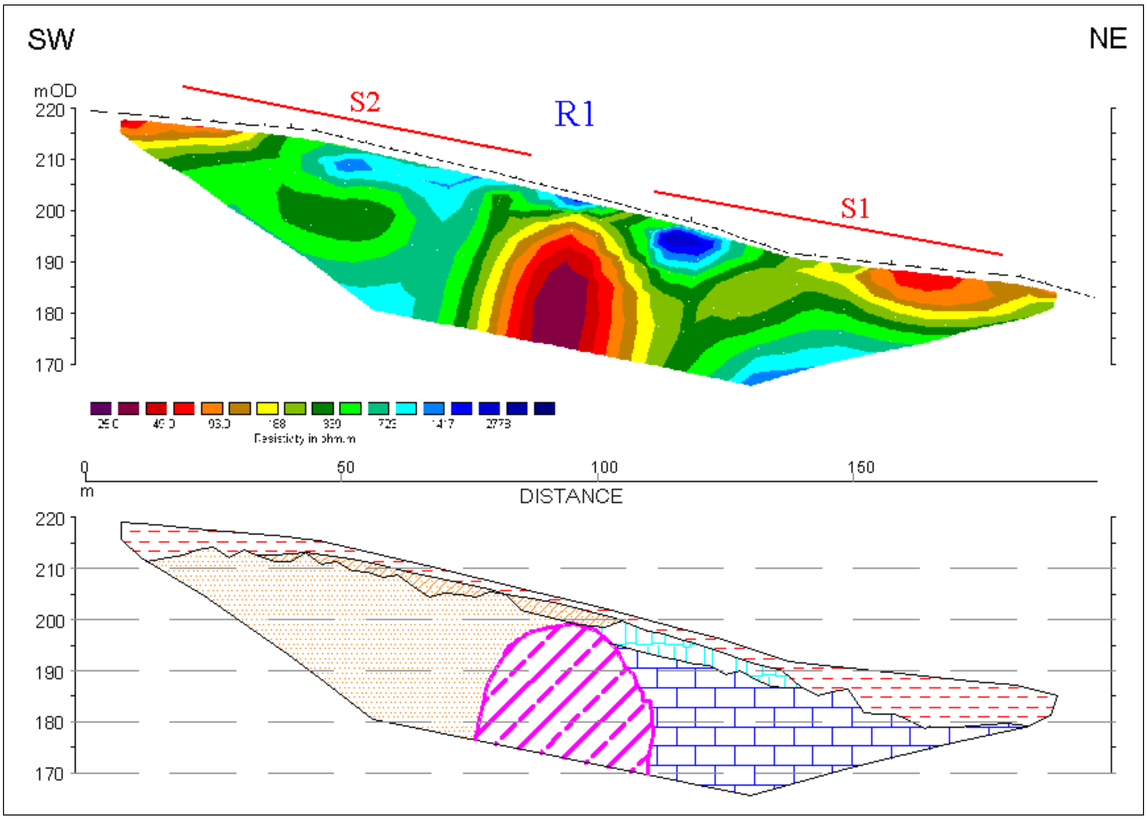

FIGURE 7. Resistivity results, showing the low-resistivity fault zone in the centre of the section.

CONSTRAINED INVERSION USING BOREHOLE LOGGING

By combining the results for surface ERT with those from downhole resistivity, the overall final pseudosection can be improved. Known resistivities at known depths from the downhole log are added to the initial model before inversion takes place, thereby providing fixed resistivity values at depths and hence improving the overall accuracy of the final model.

Examples from downhole logging at Carton House and its correlation with nearby ERT data will be presented as part of the workshop on downhole logging which takes place during the conference.

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HYDRO-STRUCTURAL CHARACTERISATION OF CATCHMENTS USING MULTI-SCALE GEOPHYSICAL TECHNIQUES.

