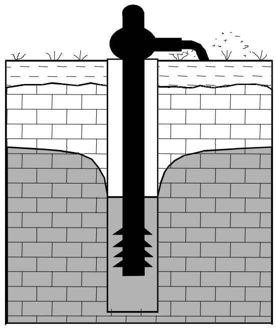
ISSN 0790 - 7753

THE GSI GROUNDWATER NEWSLETTER

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



NUACHTÁN SCREAMHUISCE SGÉ

- Taiscéalaíocht
- Bainistíocht
- Truailliú
- Nuacht Idirnáisiúnta
- Forbairt
- Cáilíocht
- Athbhreithniú
- Tuairimí

Published by the Geological Survey of Ireland,
Beggars Bush, Haddington Rd.,
Dublin 4.

Edited by Una Leader & Coran Kelly

Foilsithe ag an Suirbhéireachta Gheolaíochta Éireann,
Tor an Bhacaigh, Bothar Hadington,
Baile Átha Cliath 4.
Tel: (01)6782000 Fax: (01) 6681782

No. 46 April 2007

In This Issue

In this issue

The GSI **Groundwater web-mapping site** has been updated to make it more efficient and easier to use. Gráinne Ni Shé and Monica Lee tell us more.

The Water Framework Directive – well we just cannot get away from it. No less than 3 articles submitted fall under its far reaching cloak.

> Taly Hunter Williams provides an insight to some of the available **information & resources** falling out of this work.
> Donal Daly and colleagues summarise the revisions and updates on **monitoring groundwater**.
> Gerry Baker, Donal Crean & Sean Moran tell us about establishing **natural background concentrations of selected groundwater quality parameters.**

'Water wells and Boreholes' by Bruce Misstear, David Banks and Lewis Clarke is a newly published book and one of the primary authors is one of our own**. David Ball** puts it to the test.

David Drew and Honor Chance present findings from a survey carried out on **karst springs** throughout Ireland.

Robbie Meehan investigates the **permeability of drumlins** in Connemara.

Laurence Gill discusses results from ongoing research into **on-site wastewater treatment.**

With *Cryptosporidium parvum* in the news again and one-off housing never far from our thoughts timely research into the **health risks associated with private well supplies** in Ireland is being carried out by Bruce Misstear and Paul Hynds.

The GSI have developed a new **Irish Water Tracing Database**. Caoimhe Hickey explains what it contains.

Universities involved in **groundwater related research** describe their work in a number of short articles.

The **Annual Conference of the IAH (Irish Group)** will be held on Tuesday 24th & Wednesday 25th April 2007 at Tullamore, Co Offaly.

Geological Survey of Ireland's Groundwater Web-Mapping Site

The Groundwater web-mapping site has recently been redeveloped in order to include the most recent information and to make it more user-friendly. The fundamental change is that the site now includes the Groundwater Section's most recent national datasets rather than a combination of the national data and the older county-based data. The national data comprise:

- the ***Generalised Bedrock Map***, which groups the different Irish bedrock formations (>1000) into 28 classes based on their stratigraphy and the main lithological and structural properties that influence their groundwater flow properties;
- the ***Bedrock Aquifer Map***: subdivides Irish bedrock into three main categories and seven sub-categories depending on their specific aquifer properties;
- the ***Gravel Aquifer Map***: identifies the Irish sand/gravel deposits that function as aquifers and sub-divides them into two categories depending on their specific properties;
- the ***National Interim Vulnerability Map***, which is a composite map comprising (i) full[1] and interim[2] vulnerability mapping undertaken by the GSI for Local Authorities (i.e. the Groundwater Protection Schemes – 11 available digitally) and (ii) interim vulnerability mapping undertaken by consultants working for one or more of each of the seven River Basin Districts (RBDs);
- the ***Source Protection Areas Map***, which constitute the outer (zone contributing groundwater to the abstraction point) and inner (estimated 100 day time of travel of the groundwater to the abstraction point) source protection areas delineated by the GSI (120 sources) and other consultants (5 sources).

Furthermore, the Teagasc Subsoil (Parent Material) Map is also hosted on the site. Due to the complexity of the vulnerability and subsoil maps, these data are subdivided into the seven RBDs in order to make them less cumbersome to use.

Where groundwater protection schemes are available, the user can determine the groundwater protection response for one of three presently available activities: 1) landfills, 2) licensed landspreading and 3) on-site wastewater treatment systems. Response matrices are also being developed for two further activities – earth-lined slurry stores and out-wintering pads. These will be included on the site when they are completed and published.

The site can be accessed via the GSI's website (http://www.gsi.ie/) by clicking on the ***Groundwater 'On-Line Maps'*** link on the home page (Figure 1), or directly by entering the address http://193.178.1.182/website/Introduction_to_Groundwater_WebMapping.htm. This leads the user into an introduction page about the site with a further link to access the maps. The introduction page is particularly useful as it outlines the required browser settings that enable the site to work correctly.

The usability of the Groundwater web-mapping site (Figure 2) has been improved. The site now comprises six steps that guide you through the process of:

- viewing the disclaimer and data source information, which also includes a description of the accuracy of the data (***Step 1***),
- locating the area interest by using the zoom and pan options (***Steps 2 and 3***),
- selecting the required information i.e. map theme, such as bedrock aquifer (***Step 4***),
- printing a map (***Step 5***), and
- determining the required groundwater protection response(s) (***Step 6***).

If a response for one or more of the available activities is required for a particular location, the user must consult the individual maps to establish first the aquifer, then the vulnerability and finally the source protection zone (if appropriate) categories for that location. Once these are known, either from pin-pointing on the screen or from printing the maps, the appropriate response can be determined by referring to the response matrix (i.e. look-up table) for the activity of interest.

[1] Full vulnerability maps comprise up to five vulnerability classes– E (Rock near Surface or Karst), Extreme, High, Moderate and Low).
[2] Interim vulnerability maps comprise three vulnerability classes – E (Rock near Surface or Karst), Extreme and undifferentiated High-Low.

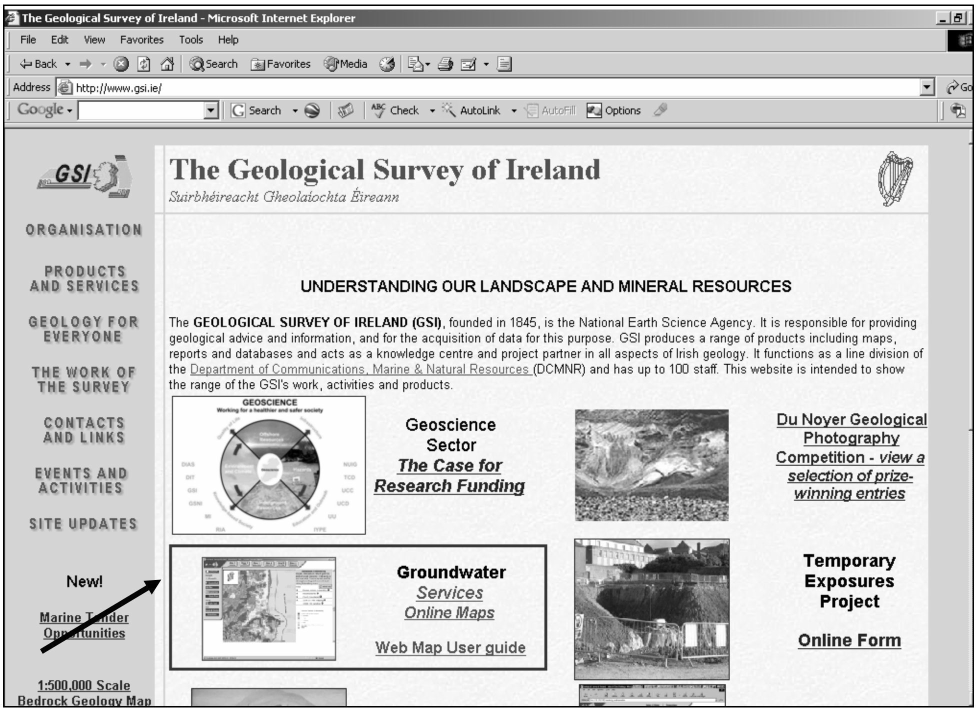


Figure 1. GSI Website's Home Page.

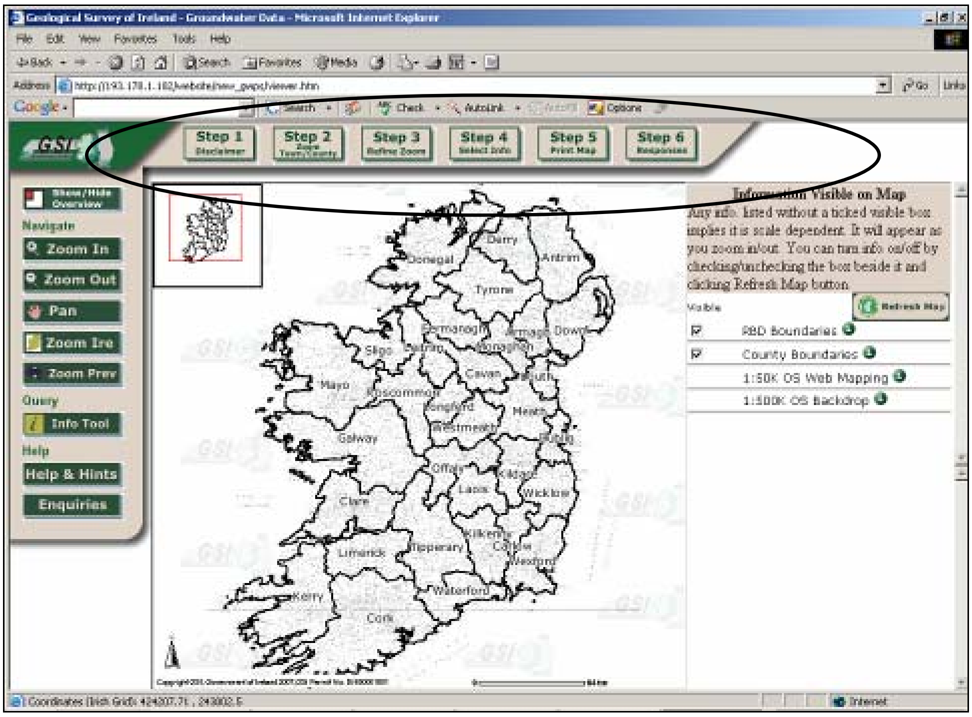


Figure 2. Initial Groundwater Web-Mapping Site

The "Help & Hints" page describes each step in detail. However, if there are any further queries or comments on the content or how to use the site, please contact Groundwater Section enquiries at Groundwaterinfo@gsi.ie.

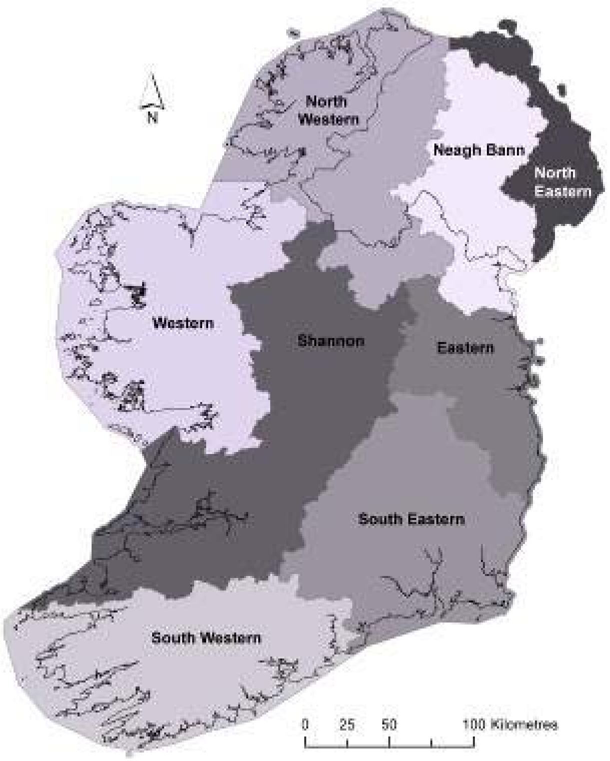
Gráinne O'Shea and Monica Lee,
Geological Survey of Ireland

Groundwater information and data related to the implementation of the Water Framework Directive in Ireland

The Water Framework Directive

As part of a substantial restructuring of EU water policy and legislation, a Directive was implemented in December 2000 (2000/60/EC). Generally known as the Water Framework Directive, it rationalises and updates existing water legislations and provides for water management on the basis of River Basin Districts (RBDs). The RBDs in the island of Ireland are shown below in Figure 1.

Figure 1. River Basin Districts in the Island of Ireland. Seven are partially or totally in the Republic.



The overall objective of river basin projects is to establish an integrated monitoring and management system for all waters within an RBD, to develop a dynamic programme of management measures, and to produce a River Basin Management Plan, which will be continually updated.

More information on the Water Framework Directive, and its implementation in Ireland, can be found at http://www.wfdireland.ie. The European Union website is at - http://europa.eu.int/comm/environment/water/water-framework/index_en.html.

Groundwater and implementation of the Water Framework Directive in Ireland

A Groundwater Working Group (GWWG) was established under the aegis of the WFD Technical Co-ordination Group to assist in the technical interpretation of the Directive, and to provide guidance for River Basin Projects on the delivery and implementation of groundwater work requirements. The working group on groundwater is convened by Donal Daly (EPA, formerly GSI). Other organisations and companies contributing to the work of the GWWG include the Geological Survey of Ireland (GSI), the Geological Survey of Northern Ireland (GSNI), National Parks and Wildlife Service (NWPS), Department of Heritage and Local Government (DEHLG), Teagasc, consultants from each of the seven Irish River Basin Districts (RBDs), and academic staff from TCD and UCD.

Groundwater-related outputs from the WFD

To date, the WFD has acted as a catalyst for the completion and initiation of many datasets and information sources. Many of these were created/ completed during the 'Intial Characterisation' phase of the WFD. Datasets and reports of key interest are listed in Table 1 below, together with weblinks, where available digitally. They include:

- Eleven Guidance documents;
- 'Article 5' Risk Assessements of risks to groundwater (surface waters were also risk assessed);
- National Aquifer map and Rock Unit Group map, National Subsoil map and Soil map, National Interim Vulnerability map;

- Groundwater body (GWB) map and descriptions;
- Estimations of Natural Background Levels of key groundwater chemical constituents;
- WFD Visualisation – images depicting groundwater concepts and its management;
- An upgraded groundwater quality and level monitoring network (also, surface water quality and quantity networks).

Future groundwater information sources from WFD work

The list above gives the main groundwater-related information arising from the WFD in the last four years. In the coming months and years, more information and data will become available, including: results and recommendations from Further Characterisation Programmes of Measures (POMs) studies; SWMI (Significant Water Management Issues) reports for each RBD (in 2007); River Basin Management Plans (RBMPs, from 2009). Groundwater-dependent terrestrial ecosystems (GWDTEs) are currently being delineated within conservation areas.

Useful Web resources

- WFD Ireland website: http://www.wfdireland.ie
- * For GWWG (and other WG) documents on WFD Ireland website: go to http://www.wfdireland.ie/WFDCharRep.htm, scroll down to 'Background Information', and choose links of interest.
- RBDs: Eastern: http://www.erbd.ie/; Southeastern: http://www.serbd.ie/; Southwestern: http://www.swrbd.ie/; Western: http://www.wrbd.ie/ ; Shannon: http://www.shannonrbd.com/; Northwestern International: http://www.nwirbd.com/; Neagh Bann International: http://www.nbirbd.com/; Northeastern: http://www.nerbd.com/.
- Geological Survey of Ireland website – http://www.gsi.ie; GSI's online maps direct link http://193.178.1.182/website/new_gwps/viewer.htm;
- EPA co-ordinated Groundwater Monitoring Network – see http://www.epa.ie/OurEnvironment/Water/WFD/Monitoring/Programme/ and http://www.epa.ie/OurEnvironment/Water/WFD/Monitoring/Results/;
- Teagasc: http://www.teagasc.ie;

Table 1. Key groundwater-related information arising from/completed during WFD Initial Characterisation

Data Type	Name	Data origin	♦ Description	♦ Availability
Guidance Document*	Approach to delineation of Groundwater Bodies (GW2)	GWWG	Outlines the approach to delineating groundwater bodies.	http://www.wfdireland.ie/Documents/Characterisation%20Report/Background%20Information/Analaysis%20of%20Characters/Groundwater/GW2%20Groundwater%20Body%20Delineation.pdf
	The Calcareous/ Non-Calcareous ("siliceous") classification of bedrock aquifers in the Republic of Ireland (GW3)		Indicator of the susceptibility of surface water to acidification as a function of groundwater buffering capacity.	http://www.wfdireland.ie/Documents/Characterisation%20Report/Background%20Information/Analaysis%20of%20Characters/Groundwater/GW3%20Calcareous%20-%20Non-Calcareous%20Classification.pdf
	Guidance on pressures and impacts methodology (GW4)		Pressures and impacts 'risk assessment' approach to decide whether water bodies are 'at risk' of failing to meet the WFD's environmental objectives.	http://www.wfdireland.ie/Documents/Characterisation%20Report/Background%20Information/Review%20of%20Env%20Impacts/Risk%20Assessments%20Gen/GW4%20Pressures%20and%20Impact%20Methodology.pdf
	Guidance on the assessment of the impact of groundwater abstractions (GW5)		Abstraction impacts on GWBs and on groundwater dependent terrestrial ecosystems (GWDTEs). Has table outlining recharge coefficients.	http://www.wfdireland.ie/Documents/Characterisation%20Report/Background%20Information/Review%20of%20Env%20Impacts/Groundwater%20Risk%20Assessment/GW5%20Abstraction%20Pressures.pdf
	Methodology for risk characterisation of Ireland's groundwater (GW8)		Detailed methodology and criteria for undertaking the risk characterisation of groundwater in Ireland.	http://www.wfdireland.ie/Documents/Characterisation%20Report/Background%20Information/Review%20of%20Env%20Impacts/Groundwater%20Risk%20Assessment/GW8%20Compiled%20RA%20Sheets.pdf
Charac-terisation Report	Article 5 - The Characterisation and Analysis of Ireland's River Basin Districts	EPA/ RBDs/ LAs	Comprehensive assessment of all waters (groundwater, rivers, lakes, transitional and coastal waters). Establishes a baseline and identifies priority actions for subsequent stages in the river basin planning cycle.	Follow links from http://www.wfdireland.ie/WFDCharRep.htm
National Map	Rock Unit Group	GSI	As named.	Follow links from Geological Survey of Ireland website – http://www.gsi.ie or access online maps directly from http://193.178.1.182/website/new_gwps/viewer.htm
	Bedrock and Gravel Aquifers			
	Interim Vulnerability	GSI & RBD consultants		
	Subsoil	Teagasc		
	Soil			Contact Teagasc Kinsealy
Coming soon	Groundwater Body reports	GSI	GWB is management unit necessary for subdivision of large geographical areas of aquifer in so they can be effectively managed.	Will be hosted on GSI's webmapping site. GWB descriptions will be available as PDFs accessed by clicking on the relevant GWB on the map.
	Groundwater Body map			
	Groundwater Monitoring Network	EPA/LAs	Groundwater quality and groundwater level.	See http://www.epa.ie
	WFD Visual	EA/GSI/ SNIFFER	Library of images visualising some of the complex processes underpinning the water environment and its management under the Water Framework Directive (WFD).	See http://www.wfdvisual.com

Taly Hunter Williams, Geological Survey of Ireland

Monitoring Groundwater – A New Beginning

Introduction

Two separate networks – water level and water quality – are required to monitor different aspects of the groundwater system. Both networks have been in operation in Ireland for a number of years. However, both are now being revised and up-dated. The impetus for this has been provided by the EU Water Framework Directive (2000/60/EC), which requires the establishment of monitoring programmes for groundwater to provide a coherent overview of water status – both quantity and quality – within River Basin Districts (RBDs) in each Member State.

Past and Present

The first regular groundwater level monitoring was initiated by the GSI in the Kildare/Laois area in late 1968. Hereafter, the GSI commenced measurements of natural (unstressed) groundwater levels in the Nore River Basin (1971), south-east Cork (1976) and the Boyle catchment (1978). Currently, the GSI, with the assistance of OPW, is maintaining a network of seven sites – four in Kilkenny and three in Roscommon. In addition, monitoring was undertaken in the vicinity of well fields by local authorities (e.g. North Cork and Wexford), and for special studies (e.g. Clara Bog, Pollardstown Fen and Curragh aquifer) by various parties. In 1995, the EPA set up a national water level monitoring programme of approximately 200 water level sites across the country.

While the GSI assessed raw groundwater quality in various study areas over the last 35 years, the first national monitoring network was not established until 1995, when the EPA initiated a national groundwater quality monitoring programme. The EPA takes groundwater quality samples twice a year at approximately 300 locations nationally, and general water quality trends are reported in the EPA Water Quality Report every three years.

The Future

The implementation of the Water Framework Directive (WFD) requires comprehensive groundwater quality and water level programmes to be operational by 22nd December 2006. This requirement has necessitated the review of the existing networks, followed by the establishment of carefully-selected new networks. Monitoring network design guidance has come from the EU, the Irish WFD Groundwater Working Group and the UK-Ireland Groundwater Task Team (e.g. WFD Groundwater Working Group, 2004; Craig, *et al*. 2006). The main features of the networks are as follows:

- There are four networks:
    - A quantitative monitoring network (based on water levels and water balance estimations);
    - A surveillance water quality monitoring network;
    - An operational water quality monitoring network;
    - Appropriate monitoring to support the achievement of Protected Area objectives, e.g. Drinking Water and Habitats Protected Areas.
- The networks are based on our conceptual understanding, both regional and local, of groundwater flow and pollutant attenuation in Ireland.
- The networks take account of the relationship with surface water, in particular groundwater-surface water interactions, and thus encourage an integrated, holistic approach to monitoring and environmental assessment.
- Pre-screening of all monitoring points (e.g. checking well construction) has been undertaken to ensure that they are suitable for monitoring purposes.

- Representativity analyses have been undertaken to ensure that the monitoring points (MPs) in combination represent both the variation in hydrogeological settings and the pressures. One outcome of this is that the installation of new MPs is required.
- In poorly productive aquifers, where flowpaths are short and meeting representativity requirements is not readily achievable, MPs will be focussed in fault zones and in ten hydrogeologically-different 'type' settings, where multi-level piezometers will be installed.
- In 2007, special consideration will be given to deciding on monitoring requirements and installing MPs around groundwater dependent terrestrial ecosystems (GWDTEs).
- The lead monitoring authority is the EPA, supported by local authorities and the National Parks and Wildlife Service.

When the WFD networks are completed, the predicted numbers of MPs are as follows:

Network	**Approx. number of MPs**
Groundwater level	200
Groundwater quality	550
GWDTEs	120 (40 in 2007)

In conclusion, this is an exciting and challenging time, as expanded and improved groundwater monitoring programmes commence in 2007. From these we anticipate that our understanding of groundwater chemistry, quality and flow systems in Ireland, and their relationships to different land uses will improve, and will provide an essential basis for establishing and evaluating programmes of measures, as required by the WFD.

Acknowledgements
The pre-screening of the monitoring points was undertaken by the RBD consultants, based on guidance drawn up by the WFD Groundwater Working Group.

Reference

Craig, M., Moe, H. and Hunter Williams, N. 2006: Screening Methodology for the WFD Water Quality Monitoring Network, *Proceedings of the IAH (Irish Group) 26th Annual Groundwater Conference*.
WFD Groundwater Working Group, 2004. Advice on the implementation of guidance on monitoring groundwater. Guidance document no. GW6. 29pp. Available on the www.wfdireland.ie website.