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ABSTRACT

Correct interpretation of groundwater and surface-water monitoring data in catchments is dependent on an accurate conceptual understanding of the structure and composition of underlying soil and bedrock. The high degree of spatial heterogeneity and inaccessibility of the sub-surface acts as a considerable impediment to achieving this, particularly in maritime north-western Europe, where a legacy of glacial activity, combined with large areas underlain by heterogeneous igneous and metamorphic bedrock, make the structure and weathering of bedrock difficult to map or model. An integrative and multi-scale approach is described, using standard geophysical techniques to generate a three-dimensional geological conceptual model of the subsurface in a catchment in Co. Down, NE Ireland. Available airborne LiDAR, electromagnetic and magnetic data sets were analysed for the region. At field-scale, surface geophysical methods, including electrical resistivity tomography, seismic refraction, ground penetrating radar and magnetic surveys, were used and combined with field mapping of outcrops and borehole testing. The combined interpretation of these methods produced a robust three-dimensional conceptual model and a valid framework for the interpretation of groundwater and surface water monitoring data from the catchment.

INTRODUCTION

In maritime temperate regions, where surface water sources are available for public water supplies and direct contributions from groundwater are less critical, the complexity and low yield of many hard rock aquifers has meant that research has been limited. Drivers prompting an increased focus on hard rock aquifers include climate change, an increased demand for private wells and the requirement for compliance with the European Water Framework Directive (E.C., 2000). This has placed pressure on regulatory authorities to provide hydrogeological data and interpretation for all aquifer types and to develop suitable monitoring programmes (e.g. Bartley and Johnston, 2006, MacDonald et al., 2008, Ó Dochartaigh et al., 2005) which address groundwater both as an entity on its own and in terms of its interconnectedness with surface waters (EPA, 2006). There is a need to develop clear strategies and appropriate methodologies for characterising hard rock groundwater systems and to recognise that although of limited utility as public water supplies, poorly productive aquifers can be of ecological importance through maintaining base flow in rivers during dry periods. While geochemical and hydraulic testing approaches are almost systematically extended to investigations in hard rock environments, the need for full-scale characterisation requires alternative approaches applied across a broader spatial scale. Recent combined geophysical, structural, hydraulic and geochemical investigations undertaken as part of the Griffith Research Programme in different hard rock aquifer units in Ireland (e.g. Comte et al. (2012), Caulfield et al. (2014)) revealed complex aquifer types and orders of magnitude difference in hydraulic properties between, for example, deep and shallow bedrock, tills and alluviums or sedimentary and metamorphic rock types. The multiplicity of geophysical techniques available, together with the variability in the physical properties of subsurface units and fluids in different locations mean that applicability of a particular method, the way in which it is deployed and subsequently interpreted can be vastly different.

In the work presented here (and in Cassidy et al, 2014) we place an emphasis on the integration and cross-validation of different geological, geophysical and hydrogeological approaches, combining methodologies to characterise – at the scale of interest - the structure of hard rock aquifers in temperate regions with a legacy of glacial activity. A range of approaches combining airborne, field and borehole investigations were applied to a test catchment in NE Ireland to determine those methods which contribute most in terms of developing an understanding of subsurface structure influencing groundwater, which are relatively easy to implement and are suited to these environments.

STUDY AREA

The Mountstewart site (Figure 1) is a 5km^2 mixed agricultural catchment on the eastern shore of Strangford Lough in Co. Down (N 54.548; W 5.588). Groundwater is monitored at 8 borehole clusters (labelled MS1-8 in Figure 1 9 open and 7 piezometer wells) distributed across ~3 ha underlain by weakly metamorphosed Ordovician-Silurian greywacke (composition sequences from fine shale – coarse sandstone) which is in contact with Permo-Triassic (P-T) sandstones to the west along a normal fault which downthrows to the south-west to form a half-graben basin (Smith et al., 1991) within which lies Strangford Lough.