Source: This paper was published originally in the IGI Conference Proceedings , Dublin 2006 "Ireland's Natural Resources 2006 – 2020, Developing Our Assets"

Donal Daly[1], Matthew Craig[1], Taly Hunter Williams[2] and Henning Moe[3]

[1]Environmental Protection Agency (EPA)
[2]Geological Survey of Ireland (GSI)
[3]CDM Ireland Ltd

Establishing Natural Background Levels for Groundwater Quality in Ireland

The Water Framework Directive (WFD) requires that the status of all water bodies be established. As part of the establishment of the chemical status of groundwater bodies in Ireland this study was undertaken to assess the natural background concentrations of selected water quality parameters. The findings of this study will be used as part of the process of defining Environmental Quality Standards (EQS) and ultimately groundwater body status. A methodology developed for the analysis of natural background levels in the South Eastern River Basin District (SERBD) under the Environmental Research, Technological Development and Innovation (ERTDI) Programme was modified and applied using data from each River Basin District (RBD) to assess Natural Backgrounds Limits (NBL) for a range of parameters on a national scale.

The preferred methodology is to assess data from before 1973, which marked the introduction of the Common Agricultural Policy in Europe and Ireland's entry into the European Economic Community (EEC). As there is little historical data available the assessment focused on the analysis of current data from locations where impacts from anthropogenic activity were low. Low Impact was either due to the absence of pressures (e.g. remote or upland areas) or good protection (areas of low vulnerability or confined aquifers). A GIS based tool was developed as part of the study to help identify monitoring points with water quality data least likely to be affected by anthropogenic activity. This resulted in the identification of 30 monitoring points, yielding around 750 water quality records distributed nationally across all seven RBDs.

Variation is expected in natural background levels based on the composition of the aquifer units from which the groundwater samples are collected. A simplified grouping process was undertaken to combine monitoring points located in aquifers of similar lithological composition. Ranges of NBLs have therefore been proposed based on the groups derived. The groups are Karst Limestone, Old Red Sandstone (ORS), Lower Palaeozoics, Granite, Confined Sandstones, Confined Limestones and a Mixed group which consists of impure limestones, shales, sandstones (Table 2). It was possible to establish a single NBL for some parameters which were considered not to be significantly influenced by lithology (e.g. Nitrate, Orthophosphate and Chloride. See Table 1). There was insufficient data to fully assess the importance of known anomalies for certain parameters in particular aquifers e.g. magnesium in dolomite aquifers in Carlow and Kilkenny.

The data for each parameter within each lithological group was assessed to determine the statistical suitability of the dataset. Results of the analysis are not reported where there were less than 50 records or the number of records reported as less than a Limit of Detection (LOD) would have caused a significant bias in the data. The main analytical technique used for validated data was to plot the data on a Cumulative Frequency Diagram (CFD). Data should plot a straight line if they have a log normal distribution, which is expected of many solutes in naturally occurring systems. The NBL is obtained by extrapolating the distribution identified as the natural distribution (i.e. the straight line section of the graph) up to the 90th percentile as recommended by EU Guidance on Natural Background analysis. Figure 1 shows the CFDs for the main indicator species.

The study produced NBLs for 22 out of 43 parameters identified for analysis by the Environmental Protection Agency (EPA). NBLs could not be derived for 13 parameters. These included heavy metals, which are not typically tested frequently enough and parameters that could not be analysed due to the high proportion of limits of detection (LOD) in the database e.g. Ammonia. The resulting NBLs are shown in Table1 and Table 2. It is important to note that the results are the **limit** of natural background conditions, the mean concentration is a better indication of typical natural background conditions, these are italicised in brackets beside the result for the parameters shown in Figure 1.
.

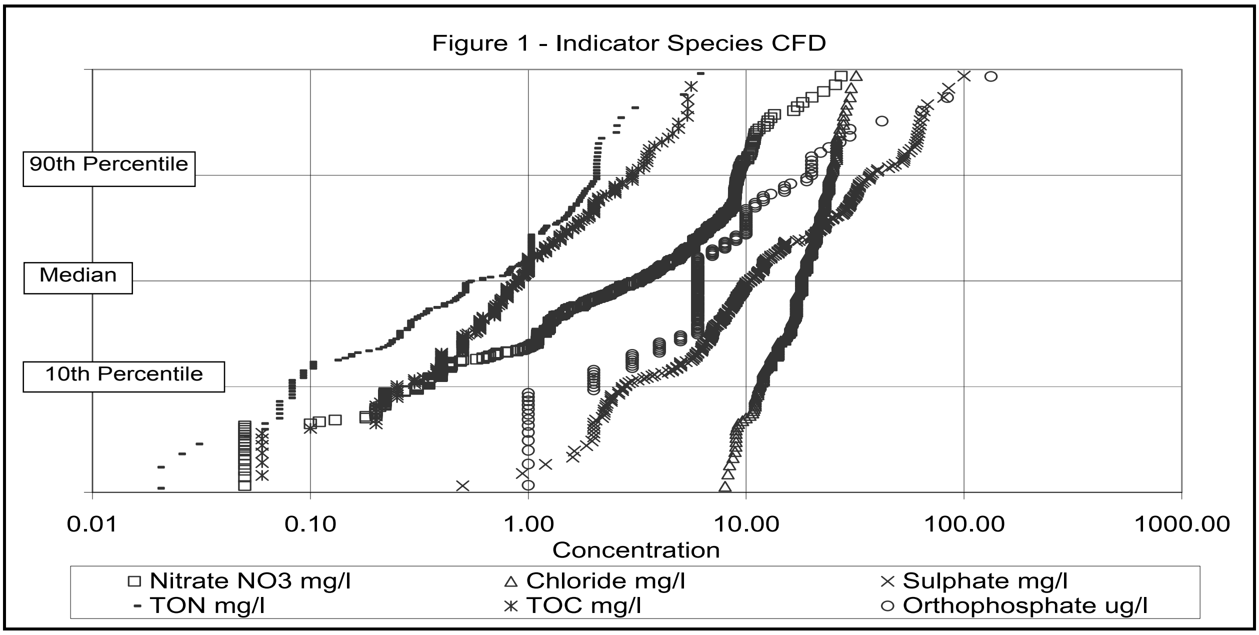


Table 1 Natural Background Limits for "Global" Parameters in Unconfined Aquifers

Parameter	**Nitrate (mg/l NO_3)**	**Orthophosphate (ug/l MRP)[1]**	**Chloride (mg/l)**	**T.O.C. (mg/l)**	**Iron (mg/l)**	**T.O.N. (mg/l N)**	**Zinc (mg/l)**
NBL	9.2 *(3.3)*	20 *(6)*	24 *(18)*	3.0 *(0.9)*	0.13	2 *(0.53)*	0.055
Parameter	**Sulphate (mg/l)**	**Copper (ug/l)**	**Chromium (ug/l)**	**Nickel (ug/l)**	**Manganese (mg/l)**	**Barium (ug/l)**	**Fluoride (mg/l)**
NBL	37 *(10)*	23	8	8	0.032	162	0.21

Table 2 Natural Background Limits for Lithologically Grouped Parameters

Bedrock Group	**ORS**	**Karst Limestones**	**Mixed Group**	**Granites**	**Confined – Limestones [2]**	**Confined – Sandstones[3]**
EC (uS/cm)	228	731	727	115	-	520
pH	7.4	7.7	7.6	6.7	7.7	7.8
K (mg/l)	2	2.8	3.8	-	3	-
Na (mg/l)	18	19	26	-	-	-
Ca (mg/l)	33	132	111	-	120	-
Mg (mg/l)	8	14	24	-	35	-
Alk. (mg/l)	92	342	308	-	407	276
Hardness (mg/l as $CaCO_3$)	95	364	364	-	419	236

[1] – Value derived from confined data to exclude the influence of shallow bedrock flow.
[2] – Data comes solely from Confined Limestones in S. Wexford and may not apply to other confined limestones
[3] – Data come solely from Westphalian Sandstones in the Castlecomer Plateau and Slieve Ardagh Hills and may not apply to other confined sandstones

A more detailed discussion of this subject is presented in the Proceedings of the 2006 IAH Conference. *OCM would like to acknowledge the enthusiasm and hard work of the groundwater section staff in the GSI and the members of the Irish Groundwater Working Group.*

Gerry Baker, Donal Crean & Sean Moran
O'Callaghan Moran & Associates, Granary House, Rutland St., Cork, Co. Cork.

BOOK REVIEW

'Water Wells and Boreholes'

by Bruce Misstear, David Banks and Lewis Clarke
Published by John Wiley & Sons, England, 2006
Reviewed by David M. Ball

A book review should be objective, therefore at the outset I should disclose that I have listened with great respect to lectures given by David Banks, and I have worked with Bruce Misstear and Lewis Clarke.

Lewis, Bruce, Geoff Wright and I worked within a group of consultant hydrogeologists in the 1970s'and 80's. We sparred with, and were influenced by, the same mentors and colleagues. We worked in many different parts of the world together, or following in each other's footsteps. Many of the principles, concepts and practical aspects contained in this book are those that I have tested and shared with others for a long time. I wish I had written this book, but I couldn't have done it. It is an enormous achievement for the two principle authors.

The book is an important and very valuable text book, with a world-wide application and appeal. It has been written, principally by the two first authors, in a seamless style and layout that will be accessible to a very wide readership. I expect that I will refer people to it, even when they have no professional training in groundwater, because, at its heart, it is a story book, that almost anyone can read. The authors tell the story of how to site, design, construct, test and manage a water well. It is a book that is designed to be read from the beginning to the end. There is a common sense logical flow in the way that the book is laid out. It is not a simple story, and it is the purpose of the book to explain, in relevant detail, this complexity and all the principles, considerations, factors and practical steps involved in constructing a water well. The book is fulsome. It is a complete counterbalance to the common, but naïve, notion that if you want a new water well 'you just go out and get yourself a driller'. This book explains how to do it properly.

Though I come from the same stable as Bruce and Lewis, I have found that I have learnt something new, or read something more clearly expressed than before, on every page. It has been a delight to find those things that I thought I knew, but always had a niggling doubt about, expressed clearly, at last. I found enjoyable clarity and reality in the sections on pumping test analysis. For example, the authors repeatedly state that most field conditions are unlikely to match the assumptions that underpin most of the equations used in the analysis of pumping test data. The authors describe why, and provide balanced guidance on how to wisely use different interpretative tools. They stick to clear concepts and practical advice and, for example, warn about the indiscriminate use of software. This book makes you think about your real data from first principles, rather than just 'grab a software package off the shelf, throw the data into it and see what comes out'. I have learnt of different ways of assessing long term yield which are directly relevant to my current work. I also picked up a tip on air lift development that I successfully used the following day. This book is not just for students or people without previous hydrogeology training. It is also rewarding and stimulating for those with more experience, who complacently think that they know it all. The book is thoroughly up to date, but, reassuringly, it covers all the well established technologies that are still relevant, and can be found in practice throughout the world.

As I said at the beginning, the contents of this book can be used anywhere in the world. This makes the book very special. So many of the major groundwater text books in the English language have a strong North American bias. I often find that these text books relate to large well understood aquifer systems that fit with classical hydrogeology models, but provide little help or encouragement when struggling with a new well field for a town or village in Ireland, or North Korea or the basement complex in Western Sudan. This book will help you, and give you confidence where ever you are working. The book draws upon experience from Nordic Europe, Europe, Africa, Arabia south east Asia, Australia, America, Britain and Ireland. The information relates to different climatic regimes and recharge considerations. Therefore, the authors' expertise and advice is well rounded, reliable and widely applicable.

Water Wells and Boreholes is a story that, as the authors put it, describes 'the life cycle' approach to water wells. This is a successful, and innovative approach that directly compliments the other 'Bible' on water wells by Driscoll (Groundwater and Wells). The authors have not tried to replicate Driscoll's numerous reference tables in the appendices. This sort of information is available from several sources. Instead the authors have focussed on providing a full, coherent, logical and cogent description of the process of how to properly and successfully create a water well. This process is well illustrated with clear diagrams, very interesting 'box texts' with special information or background information, and numerous photographs. The index is also excellent. I have few criticisms, but I felt that the photographs would have been more informative at a larger size and in colour (maybe if we all buy a copy the publishers will realise it is a best seller and invest in colour printing). I also would recommend that a first time reader does not give up in Chapter 1. Chapter 1 is essential, and an excellent summary of fundamental concepts, but I can imagine someone new to the whole field becoming terribly confused trying to understand vertical gradients in recharge and discharge zones. I do not entirely agree with some of the descriptions of techniques, but then we all have had different experiences, and no one can encapsulate everyone's experience in one book. We learn from each other. I have learnt from this book.

I have noticed in recent years that modern, younger, hydrogeologists and engineers are no longer completely beguiled by the slick graphics, and unreal assumptions of the digital world. Instead they have realised, almost as a gut instinct, that you can't be a complete hydrogeologist unless you have real experience in drilling water wells.

Drilling a water well is where all the training and preconceptions are put to the test. You've got to cope with what nature gives you, and really understand the dynamic flow of water through a static framework of rock. This particularly applies in Ireland, where the hidden bedrock is so variable and poorly understood, and every borehole is, literally, a voyage of discovery. The assumptions that you had before you left the cosy office and computer are usually challenged in each borehole every few metres.

Therefore, in short; if you want to be a complete hydrogeologist who can work anywhere in the world, buy this book, read it and then go out, with it and Driscoll, and other books of tables by your side, and put the authors' process into practice. You'll have fun, you'll learn a lot about dealing with uncertainty, you'll feel challenged, but at the same time, you'll also feel secure that you have a book next to you that will answer most of your questions and give you a lead when your first efforts don't seem to quite work out. Such a book is invaluable. When you come back, your risk assessments, groundwater vulnerability mapping, or Environment Impact Statements documents will be more firmly rooted in real hydrogeology. In other words, they will be credible.

I would like to congratulate and thank David Banks and Bruce Misstear for producing this excellent and very valuable major text book. It is an important achievement. I expect that it will become a 'Bible' that will be on the desk or in the field with every practical hydrogeologist that really wants to explore the subsurface and use their skill for the benefit of all people who need a better water supply.

The Hydrogeology of Karst Springs in the Republic of Ireland

In Ireland, most of the largest springs discharge from karst aquifers. The springs discharging from these aquifers represent an important water resource both for public and commercial supply as well as for ecologically important sites such as the turloughs of the west of Ireland. Despite their importance, very few systematic investigations of Irish springs have been undertaken. This research was carried out with the aim of developing a basic understanding of karst springs in Ireland with respect to their locations, hydrological and hydrochemical behaviour.

A survey was carried out on springs with a minimum low flow discharge of 10 litres per second (10 l/s = 0.001m³/s) and which are located within eight sample counties across the Republic of Ireland (Galway, Clare, Sligo, Westmeath, Offaly, Kilkenny, Tipperary and Cork). The sample counties were chosen on the basis that they would represent the different limestone areas in the country. Limestone categorisation was based on the GIS rock unit categories as assigned by the GSI. These are: pure bedded limestone; pure unbedded limestone; upper impure limestone; and lower impure limestone.

Each spring was visited during high and low flow conditions (winter and summer respectively). At each visit and where possible, readings for discharge, electrical conductivity (EC), temperature, pH and dissolved oxygen were taken. In total, 81 karst springs were included in the spring survey (Figure 1). However complete data (for all parameters) was not obtained for all of these.

It was not within the scope of the research to survey all the large karst springs (>10 l/s) in Ireland and their number remains unknown. However the survey carried out in the eight sample counties located 81 springs and the area of limestone in these countries represents less than half that underlying the Republic of Ireland. Thus a total of 200 large karst springs in Ireland may be a reasonable estimate

The details of the spring survey are described in the thesis including information on: spring location; elevation; geology; discharge; and hydrochemistry data, gathered by the author. Spring data from other authors are also included. A copy of the thesis, which includes the data held on an enclosed CD, is held in the groundwater section of the GSI, the Trinity College main library and Geography Department library.

As might be expected there are a greater number of small karst springs than large ones. If spring discharges are classified in terms of orders of magnitude (as per Meinzer, 1927), it can be seen that only two Irish karst springs fall within the first order of magnitude 10,000 l/s). These are Cong springs, Co. Mayo and Kinvara Springs, Co. Galway. After Kinvara springs, the second largest spring included in the survey is Elmvale spring, Co. Clare with a high flow discharge of 3,900 l/s (Drew, 1990), making it a second order of magnitude spring. The majority of the springs surveyed (66%) fall within the fourth order of magnitude (10 – 100 l/s). However, as evidenced by the large total number of springs in the GSI databases (2,000 at the start of the research), it is certain that the largest proportion of springs in Ireland is represented by those with small discharges (< 10 l/s).

The survey showed that spring discharge was highly variable: 83% of springs showed discharge ratios (low flow: high flow) of < 1:5. Of the remaining 6 springs, 4 had discharge ratios just under or above 1:10. The most variable spring surveyed was Killeany, Co. Clare with a discharge ratio of 1:60

The EC of the springs surveyed ranged from 232 – 828 µS/cm. However 70 % of the springs showed readings between 600 and 800 µS/cm. Readings outside this range may be interpreted as groundwater with a significantly higher or lower residence time than normal or the result of the existence of particular geological conditions. The majority (76%) of springs showed higher EC readings under low flow than high flow conditions. For the other parameters measured, temperatures ranged between 8 and 12 °C. pH ranged from 6.8 – 7.9 and dissolved oxygen ranged from 14% to 125% saturation.

The spring survey data were analysed statistically to determine if any relationships exist between the springs in terms of their behaviour and their distribution. For example, to see if springs located in certain limestone lithologies or within particular regions, have particular characteristics. The statistical methods used were limited to non-parametric tests, as the spring datasets were not normally distributed.

The results indicated that there were pronounced differences between the springs surveyed when grouped according to region. Specifically:

- EC range was greater for springs in the West than those in the East and South; and
- temperature range was greater for springs in the West than those in the South.

The differing characters of the regional limestone aquifers in the east, west and south of Ireland may explain the differences in spring variability. In the west, thin glacial overburden, significant amounts of point recharge and the underlying pure bedded limestone are factors which contribute to produce a variable spring hydrochemistry. Conversely in the east of Ireland the low variation in spring chemistry is likely to be a result of the presence of a thick glacial overburden as well as being underlain by argillaceous impure limestones. In the south of Ireland stable spring temperatures may result from deeper groundwater flow and a longer residence time in the complex geology of the faulted and folded limestones.

A second phase of the research involved the selection of 6 springs from those surveyed for continuous monitoring using dataloggers. The selection of the 6 springs was based on the hypothesis that they would be different in their behaviour, as indicated by the preliminary measurements under low and high flow conditions. Two springs were chosen because they showed high variation (between the low and high flow readings) in discharge and conductivity respectively. A further two were selected because of a low variability in parameters while the remaining two were selected for their intermediate variability. The logger data for each of the six springs provided continuous data which could be plotted alongside rainfall data to show the response of the spring to any precipitation events.

Table 1 presents a summary of the data gathered at each of the monitored springs. The coefficient of variation was calculated to allow classification of the springs as per Shuster & White's (1971) categories (where a coefficient of variation of <5% shows diffuse flow fed springs and >10% indicates conduit fed springs). Similarly the frequency distribution was calculated to allow classification according to the method proposed by Bakalowicz & Mangin (1980) (Porous aquifer: unimodal, high conductivity; fractured aquifers: unimodal, low conductivity; and karstified aquifers: polymodal, wide range of conductivity).

The lack of high resolution spring data was the main impediment to making firm conclusions in this research. The use of spot measurements and continuous time series data served to highlight the importance of an appropriate monitoring program for any particular karst spring.

References

Bakalowicz, M. & Mangin, A. (1980) L'aquifère karstique. Sa définition, ses charactéristiques et son identification. *Mem. H. Ser. Soc. Geol.* France, **11**: 71-79.

Drew, D.P. (1990) The hydrology of the Burren, County Clare. *Irish Geography*, **23**(2): 69-89.

Meinzer, O.E. (1927) Large springs in the United States. *U.S. Geological Survey Water Supply Paper 557*. Washington.

Shuster, E.T. & White, W.B. (1971) Seasonal fluctuations in the chemistry of limestone springs: a possible means for characterising carbonate aquifers. *Journal of Hydrology*, **14**: 93-128.

David Drew and Honor Chance *(MSc. TCD 2005)*
Trinity College Dublin

		Bunatober	Sillogue well	Roaring well	Killeany	Toberpatrick	Toberfin
Data from the spring survey	**Basis for selection**	Varied Q	Steady EC	Intermediate Q	Varied EC	Intermediate EC	Steady Q
	EC readings (µS/cm) (range)	629 – 755 (126)	787 – 800 (13)	661 – 674 (13)	232 – 504 (272)	716 – 752 (36)	750 – 765 (15)
	discharge (l/s) from low to high flow (discharge ratio)	82 – 700 (8.54)	65 – 93 (1.43)	92 - 166 (1.8)	8 - 467 (58.38)	9 – 12 (1.33)	18 - 18 (0)
Datalogger derived information	**Dates and total number of consecutive days monitored**	31/07/03 – 05/06/04 310	27/12/03 – 13/04/04 108	7/6/04 – 16/7/04 39	10/8/04 – 9/9/04 30	15/9/04 – 13/10/04 28	22/6/04 – 2/7/04 10*[1]
	mean EC (µS/cm) (mean)	692.56	795.34	677.82	324.63	790.92	821.20
	standard deviation (SD)	43.01	5.97	0.38	17.34	2.53	4.48
	Coeff of var. (mean/SD × 100)	6.2%	0.8%	0.06%	5.3%	0.3%	0.5%
	Frequency distribution type	Polymodal, wide range of EC	Unimodal, high EC	Unimodal, low EC	Polymodal, wide range of EC	Unimodal high EC	Unimodal high EC
External factors	**County & Region**	Co. Galway West	Co. Offaly East	Co. Kilkenny South	Co. Clare West	Co. Kilkenny South	Co. Offaly East
	Geology **Unit name** **Rock unit** **Aquifer category**	Knockmaa PBL Rkc	Borrisokane/ Allenwood PBL Rkd	Killsheelan PBL Rkd	Ballyelly PBL Rkc	Durrow UIL Ll	Lucan (calp) UIL Ll

Table 1 Summary of the hydrogeological attributes of springs monitored continuously for a period.

*[1] Toberfin was monitored by the author initially every 6 hours and subsequently every 24 hours

PBL: Pure bedded limestone
UIL: Upper impure limestone

Rkc: karstified aquifers dominated by conduit flow
Rkd: Karstified aquifers dominated by diffuse flow
Ll: Bedrock which is moderately productive only in local zones