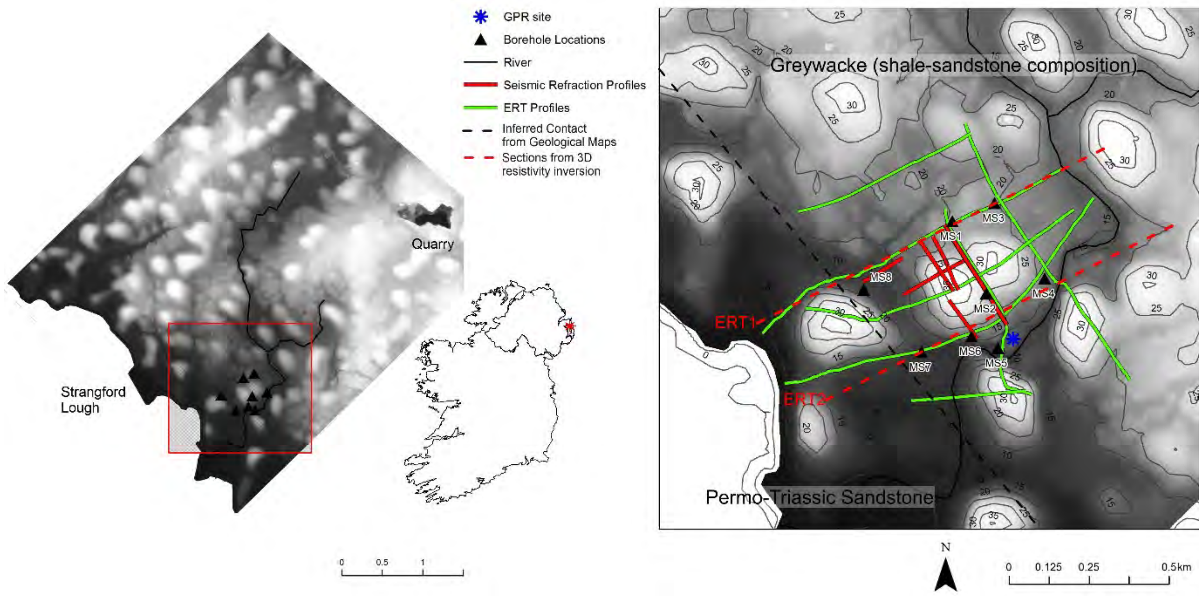

Figure 1: Study area, Mountstewart, Co. Down.

METHODS

The approach operates downward in scale from regional to borehole and outcrop scales. A comprehensive desk survey provided the basis for targeted field and borehole-scale investigations. Airborne data sets encompassing both high-resolution LiDAR elevation mapping and regional scale geophysical mapping were interrogated over the extent of the surface water catchment to identify geological structures of relevance to site hydrogeology. Field scale investigations into the structure of the subsurface in the study area included surface geophysical investigations using electrical resistivity tomography (ERT), seismic refraction, magnetometry and ground penetrating radar (GPR). A summary of techniques is provided in Table 1.

Technique	Application	Coverage
Regional Scale		
1 m resolution LiDAR DTM	Topography (glacial cover, lineament mapping	6 x 4 km^2 survey flown by NERC ARSF
3 kHz and 12 kHz Electromagnetic data sets (TELLUS, Beamish et al. (2006))	Geological variation, greywacke tract boundaries, saline interface (3 KHz - 60 - 100 m depth; 12 kHz –near-surface)	6 x 4 km^2 survey section.
Magnetic airborne data sets (TELLUS)	Igneous intrusions; geological contacts (different magnetic susceptibility)	6 x 4 km^2 survey section.
1:10000 and 1:250000 geological maps, aerial imagery, field sheets	Outcrop mapping – composition orientation and inclination of units	Ards Peninsula and Strangford Lough
Field-scale		
Electrical Resistivity Tomography (ERT)	Delineation of the regional geological contact, drumlins and weathered/ fractured zones from spatial variation in resistivity	6.21 km (5 profiles normal and 2 parallel to inferred geological structure). Dipole-dipole array; 5m electrode spacing; 3D inversion using BERT
Seismic refraction	Delineation of drumlins – layering and interface with bedrock	Multiple cross-cutting spreads across the drumlin
Magnetics	Igneous intrusions – dykes and sills	2km^2 area, measurements at 10-15m spacing along parallel profiles
Ground penetrating radar (GPR)	Identification of water-filled fractures but limited utility in highly conductive materials (e.g. clays, silt or saline water)	Localised areas of exposed bedrock (clay-free) using 100MHz and 200MHz antennae
Fracture mapping	Orientation and Inclination of greywacke and sandstone strata.	Outcrops ; local quarry, borehole televiewer logs
Borehole geophysical logging	Depth specific confirmation of surface geophysical measurements. Sondes: T-C; 3-arm caliper; bulk electrical resistivity; natural gamma (γ); acoustic televiewer.	Open boreholes (min diameter 4” and up to 95m depth)
Hydraulic Testing	Pumping tests, packer pump tests, and heat pulse flowmeter measurements	Pumping tests in all BHs; heat pulse flowmeter in open BHs.