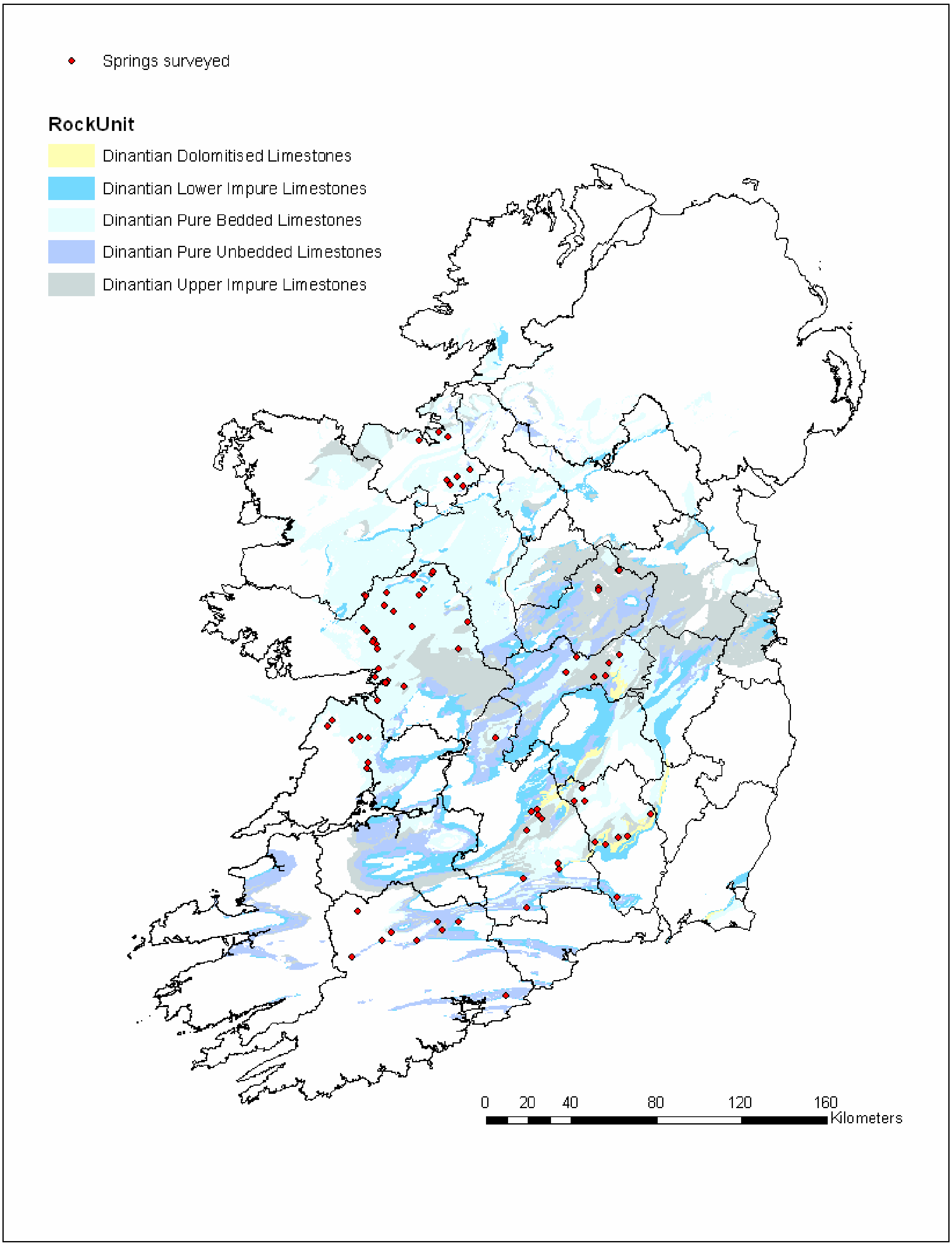


Figure 1 Limestone lithology and the location of the springs surveyed in the eight sample counties

New Irish Water Tracing Database

Karst is a significant aspect of Ireland's hydrogeology as carboniferous limestones underlie more than half the area of the Republic. In a non-karst aquifer, most information about groundwater velocities, flow directions and aquifer storage can be obtained from pumping test data. In karstified aquifers these parameters are extremely difficult to determine by borehole analysis. Karst aquifers often contain open conduit flow paths with hydraulic characteristics more like surface streams than groundwater. Wells rarely penetrate the main conduits of a karst groundwater basin as conduits usually account for only a very small percentage of the aquifer but often contain most of the flow. To get a real idea of aquifer characteristics, especially for these heterogeneous, anisotropic conditions, a special method of investigation is used; water tracing.

Water tracing at its simplest involves 'tagging' water as it enters the karst system and monitoring possible exits to see where it re-emerges. The time the tracers take to get from one point to the other is also usually recorded. Thus, the most common usages of water tracing are the identification of subsurface flow directions, the delineation of underground catchment areas, and the estimation of groundwater flow velocities. Most water tracing is carried out using artificial dyes. For short distances, where the water is restrained to a system of conduits, and there is not much ponding in the underground waterways the colour can be observed coming out at resurgences. In most cases however, this discolouration of the water is not desirable and a water samples are tested for dilute concentrations of the dye using a spectrofluorometer. This type of analysis allows for the determination of dye-break through curves, the shape of which yields large amounts of information about the workings of the karst system.

Stories of water tracing involving the use of chaff or hayseeds have been past down for generations in many parts of Ireland, but it wasn't until the early twentieth century that the first scientific water tracing experiment was conducted. Although many water-tracing experiments have been carried out in Ireland since, the literature is hard to find, often located in obscure caving journals.

A new database attempting to compile and detail water tracing experiments carried out in the Republic of Ireland has recently been established by the Groundwater Section of the Geological Survey of Ireland. The primary purpose of creating this database is to serve as an inventory of known water tracing experiments and to store details of the traces. Data are complied from numerous sources including maps, academic and caving journals, company reports and personal communication. The database is designed for use in a Geographical Information System (GIS), which can be overlain on other data layers. The database is also designed to compliment the existing GSI's karst feature database. Figure 1 shows and example of the water-tracing database for east of counties Galway and Mayo

The database contains specific details for each tracing experiment. There are 20 fields, which can be searched and queried by a certain topic, locality or catchment. These fields are shown in table 1. The database has recently been populated with all known traces and currently contains details of almost 300 individual water traces carried out in Ireland.

An interactive version of the database will shortly be made freely available on the Geological Survey of Ireland website (www.gsi.ie). See article by Gráinne Ni Shé and Monica Lee in this newsletter on page 3 describing the contents of the groundwater web mapping site.

In order to maintain its usefulness it is essential that continued data compilation is sustained. Any existing water tracing data, which has not been already recorded in the database, should be sent to the Groundwater Section of the Geological Survey of Ireland. For further details please contact Caoimhe Hickey at (01) 678 2824.

References:

Gunn J. 1982 Water tracing in Ireland: A review with special reference to the Cuilcagh Karst in *Irish Geography 15: 94-106*

Burke M. 1999 The GSI karst features database in *The GSI Groundwater Newsletter, No. 36*

Hickey C. 2006 Landforms and hydrology of the lowland karst of County Roscommon, Ireland. Unpublished Ph.D. thesis.

Caoimhe Hickey
Groundwater Section, Geological Survey of Ireland

Field Name	Explanation
Input Site	Records the type of input (e.g. swallow hole, sinking stream, turlough) and feature name (if any)
Input Number	Corresponds to the karst feature number from the GSI's karst feature database
Output Site	Records the type of output site (e.g. spring, river) and the feature name (if any)
Output Number	Corresponds to the karst feature number from the GSI's karst feature database
County	Records which county/ counties the trace occurred in
Surface Water Catchment	Records which surface water catchment(s) the trace occurred in
Date	Records the date which the water trace took place
Weather Conditions	Details the weather conditions at the time of trace. For example, high flow conditions, low flow conditions
Tracer Used	Records the type of tracer used. For example optical brightener
Quantity	Records the quantity of tracer used
Operator	Records who carried out the trace
Result	Degree of certainity (e.g.weakly positive, dubious result)
Flow Rate	Minimum flow rate to peak of tracer breakthrough (m/hr)
Hydrological Gradient	Hydrological gradient from input to output
Peak Concentration	Records the maximum tracer concentration observed at the sampling point
True Representation	Records whether trace is considered to be linear (i.e. A goes to B) or via a more complicated route (i.e. A goes to B via C & D)
Data Source	Records the data source of trace
Additional Information	Additional comments about trace, inputs and outputs etc
Flow Path	Describes the suspected flow path (if known)

Table 1 List and explanation of the attributes of the groundwater tracer database

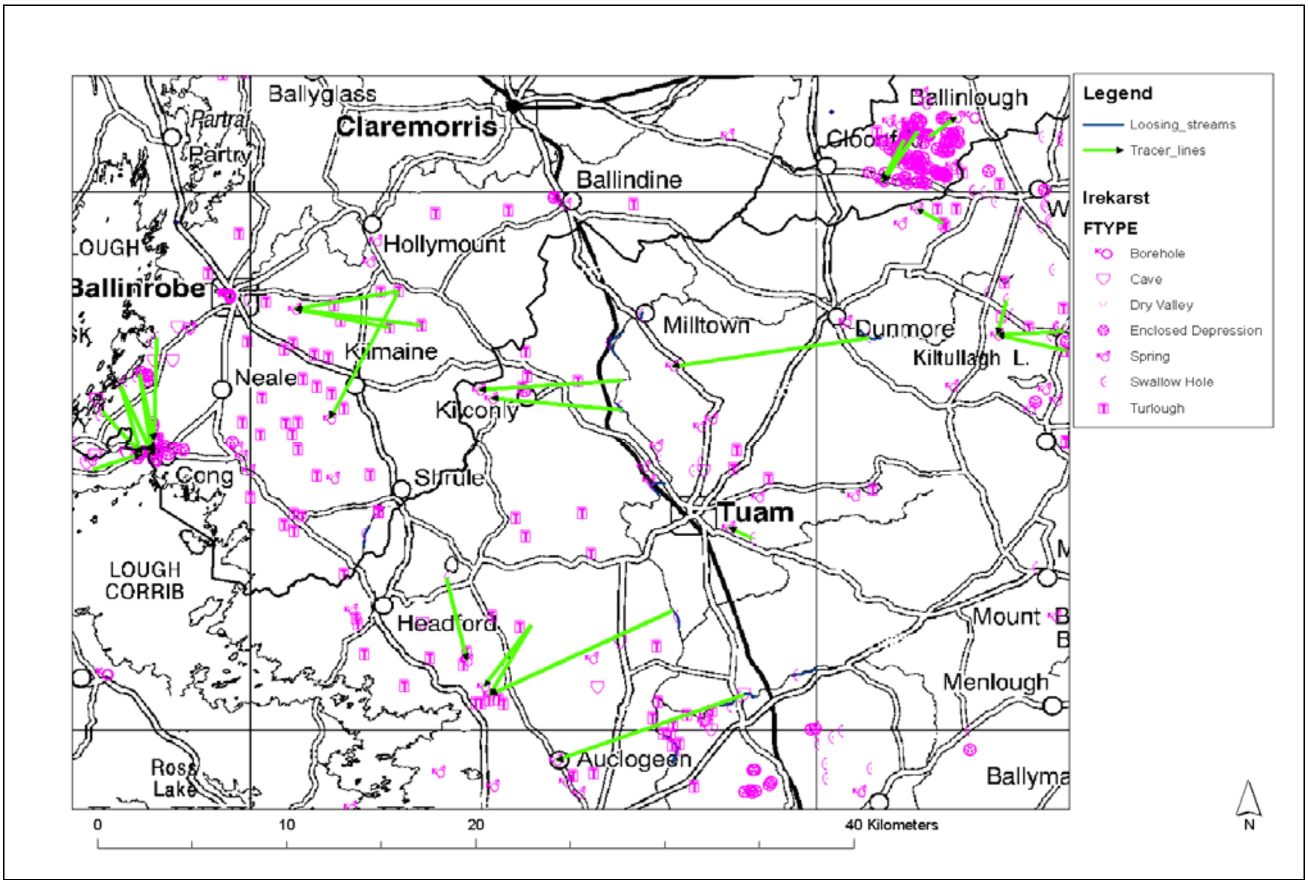


Figure 1 An example of the GSI's groundwater tracing database for east Galway/Mayo

The importance of glacial carry-over in permeability mapping: a note on the permeability of drumlins in Connemara

Introduction.

Drumlins were first noted as a significant feature of the Connemara granite landscape in 1872, when Kinahan and Close summarised the glacial history of Connemara for the first time. Since then Hallissy (1914), Charlesworth (1929), Mitchell (1957, 1960), Synge and Stephens (1960), Farrington and Stephens (1964), Synge (1969) and Orme (1967) have all improved the accuracy of the drumlin landform mapping, as well as furthering our understanding of the significance of the drumlins in terms of ice flow and related glacial models. Recently, the exact spatial location of drumlin tills protruding through the Connemara peat has been mapped at 1:50,000 scale (Teagasc Soil and Subsoil Mapping Project, 1998-2005). Within all these spatial studies, little attention has been paid to the characteristics of the sediment which comprises the drumlins and the overall permeability of the features themselves, and its hydrogeological significance, has been neglected. McCabe (2005a, b) and Warren (1992) did examine some aspects of the sedimentology of the features, but this was used to infer models of glacial deposition, rather than advancing knowledge of the sediment characteristics.

Subsoil permeability.

The GSI Vulnerability Mapping Guidelines (Fitzsimons *et al.*, 2003) outlines the approach taken in subsoil permeability. This is a holistic method involving:

- field description/classification/analysis of texture using BS 5930;
- sampling and detailed grain size analysis at 'type' localities;
- examination of soil type, particularly presence or absence of mottling;
- presence or absence of wetland vegetation indicators in the areas examined;
- data on artificial and natural drainage density;
- parent bedrock characteristics and;
- topographic data.

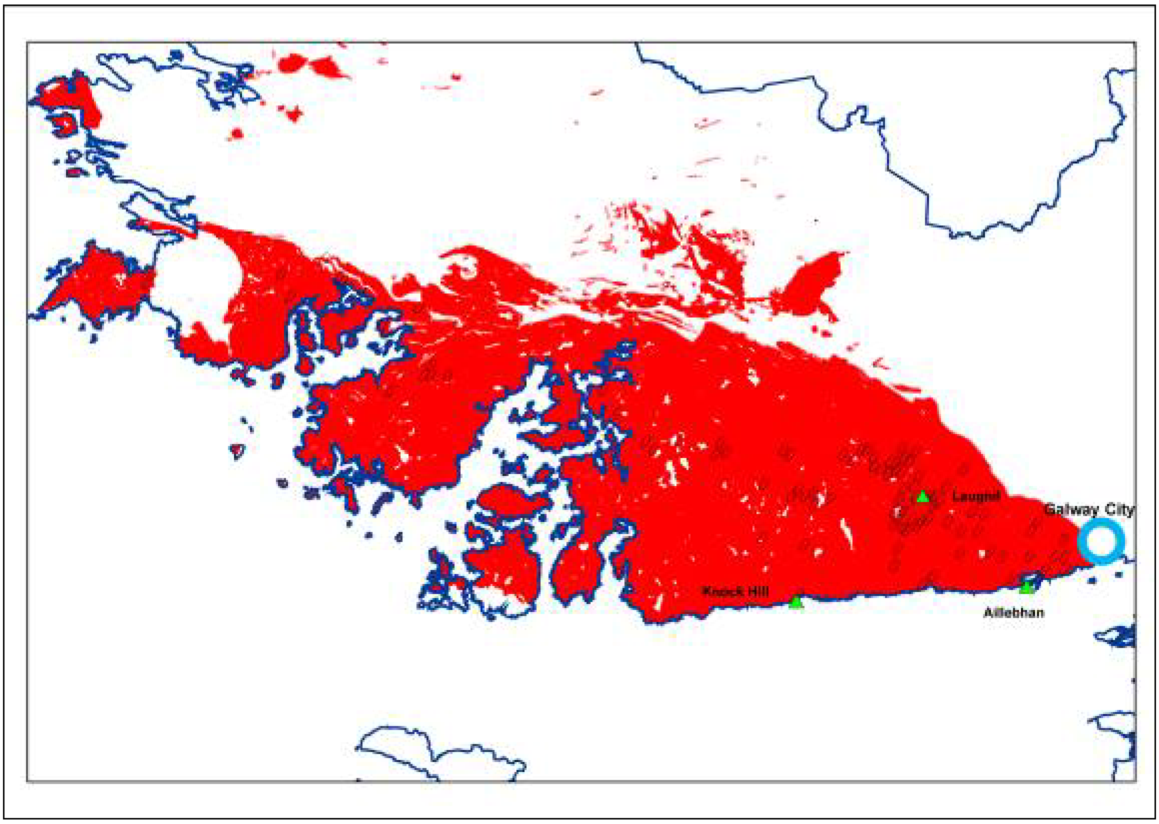


Figure 1: Location of drumlins on granite bedrock in Connemara, as well as site locations.

High permeability subsoil materials are sands and gravels that, if sufficiently saturated and areally extensive, are capable of constituting aquifers. Moderate permeability subsoils are silty to sandy glacial tills that are generally quite free draining, except in lowlying areas and/or areas of groundwater discharge. Low permeability subsoil materials are clayey tills, peats and lake clays that allow less than 20% recharge acceptance, regardless of thickness or saturation conditions. Generally those subsoils with 12% or more CLAY as a percentage of the non-gravel (<20mm) particle size fraction fall into a low permeability category.

Description of sediment exposures and permeabilities.

The permeability characteristics of the sediment within three drumlins in Connemara, all on granite bedrock, are outlined here. Two of these drumlins are well exposed at the coast: the other is inland and was quarried for fill historically. Each drumlin consists of 'lodgement[3]' till which is very fissile (easy to split along close parallel planes). Two of the three have developed preferential flowpaths along the fissile structures (to such a degree that the features' sediments are almost stratified). From the three features we can infer much about the essential determinants of the permeability of till at a particular location, as well as relate the characteristics to ice processes and depositional history, and the importance of the bedrock geology in the related ice-moulding of the landscape during glacial periods.

Drumlin 1: Aillebhan, Barna (NGR 125065 222769).

The Aillbhan drumlin is oriented north-northeast to south-southwest and has been deposited by ice flowing along that plane, from the area now occupied by Lough Corrib, across the southeastern extreme of the granite bedrock, and out into Galway Bay. The coastal section cut into the drumlin is just over five kilometres down-ice of the nearest limestone bedrock source.

At the Aillebhan section, between 4m and 15m of till deposited at the base of a glacier is exposed in a coastal cut. The section is dominated by units of grey, very stiff to hard till, interbedded with subhorizontal silt and fine sand lenses and beds, with some gravel beds at the base of the section. Though beds of sorted sediment are common throughout the profile, the permeability is governed chiefly by the till units.

The matrix within these units is comprised of a SILT (2, 2, 1 threads; 60mm, 90mm, 100mm ribbons; strongly dilatant). As this material is raspy the till is classified as a **gravely sandy SILT**. The grain-size analysis shows 41% SAND, 49% SILT and 10% CLAY. The soil profile is difficult to access but the soil seems to be a well drained basic soil (brown earth hi-base status or a grey-brown podzolic). The landcover on the drumlin is of dry, unimproved grassland with no drainage ditches or rushes in evidence.

The clasts within this drumlin are dominated by limestone (over 90%). Granite and metamorphic clasts comprise the rest of the material. The till is alkaline with strong effervescence when exposed to dilute hydrochloric acid.

The sequence is interpreted as a crushed till almost totally dominated by limestone which has been subglacially transported from its limestone source to the north-northwest over the granite scarp, and deposited directly on the granite bedrock. The permeability of the till is interpreted as being **moderate**.

Drumlin 2: Knock Hill, Spiddle (NGR 108717 221963).

The drumlin at Knock Hill is oriented just east of north to just west of south and has been deposited by ice flowing along that plane, from central Connemara across the granite bedrock, and out into Galway Bay towards Inisheer. Here the section cut into the drumlin is over seventeen kilometres down-ice of the nearest erratic bedrock source.

At Knock, between 1m and 10m of lodgement till is exposed in a coastal section. The section is dominated by units of light yellowish brown, very stiff till, interbedded with subhorizontal silt and fine sand lenses. Though beds of sorted sediment are common throughout the profile, the permeability here is also governed chiefly by the till units.

[3] Lodgement' till is glacial sediment deposited by plastering of debris from the sole of a glacier by pressure melting or other mechanical processes.

Plate 1: Light yellowish brown till dominated by granite exposed in drumlin long-section at Knock.

Plate 2: Drumlin protruding above the surrounding peat at Laughil. Upon first impression the drumlin appears well drained, but rushes occur in the fields to the right of the white house, the soil is gleyed from augering, and the material encountered in a borehole here is CLAY

The matrix within these units is comprised of a sandy SILT (2, 1, 2 threads; 40mm, 60mm, 50mm ribbons; strongly dilatant). As this material is raspy the till is classified as a **gravely sandy SILT,** with the sand being particularly coarse. The grain-size analysis shows 56% SAND, 39% SILT and 5% CLAY. The soil varies depending on the position on the drumlin but both podzols and acid brown earths occur[4]. The landcover on the drumlin is of dry, unimproved grassland with some gorse and no drainage ditches or rushes in evidence.

Unlike the situation at Aillebhan, the clasts within this drumlin are completely dominated by local granite (over 95%). Some rare erratics of limestone are present, and the till is acidic.

The sequence is interpreted as a crushed till dominated by granite which has been subglacially transported from its granite source in mid-Connemara and deposited on the granite bedrock at Knock. The colour and texture of this till is of the type expected from a 'pure' granite source. The permeability of this till is also interpreted as being **moderate**.

Drumlin 3: Laughil, Moycullen (NGR 117806 229357).

The Laughil drumlin is oriented northeast to southwest and has been deposited by ice flowing from the area now occupied by Lough Corrib, across Moycullen and up onto the granite scarp, and into mid-Connemara. The quarry section cut into the drumlin is five kilometres down-ice of the nearest limestone bedrock source, but is also just over five kilometres down-ice 'regionally' of metamorphic schists, gneisses and quartzites.

At the Laughil section, between 2m and 10m of lodgement till is exposed in a pit section. The section is dominated by units of stiff, brown till with no interbeds.
The matrix within these units is comprised of a CLAY (7, 5, 7 threads; 90mm, 100mm, 100mm ribbons; non-dilatant). As this material is raspy the till is classified as a **gravely sandy CLAY**. The grain-size analysis shows 50% SAND, 38% SILT and 12% CLAY. The soil profile is variable but is comprised of gleys or peaty gleys with peat depths above 1m in some localities. The landcover on the drumlin is of wet grassland with few drainage ditches, but with rushes prevalent on slopes.

The clasts within this drumlin are dominated by almost equal proportions of granite and limestone rocks. Metamorphic rocks are also common.

The sequence is interpreted as a crushed till comprising local granite, as well as limestone and metamorphic rocks which have been subglacially transported from the area to the north. The permeability of the till is interpreted as being **low**.

Discussion and conclusions

From the three exposures we see that:

- The permeability of the tills within the drumlins varies depending on the exact bedrock source crushed, transported and deposited by the glacier;
- The permeability of subglacial tills is predominantly directly related to the underlying bedrock only at a considerable distance down-ice of another large bedrock body;
- The carryover of erratic material which effects the macro-permeability of subglacially deposited tills is at least five kilometres, and probably quite a distance more;
- Till derived from predominantly pure limestone or granite **in Connemara** crushes to a SILT matrix, whereas till derived from granite in a mixture with metamorphic and limestone rock crushes to a CLAY.

[4] Both these soil types are well drained with leaching/throughflow dominating the soil formational process.

In examining the drumlins regionally throughout southern Connemara, they are predominantly situated in the northern portion of the granite bedrock area, with fewer features southwards towards the coast (see Figure 1). In total, out of *c.* 100 features on granite bedrock mapped using permeability indicator criteria in summer 2006 (presence of wetland indicators and drains, poorly drained soils), about 90 are mapped as CLAY dominated features (generally in this northern area), with 10 mapped as limestone derived SILT (around and immediately west of Galway City), and only 2 are derived from granite derived SILT (both along the south coast road along the Bay). From this, the relationship between the carry-over within the sediments comprising the features is clearly seen, and highlights the importance of a knowledge of soils and glacial history in mapping permeability in Irish tills. As well as this, it can be postulated that the maximum distance whereby an 'erratic' till 'loses' its dominance with respect to permeability is in the order of around ten kilometres.

References:

Charlesworth, J.K., 1929. The glacial retreat in Iar Connaught. Proceedings of the Royal Irish Academy, **39B, pp. 95-106**.

Farrington, A. and Stephens, N., 1964. The Pleistocene Geomorphology of Ireland. In Steers, J.A. (ed.) *Field Studies in the British Isles*. **Thomas Nelson and Sons Ltd., London.**

Fitzsimons, V., Daly, D and Deakin, J., 2003. GSI Guidelines for Assessment and Mapping of Groundwater Vulnerability to Contamination. **Groundwater Section, geological Survey of Ireland,75pp.**

Hallissy, T., 1914. Clare Island Survey, Part 7. Geology. Proceedings of the Royal Irish Acedemy, **31(1), part 7, 22pp. plus plates and figures**.