Table 1: Overview of techniques applied at different scales.

INTEGRATED INTERPRETATION AND DISCUSSION

Resolving the 3D structure of the units

Multiple electrical resistivity tomography (ERT) profiles, each between 1 – 1.5 km in length (Figure 2 with positions indicated in Figure 1), across the study area provided information on the main structural features including:

(i) the position of the regional geological contact, highlighted by the resistivity contrast between the greywacke (500 to >10^4 Ωm) and the Permo-Triassic sandstone unit (generally <100 Ωm).

(ii) the drumlin tills (low resistivity clays, ~100 Ωm). As near-surface clay cover impacts current propagation to depth seismic refraction was used to clarify drumlin structure and the position of the bedrock interface.

(iii) the depth and extent of weathered and fractured zones across the site (broken rock with higher porosity and clay content, so low resistivity, 500-1000 Ωm). The shale-dominated greywacke, with thin beds and high clay content more susceptible to physical and chemical weathering, has lower resistivity values to a greater depth, indicative of deeper weathering profiles while the coarse sandstone-greywacke shows little change in resistivity with depth.

Lineaments identified from airborne LiDAR and geophysical surveys yield important information regarding the structure of the sandstone and shale beds within the greywacke tract in the study area. Airborne lineaments display 4 trends – NNE, ENE, NE with an orthogonal NNW set mapped proximal to the contact with the Permo-Triassic sandstones in the west. It is not possible to determine dip from the airborne data but the large area covered provides a means for interpreting smaller scale measurements and fitting them within the regional geological setting.

At field-scale, combined interpretation of fracture mapping at outcrop and borehole, GPR, seismic refraction and packer tests indicate that fracture sets with a NNW orientation, parallel to the geological contact with the Permo-Triassic sandstone, have larger apertures and are more hydrologically active than those in the NNE orientation (corresponding to the greywacke bedding planes). Within the boreholes, just 10% of the 184 fractures identified were clearly hydraulically active and the majority of those had a NNW strike. Observations in outcrop and GPR soundings also found NNW orientated sets to have larger apertures, some with a Permo-Triassic sand infill and reflections consistent with the presence of water. At field-scale, differences in bedrock p-wave velocities observed between NW and NE aligned profiles again supported the concept of larger apertures in this fracture set, with voids and gaps in the bedrock slowing and attenuating p-wave propagation in this direction. This anisotropy has important implications for flow within the aquifer.

Depth of weathering

Repeated glaciations have effected extreme modification of the Irish landscape, with extensive denudation and removal of most of the ancient decomposed and weathered material, particularly in the north of the island. Subsequent deposition of eroded material often occurred on a fresh bedrock surface with relatively little chemical or physical alteration. This is the case across the Mountstewart site, with the hydrologically important transition zone between the soil/till cover and the underlying weathered fissured bedrock, limited or absent depending on whether the greywacke is of shale of sandstone composition.

In the ERT profile in Figure 2, which intersects a coarse sandstone lithology within the greywacke unit, a shallow (0-10 m), low resistivity zone in the near-surface is interpreted as weathered, fissured bedrock, confirmed by borehole geophysical analyses and observations in outcrop, and appears closely correlated with the lithology of the bedrock unit. Comparison of permeabilities between shallow and deep boreholes in each of the well clusters in this unit (MS-1 and MS-3), indicate markedly higher permeabilities in the shallow zone and supports the interpretation that these near-surface zones are open fractures, with little in-situ weathered clay minerals or infill of glacial till. By contrast within the shale-dominated greywacke, the extent of this low resistivity zone is much greater, extending to ~40 m bgl. The implications of this in terms of the hydraulic properties of the units, in particular permeability and storativity, are significant (Comte et al. 2012) and understanding the likely distribution of this deeper weathering across the site is important.