Kinahan, G.H. and Close, M.H., 1872. The general glaciation of Iar Connaught and its neighbourhood in the counties of Galway and Mayo. **Hodges, Foster and Co, Dublin, 20pp.**

McCabe, A.M., 2005a. AMS ^{14}C chronology/ ice sheet model for western Ireland. In Coxon, P. (Ed) '*The Quaternary of Central and Westerm Ireland'*. **QRA Field Guide, pp. 25-34.**

McCabe, A.M., 2005b. Barna drumlin. In Coxon, P. (Ed) '*The Quaternary of Central and Westerm Ireland'*. **QRA Field Guide, pp. 64-70.**

Mitchell, G.F., 1957. The Pleistocene Epoch. In J. Meenan and D.A. Webb (Eds.) '*A view of Ireland*', **pp. 33-39**.

Mitchell, G.F., 1960. The Pleistocene History of the Irish Sea. Advancement of Science, **68, pp. 313-315**.

Orme, A.R., 1967. Drumlins and the Weischel Glaciation of Connemara. Irish Geography, **5, pp. 262-274**.

Synge, F.M., 1969. The Wurm Ice limit in the west of Ireland. In: Quaternary Geology and Climate, **Publication 1701, pp. 89-92, National Academy of Sciences, Washington**.

Synge, F.M. and Stephens, N., 1960. The Quaternary Period in Ireland – an assessment, 1960. Irish Geography, **4, pp. 121-130**.

Warren, W.P., 1992. Drumlin orientation and the pattern of glaciation in Ireland. Sveriges Geologiska Undersoking**, 81, 359-366**

Dr. Robert Meehan,
Geological Survey of Ireland

Results from recent research into on-site wastewater treatment

There has been rising concern into the pollution caused by septic tanks and other on-site wastewater treatment systems in Ireland over the last few years, particularly due to the well publicised, burgeoning number of one-off developments in unsewered rural areas. However, little field research has been carried out into the effectiveness of on-site treatment with respect to groundwater protection and hence a three year research project was commissioned by the EPA entitled, *"An investigation into the performance of subsoils and stratified sand filters for the treatment of wastewater from on-site systems"*, the results of which were published last year (Gill et al., 2005).

The treatment of effluent from a domestic dwelling is carried out by a combination of a pre-manufactured unit process (septic tank, filter system, BAF, RBC etc) and then – and in many ways more importantly - within the subsoil as the effluent percolates down through the matrix en route to the water table. Hence, the project was conceived to research the pollutant attenuation efficiency of the subsoil with respect to both depth of the subsoil and also laterally across the percolation area. Different subsoils were investigated receiving different quality (septic tank or secondary treated) wastewater effluent.

Site set-up and installation

This study involved four separate, intensively monitored sites: two receiving effluent from septic tanks (Sites 1 and 3), the other two receiving effluent from two secondary treatment peat filters (Sites 2 & 4). Sites 1 and 2 were both in Kildare with T-values of 15 and 29 whilst Sites 3 and 4 were in Wicklow with T-values of 33 and 52 respectively. In addition, the effluent on Sites 3 and 4 was split with half directed to percolation trenches and the other half passing to stratified sand filters in order to provide a direct comparison and evaluation of this treatment option.

An interesting statistic that emerged early on in the project while looking for suitable sites was that out of a total of 74 sites assessed (all in Leinster), only 4 were deemed suitable for the project (i.e. having T values between 5 to 60 and greater than 2m depth of unsaturated subsoil). The most common reason for rejection of over 50% of the sites was high water tables which is perhaps indicative of the vulnerability of groundwater in Ireland. It must be considered, however, that it would have been possible to design a solution for many of these sites rejected for the research project, for example by raising the percolation area, such that they would be compliant with the EPA guidelines and thereby suitable for the on-site treatment of domestic wastewater.

The four chosen sites were constructed in exact compliance with the EPA 2000 guidelines (trench lengths and widths, pipe gradients, gravel and sand specifications etc) and all surface water was diverted away from the foul network. The stratified sand filters were 1.05 m deep, consisting of three layers of coarse, medium and fine sand media, decreasing in size with depth. Each percolation area was intensively studied for one year with soil moisture samples taken at three nominal depths below the invert of the percolation trenches (0.3, 0.6 and 1.0 m) at several different locations across the area. Meteorological variables were continuously recorded to calculate recharge and thus dilution of effluent at depth in the percolation area. In addition, tensiometers were installed across the area to measure the soil moisture pressure.

A pertinent adjunct to the description of these tightly controlled research sites is that in the author's experience of installed on-site systems, it is common to find roof gutters illegally connected to the wastewater system, significantly increasing the hydraulic load to percolation areas. Other common installation problems include: too few and/or too short percolation trenches for the premises; an uneven distribution of effluent between percolation pipes, often with all the flow going down one trench; land drain pipe being used instead of percolation pipe which quickly blocks up with biofilm; and poor pipe connections into and out of septic tanks resulting in effluent dribbling down the side of tank and thereby not making it to the percolation area. It is clear therefore that all too often the installation stage of on-site wastewater treatment leaves a lot to be desired, a problem that urgently needs to be addressed. Positive moves have been made over the last few years regarding the site assessment procedure with the development of the FAS course and many county councils have now made the qualification a pre-requisite for assessors on their panels. But if the carefully formulated designs are not being put into the ground then the overall system is still failing, placing both ground and surface water resources at risk. It is recommended that an independent check of all pipework, inverts, connections etc should be required by a qualified person before the work can be signed off and completed.

Project results

In general, the research showed that a properly constructed septic tank and percolation area provided a comparable treatment performance with respect to groundwater protection as a packaged secondary treatment system and percolation area (O'Súlleabháin, 2005). However, a notable finding was that the development of a biomat across the percolation areas receiving secondary treated effluent was muted on these sites compared to the sites receiving septic tank effluent. On Sites 2 and 4 the effluent was shown to have only reached one quarter of the length of each percolation trench after one year. This result is not surprising as the organic load in the wastewater (the food for the microorganisms in the soil) is significantly removed in the secondary treatment process. The consequence of this is a more concentrated hydraulic loading at the front of the trenches compared to the sites receiving septic tank effluent where the effluent is more evenly spread over the whole percolation area. So, even though the concentrations of organics and microorganisms were significantly lower in secondary treated effluent, the higher hydraulic loading (and consequential high pollutant mass loadings) resulted in a similar quality of effluent at depths of 0.6m of subsoil beneath the percolation trenches when compared to the sites receiving the septic tank effluent. Another important discovery was that there were much higher nitrogen loads at the 1.0m sampling plane beneath the secondary treated effluent sites compared to the equivalent septic tank sites. The total nitrogen load is not reduced in the secondary treatment processes, rather it just changes form from ammonia and organic nitrogen into nitrate. This nitrate then percolates down through the subsoil in a relatively concentrated plume without any significant reduction. The processes in the more developed biomats in the percolation gravel and subsoil receiving septic tank effluent, however, appear to be suitable for both nitrification of the effluent and then subsequent denitrification, resulting in a significant reduction in total nitrogen loading. The balance of compounds contained in septic tank effluent is more akin to the normal waste products deposited on the ground by animals which are degraded by natural processes thereby cycling elements such as carbon and nitrogen round the ecosystem, compared to the modified effluent from a typical secondary treatment process which has been stripped of much of its organic load. It would appear therefore that nature, as is often the case, knows best. The removal of the other nutrient of interest, phosphorous, appeared to be dependent on the soil type through which the effluent percolates, and in particular the clay content and also presence of Al, Fe and/or Mn as dissolved ions or oxides.

The other parameter of particular concern from a groundwater protection perspective is the ability of the subsoil and associated biomat to remove enteric bacteria from the percolating effluent. The results of the bacteriological analysis showed that, as expected the installation of the secondary treatment system greatly reduced the bacterial load. The septic tank effluent had average *E. coli* concentrations of 5 x 10^5 cfu/100ml (with total coliforms at 7 x 10^8 cfu/100ml) compared to average *E. coli* concentrations in the secondary treated effluent of 8 x 10^3 cfu/100ml (total coliforms at 4 x 10^5 cfu/100ml). However, there was little evidence of contamination after 1.0m depth of subsoil on any of the four sites with the exception of two isolated incidences of low concentrations of *E. coli* on Site 1 receiving septic tank effluent and one incidence of *E. coli* obtained from the secondary treated effluent on Site 2.

It should be stressed that the sites were only monitored for one year and further research is needed to determine the development of the biomat over longer time frames. An ongoing EPA funded project entitled, "*The effective distribution of on-site wastewater effluent into percolation areas via distribution boxes and treatment by reed beds compared to attenuation of pollutants in sandy subsoils",* is currently evaluating two sites in a similar manner but this time the sites have T-values of between 1 and 5 and the sites will be monitored for a minimum of 2 years. At the time of writing after 11 months of operation, a similar pattern is being observed with a much reduced biomat formation on the site receiving secondary treated effluent compared to the site receiving septic tank effluent.

These results suggest that in situations where T-values are suitable and there is at least 1.2m of unsaturated subsoil to the bedrock or water table, a septic tank should be specified rather than the intuitively conservative call for secondary treatment plants which seems to be the tenet of some county councils at present. A septic tank provides a more sustainable long-term solution in such circumstances as it does not require any energy to run it and the bemoaned lack of maintenance agreements with manufacturers of secondary systems (which typically lapse after their first year), mean that many of these systems will effectively evolve into under-sized septic tanks over time. However, as discussed above and covered in a previous article in GW newsletter no. 43 (Gray, 2004) attention must be paid to the correct installation of these units to prevent leaks.

Other findings from the research were that no discernible differences in treatment performance were found between the sites of different percolation characteristics – which is one of the reasons for the follow-up project looking at faster percolating sites with T-values in the range 1 to 5. The wastewater generation was accurately measured continuously throughout the trials at each site and was found to be much lower than EPA guideline value of 180 lcd (litres per capita per day). When the two sites currently being monitored are included, an average value of approximately 100 lcd would seem to be more appropriate, although one site did produce an average flow of 146 lcd. It should be noted that the higher guideline value of 180 lcd would take into account the fact that, in reality many houses also have illegal storm water connections. It was also noticed that the concentration of effluent from the septic tanks proved to be on the high side when compared to the ranges given in the new CEN European standards, presumably due to the low wastewater generation experienced at the sites.

The stratified sand filters on Sites 3 and 4 performed slightly better compared to the percolation areas for both septic tank and secondary treated effluent. However, it is recommended that the loading rate for a sand filter receiving septic tank effluent should be reduced to 30 l/m^2d but kept at 60 l/m^2d for tertiary treatment applications. There were also difficulties sourcing the sand in Ireland according to the specification and so it is recommended that the design in the EPA guidelines should be slightly modified to allow indigenous sand to be used.

Finally, it was found that current distribution boxes available on the Irish market do not distribute effluent effectively and a functional design needs to be specified in the EPA guidance manual. Again, this is being focused on in the current research project whereby different devices from around the world are being evaluated both in the controlled laboratory environment using clean water and also out on site under real effluent conditions. The faith in the performance of any correctly designed on-site treatment system is based upon the assumption of an equal loading of effluent across the percolation area which is obviously not the case if all the effluent is passing down one trench.

Nitrogen loading and the Nitrates Directive

As discussed, the main difference found between the percolation areas receiving septic tank and secondary treated effluent was the potential for higher nitrogen loadings to groundwater for the latter system. A lot of attention has been paid recently in the media in Ireland to the introduction of the Nitrates Directive and so it is worth considering the role of on-site treated effluent in terms of its addition of nitrates to groundwater. The E.U. Nitrates Directive 91/676/EEC states that the annual limit for nitrogen application to ground is 170 kg-N/ha equating to a stocking rate of 2 cows per hectare. This application is to the ground <u>surface</u> and presumably the intention of the application limit is that the majority of the nitrogen is picked up by the plants with little making it down to the groundwater. Indeed, the results from a recent EPA funded project (Bartley, 2003) showed that approximately 10% of total-N applied at the surface from dairy cows made it to the groundwater. This is not the case, however, with on-site wastewater effluent which is introduced into the subsoil typically at depths of 0.6 to 1.0m below the ground surface and so is not picked up by the vegetation. This nitrogen will thus percolate to the groundwater if not transformed into nitrogen gas by the natural processes in the vadose zone.