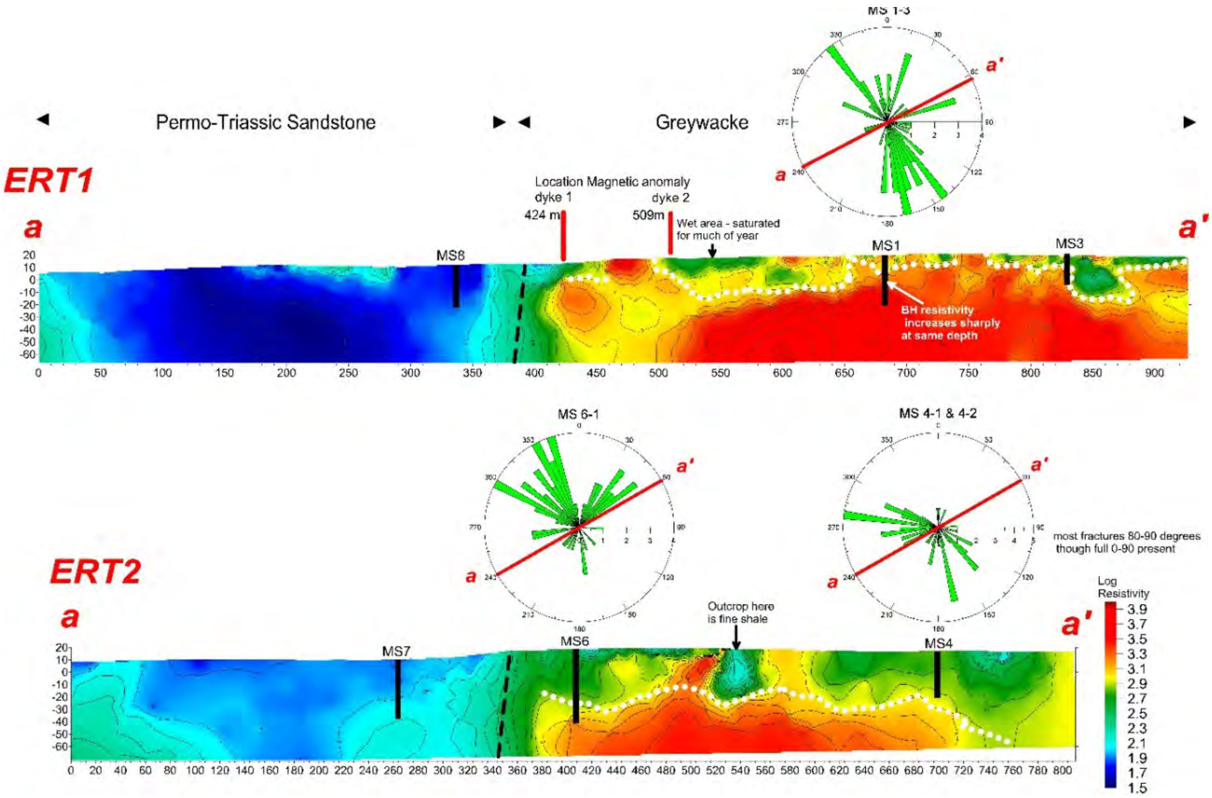

Figure 2: ERT sections (red dashed lines in Figure 1) across the Permo-Triassic sandstone/greywacke contact intersecting the sandstone-greywacke (ERT1) and the shale-greywacke (ERT2) lithologies. Rose diagrams indicate the strike of fracture sets from BH logs, relative to the orientation of the profile (red line indexed a–a'). The extent of the weathered, fissured layer (white dash), major faulted contact (black dash) and location of the possible dykes identified from magnetometer survey are indicated.

The composition of the till in the field site reflects the underlying geology and the southward flow of ice, with dense clays in the east becoming increasingly sandy in proximity to the Permo-Triassic sandstone unit in the west. The high density of the compact tills at the base of the drumlins, surveyed using seismic refraction, is indicative of low permeability and thus recharge through the glacial till is expected to be limited. Preferential flow is laterally through the less compact surface material and off the flanks of the drumlins, resulting in saturated areas around the base of the drumlins except during prolonged dry periods. Lack of a transition zone and associated storage means that these saturated areas often overflow into surface runoff and field drains during rainfall events.

All structural data were input into Geomodeller (Intrepid Geophysics) to produce a 3D structural model for the study area, incorporating features delineated and mapped at all scales using the combined geophysical methods. Cross-sections and a three-dimensional output are shown in Figure 3. Superimposed on this manually were data on the weathering variations across the site and the inferred flow directions based on piezometric mapping of borehole levels.

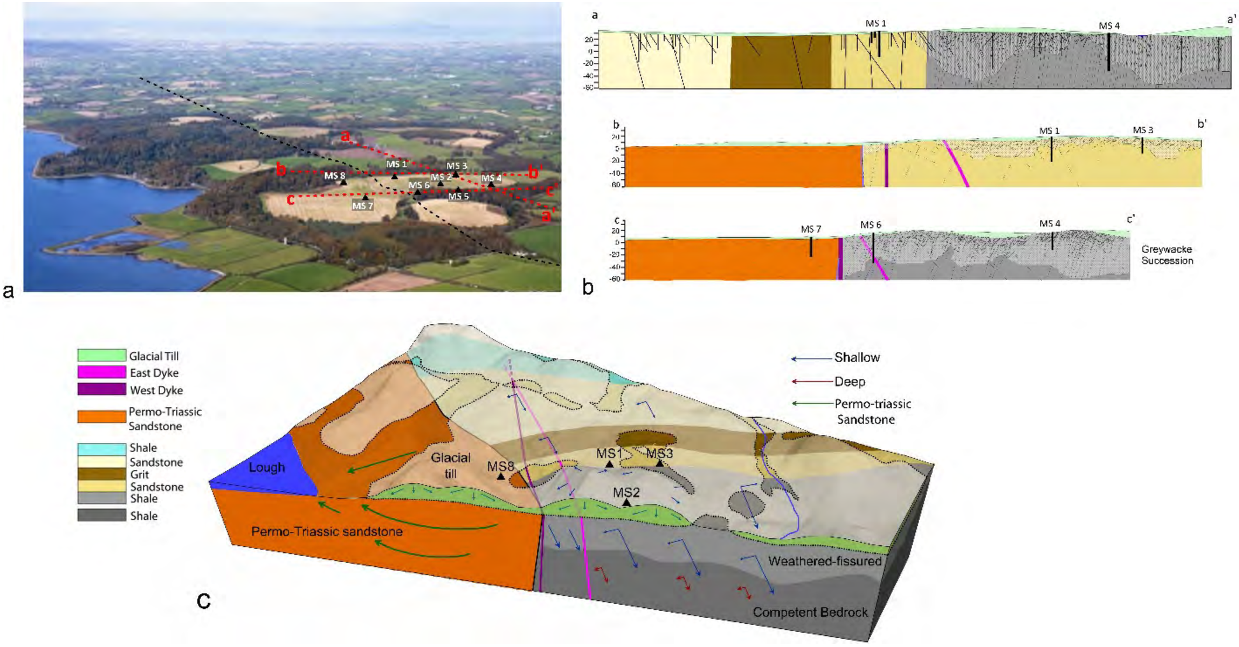

Figure 3: Structural model of the study area generated from combined geophysical surveys (air, field and borehole), desk survey and mapping. Fracture patterns based on borehole logging, weathering profiles from ground geophysics and assumed flow directions and magnitudes have been added manually. (a) aerial imagery with borehole clusters, geological contact and cross-section profile positions overlain (b) interpreted geological cross-sections of the 3D model (a-a'; b-b', c-c') (c) 3D model.

IMPLICATIONS FOR GROUNDWATER MONITORING/CATCHMENT MANAGEMENT

The position of the contact between the greywacke and Permo-Triassic sandstone bedrock units is important in interpreting hydrogeological observations in the catchment. The contrasting permeabilities of the Permo-Triassic sandstone ($7 \times 10^{-2} – 7 \times 10^{-1}$ m day^{-1} from on-site pumping tests) compared to both the shale- and sandstone-greywacke ($4 \times 10^{-4} – 8 \times 10^{-2}$ m day^{-1}) mean that inaccurate delineation of the extent of each unit can lead to misinterpretation of the hydraulic responses of the wells.

There are also implications for understanding exchange between ground and surface waters in the hyporheic zone due to the difference in potential inflow from the contrasting units and difficulty in establishing the location of the contact from surface observations alone. The geological map of the area positions the contact 400 m west of the position identified in this study and the high permeability Permo-Triassic sandstone influences the river approximately 200 m further upstream than previously thought. Identifying this improves interpretation of river discharge monitoring in this small catchment; as well as accounting for any impacts the lithological differences might have on water chemistry.

The main geological lineaments provide a guide to the expected anisotropy in transport pathways in the catchment. The strong NE orientation of the sedimentary sequences in the greywacke succession might suggest that most fluid movement would be parallel to this. However seismic and GPR indicate that fractures normal to this and of later origin (Alpine) may be more open and transmissive and therefore exert a greater control on groundwater discharge to stream flow (Oxtobee and Novakowski, 2002).

The change in the lithology of the greywacke along the stratigraphic sequence also has strong implications for groundwater flow and storage. A comparison of the response of boreholes in the shale-greywacke lithology with those in the sandstone greywacke lithology (Figure 4) to rainfall demonstrate the lithological influence on groundwater dynamics. The deep and shallow wells in the shale-greywacke show similar, muted responses to rainfall while the wells in the sandstone-greywacke are markedly more responsive. The deep zone in the shale-greywacke unit has similar hydraulic properties as the shallow zone in the sandstone-greywacke unit, which is consistent with much deeper weathering of the shale-greywacke compared to the sandstone-greywacke and consequently higher bulk productivities (Comte et al., 2012). It demonstrates that appropriate spatial mapping of such weathering features is crucial for interpreting groundwater observations in boreholes.

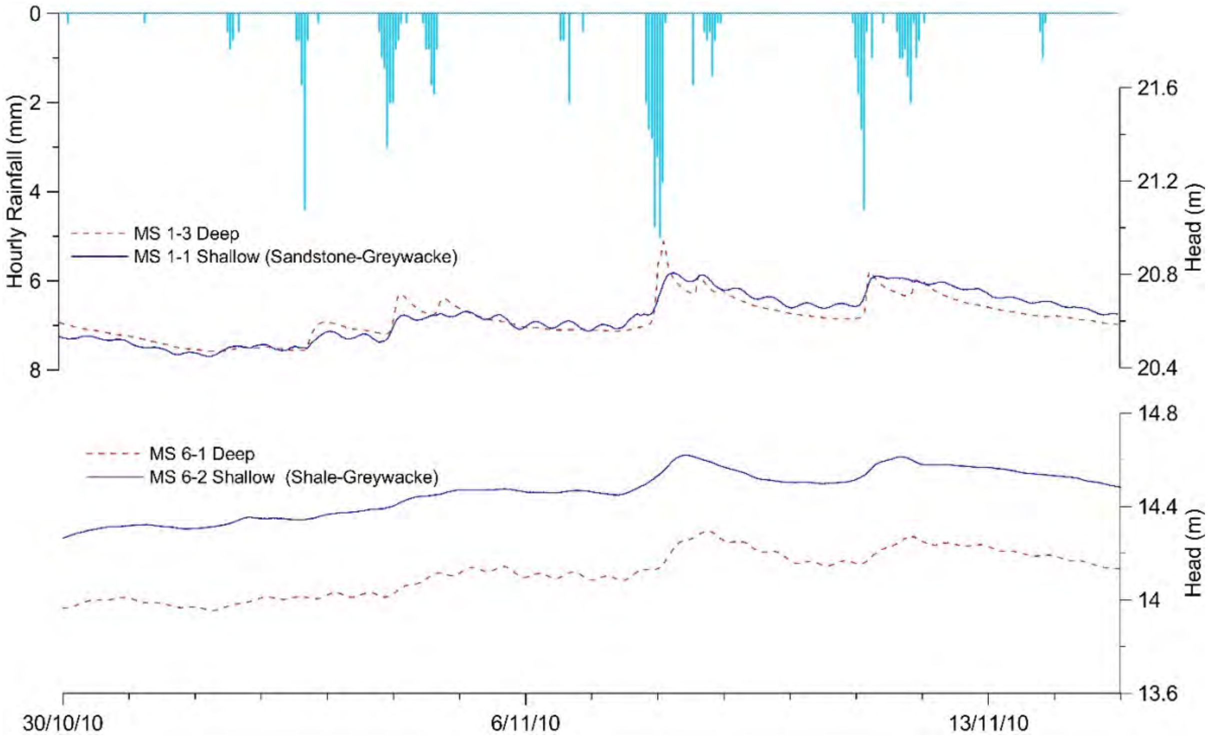

Figure 4: Comparison of well head response to rainfall between the MS-6 cluster in the shale-greywacke lithology and the MS3 cluster in the sandstone-greywacke lithology.

For monitoring and the interpretation of monitoring data these findings have important implications. Although these boreholes are in the same field, with the same agricultural management (arable) and with any downslope runoff from the same drumlin, sampling each at the same lag following a rainfall event might give very different impression of chemistry due to the lithological influence on flow rates or mass transport.

The extent and depth of till cover is also variable and of significance from a vulnerability perspective where the dense clay-rich till buffers the bedrock from contaminants and simultaneously acts as an aquitard and limiting recharge (Misstear et al., 2008). Delineating the depth and layering within the till cover provides an indication of aquifer recharge and subsequent vulnerability from agricultural contamination.

CONCLUSION

Taken independently, there can be multiple interpretations for features resolved using any of the methods applied in this study. The strength of the approach, however, lies in the cross-comparison of the methods, particularly where different physical properties are measured. This allows artefacts to be excluded and depths of interfaces to be resolved with greater confidence and accuracy.

The time and cost of the investigations undertaken in this study is not prohibitive when viewed in comparison with the cost of instrumentation, sampling and analysis of chemical data from a catchment study, and is a one-off outlay. The geophysical equipment used here are relatively standard and available from equipment pools and most consultancies, if required as a service. In terms of time the ERT survey can take less than 1 day to complete a 1 km length, depending on the terrain and accessibility; the magnetic survey required 10 hours to complete. The seismic spreads used to characterise the drumlin at the centre of the well clusters could be completed within a day. Well tests and borehole geophysics were completed over an intermittent period but could, in favourable conditions be completed in less than 2 weeks.

Given the quality of information these technologies provide, there is a strong case for incorporating them systematically into more surface water dominated catchment studies and hydrologic monitoring programmes.

ACKNOWLEDGEMENTS

This work is based on research grant-aided by the Irish Department of Communications, Energy and Natural Resources under the National Geoscience Programme 2007–2013. Airborne conductivity and magnetic data are provided under licence from the TELLUS Project, which was funded by DETI and by the Building Sustainable Prosperity scheme of the Rural Development Programme (DARD-NI). The Digital Elevation Model was grant funded by NERC ARSF GB12/07. We thank Carsten Rücker and Thomas Günther for permission to use BERT 3D inversion software. We also acknowledge the GNSI/NIEA who installed the borehole infrastructure and gave us access and Mountstewart Estate for access to the estate and assistance when required.

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The IAH (Irish Group) would also like to acknowledge the support of the following members and organisations whose staff have worked on the committee of the IAH-Irish Group throughout the year and helped to organise the conference:

David Drew

TRINITY COLLEGE DUBLIN
COLÁISTE NA TRÍONÓIDE
THE UNIVERSITY OF DUBLIN

SLR

Department of Enterprise, Trade and Investment
Geological Survey of Northern Ireland

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IE CONSULTING
WATER-ENVIRONMENTAL-CIVIL

STREAM
BIOENERGY

Roberta Bellini

MOR
MALONE O'REGAN

TOBIN
Patrick J. Tobin & Co. Ltd.

ARUP

ROD
ROUGHAN & O'DONOVAN