The results from the project showed that the average total inorganic nitrogen load after 1.0 m depth of unsaturated subsoil, was 14.7 g-N/d for the sites installed with secondary treatment systems compared to 3.1 g-N/d on the sites receiving just septic tank effluent. If these figures are scaled up to annual loading rates, a minimum total site area per household can then be calculated which would equate to the Nitrate Directive limit of 170 kg-N/ha. This can be used to determine the maximum housing density that should be permitted, above which on-site disposal of effluent to ground is likely to be in breach of the Directive. If a conservative estimate is taken that the application limit stated in the Directive allows for a maximum of 10% of the total-N applied at the surface to make it past the root zone to the groundwater, a simple calculation yields that a maximum density of one household (4 person) every 0.32 ha (~0.8 acre) for secondary treatment on-site systems would be at the nitrogen loading limit. This is compared to a minimum plot size of 0.07 ha per house using septic tank systems. This implies that realistically the density of houses using properly installed septic tanks is not going to get to the point which will promote concern with respect to Nitrates Directive whereas a continuity of single acre plots using secondary treatment systems is perhaps a more realistic scenario. In such cases this research would indicate that the councils should be considering moving away from the on-site disposal of wastewater towards the development of a sewered system and centralized treatment facility. Finally, if the annual nitrogen loading is calculated on the percolation area alone, it equates to 342 kg-N/ha.yr for the secondary treated systems which does exceed the nitrate application guidelines. This can be compared to 58 kg-N/ha.yr for a household discharging to a septic tank and percolation area.

Conclusion

The results from the project and ongoing results from current projects indicate that under suitable conditions septic tank systems perform similarly to secondary treated systems. Hence, the position taken by some county councils to insist upon secondary treatment systems where suitable conditions exist for septic tanks systems would not appear to be the most sustainable option due to ongoing energy requirements and higher maintenance demands for such systems, which are rarely met. The research also shows that, in the first year of operation at least, the nitrogen loading to the groundwater from the percolation areas receiving secondary treated effluent was approximately four to five times that from the equivalent septic tank percolation areas. One implication of this is that the manufacturers of secondary treatment package plants should be encouraged to incorporate a denitrification process into their systems in order to reduce the nitrogen loads in the effluent before it is discharged to ground. Finally, it should be re-emphasised that these research results have come from carefully installed and closely monitored on-site systems, where great care has been taken to ensure an even distribution of effluent across each percolation area. Unfortunately this does not appear to be the reality on the ground for many of the existing on-site wastewater treatment systems in use today.

References

Bartley, 2003. *Nitrate responses in groundwater under grassland dairy agriculture.* PhD Thesis. Department of Civil, Structural & Environmental Engineering, Trinity College Dublin.

Gray, N.F., 2004. *Septic tank design and installation: observations and recommendations.* GSI Newsletter No. 43 (October 2004). The Geological Survey of Ireland.

EPA, 2000. *Wastewater Treatment Manuals: Treatment Systems for Single Houses*, Environmental Protection Agency, Wexford, Ireland.

Gill L.W., O'Súlleabháin C., Misstear B.D.R, Johnston P.J., 2005. *An investigation into the performance of subsoils and stratified sand filters for the treatment of wastewater from on-site systems* – ERTDI Report Series No.9, Wexford, Environmental Protection Agency [ISBN 1-84095-154-0].

O'Súlleabháin C., 2005. *The attenuation capacity of different subsoils receiving domestic wastewater effluent.* PhD Thesis. Department of Civil, Structural & Environmental Engineering, Trinity College Dublin.

Laurence Gill
Department of Civil, Structural & Environmental Engineering
Trinity College Dublin

Research into the health risks associated with private well supplies in Ireland

As readers of this Newsletter will be aware, a water well can provide a safe, reliable and inexpensive source of water supply to a private household - provided that care is taken in the location, design and construction of that well. Unfortunately, many wells in Ireland are poorly sited and constructed, resulting in potential health risks to the consumer. The health risks associated with a well supply depend on a variety of factors, including: the type of contaminant; the contamination source and loading rate; the design, location and construction of the well scheme; the presence or absence of water treatment, notably disinfection (usually absent in private well schemes); and the awareness (or lack of awareness) of the health risks amongst the consumers.

The main water contaminants of concern in terms of health are microbiological pathogens.

These include:

- bacteria, such as verocytotoxigenic *Escherichia coli*;
- viruses, including rotavirus;
- protozoa, notably *Cryptosporidium parvum*.

There is a wide range of illnesses that may result from waterborne microbial infection. The most common illness is generalised acute gastrointestinal illness (AGI). Symptoms of AGI include nausea, vomiting and diarrhoea. Most microbial-related illnesses are relatively minor and of short duration, but some AGI cases can be severe or even fatal, especially amongst the elderly, the very young and the immuno-compromised. The main sources of pathogens in water are human and animal sewage.

There are estimated to be about 138,000 households in Ireland that have a private water source, the vast majority of which are located in rural areas (Central Statistics Office, 2004). Additionally, there are in the region of 50,000 dwellings obtaining their water supply from a private group water scheme (PrGWS). Most of the private sources are wells, and the majority of PrGWSs also obtain their supply from a groundwater source.
Although the data available for private wells are sparse, there has been some monitoring of the PrGWSs in the last decade. The EPA report on drinking water quality in Ireland for the period 2003-2005 indicated that approximately 30% of groundwater and spring samples tested contained faecal coliforms, with 36.1% of PrGWS testing positive for *E. coli* during the year 2005 (EPA, 2006). These are worrying statistics, and perhaps of equal concern is the lack of corresponding information for small private supplies.

Given that the majority of private groundwater supplies in Ireland are untreated, the water quality situation with respect to private sources for individual dwellings is likely to be worse than for PrGWSs. In the USA, for example, up to half of all drinking water wells tested in recent studies showed evidence of faecal contamination, and it is estimated that there are between 750,000 and 5 million illnesses per year attributable to groundwater-based community water supply schemes – and perhaps between 1,400 and 9,400 deaths per year (Macler and Merkle, 2000). Using a similar approach to that applied in the USA, Vaury (2003) tentatively estimated that there could be in the region of 94,000-137,000 waterborne illnesses per annum in Ireland attributable to consumption of water from private wells and group water schemes; however, there were significant uncertainties involved in this computation.

The purpose of the current research is to investigate in more detail the scale of the health risks associated with the many small private well supplies in Ireland. It is also proposed to prepare guidelines for the owners of private dwellings, explaining how they can assess the risks to their own water supply, how they can make improvements, and giving advice on locating and developing new water sources. This research is particularly timely, given the significant increase in numbers of "one-off" housing developments in Ireland over the past 10 years and the likelihood that this trend will continue.

The specific objectives of the research are as follows.

Objective 1: To undertake a quantified assessment of the magnitude of risk to health from contamination of private well supplies in Ireland

This initial, overall risk assessment is based mainly on microbial contamination of water supplies. The data needed include:

- percentage of wells with evidence of microbial contamination;
- selection of appropriate pathogens for risk assessment (e.g. rotavirus, *cryptosporidium parvum*);
- contribution and infection/illness rate for the selected pathogens;
- number of people exposed, including percentages of particularly sensitive groups (elderly, young, immuno-compromised);
- water consumption for different population groups.

This initial risk assessment is relying on existing water quality data for Ireland. Sources of data include: the EPA, the Geological Survey of Ireland, local authorities, environmental health officers and third level institutions. Information on pathogen recovery rates, infection rates etc is being derived from Irish sources where available, augmented by data from international studies such as Gerba *et al.* (1996), Macler and Merkle (2000), Buchanan *et al.* (2000), Lammerding and Fazil (2000), Abbaszadegan (2001) and Vose (2001).

This overall risk assessment will provide the context for the more detailed analyses below.

Objective 2: To investigate the link between the contamination risk, and hence health risk, and the groundwater vulnerability category.

The groundwater vulnerability assessment will be based partly on the aquifer vulnerability maps prepared by the Geological Survey of Ireland, which show extreme, high, moderate and low vulnerability categories. The assessment will also take account of other factors that affect the susceptibility of a well supply to contamination, including the type of well construction (e.g. whether or not the well head is protected from pollution). The aim is to link the available evidence of groundwater contamination with the assessment of groundwater susceptibility. Existing data will be supplemented by a limited amount of field sampling and on-site susceptibility assessment. The study sites are currently being identified with the aid of a site selection matrix.

This phase of the research will enable the overall risk assessment completed under Objective 1, to be to extended and refined to indicate the health risk associated with each susceptibility situation. This will aid in the preparation of the guidance document referred to under Objective 4.

Objective 3: To carry out a survey to determine the awareness amongst private well owners of the health impacts from contaminated water supplies

Key steps in improving public health are to find out how aware the public are of particular health risks, and then to provide appropriate education. In the case of small rural water schemes, the level of awareness about the health risks associated with contamination of drinking water is thought to be low. The general public does not have a good understanding of the concepts of groundwater occurrence and movement, and hence of the contamination and health impacts that can result from on-site wastewater systems, farmyard pollution and so forth. Many of the wells constructed in Ireland are not constructed with pollution risks in mind. If the potential well owner appreciates the risks, then he/she is likely to seek a better product from the contractor.

Under Objective 3, surveys of private well owners will be carried out in selected areas. A questionnaire is currently being developed for these surveys. The aim of these surveys will be to assess the present situation with respect to the susceptibility of the existing well (and hence contribute to Objective 2), and to gauge the understanding of the well owner about the relationship between pollution risk, water source and health. This information will provide essential background for developing the guidelines under Objective 4.

Objective 4: To develop guidelines for the owners of new and existing wells on the location, construction and operation of well schemes, so as to reduce the adverse health impacts in the future

The proposed guidelines will cover:

- an introduction to the health risks associated with a contaminated water supply, and hence an explanation of the importance of minimising these risks;
- a section on how to assess the pollution risks to an existing well scheme;
- considerations in the siting of a new well, including an introduction to the concepts of

groundwater vulnerability and assessing the risks of pollution;

- the basic concepts of the design and construction of a new well;
- some guidelines on what to look for in the selection of a drilling contractor;
- collecting and sending water samples for testing;
- an introduction to treatment options, if needed;
- considerations in the operation and monitoring of a domestic water supply from a private well source.

These guidelines will be aimed specifically at the private well owner. The guidelines will complement existing or proposed guidelines or standards on water wells, including the *Water Wells Drilling Guidelines* to be published shortly by the Institute of Geologists of Ireland.

If any readers have data that are potentially relevant to this project, the authors would be grateful if they could contact Paul Hynds at: hyndsp@tcd.ie.

Acknowledgements
This research is being carried out under the remit of the Environmental Protection Agency ERTDI Programme 2000-2006, entitled 'Enhancing Human Health through Improved Water Quality', an interdisciplinary research programme launched in March 2006.

References

Abbaszadegan M (2003) Occurrence of viruses in groundwater in the United States. *Journal of the American Water Works Association*, 95(9)

Buchanan RL, Smith JL and Long W (2000) Microbial risk assessment: Dose-response relations and risk characterisation. *International Journal of Food Microbiology*, 58: 159-172

Central Statistics Office (2004) *Census 2002 Report, Volume 13 – Housing* Government of Ireland, 2004

Environmental Protection Agency (2006) *The Quality of Drinking Water in Ireland: A Report for the Year 2005*. Environmental Protection Agency (Office of Environmental Enforcement), 2006

Gerba CP, Rose J and Haas C (1996) Sensitive populations: Who is at the greatest risk? *Journal of Food Microbiology*, 30: 113-123

Lammerding AM and Fazil A (2000) Hazard identification and exposure assessment for microbial food safety risk assessment. *International Journal of Food Microbiology*, 58: 147-157

Macler B and Merkle J (2000) Current knowledge on groundwater microbial pathogens and their control. *Hydrogeology Journal*, 8(1) 2000: 29-40

Vaury E (2003) *Microbiological Contamination of Groundwater in Ireland*. Unpublished BAI dissertation, Department of Civil, Structural and Environmental Engineering, Trinity College Dublin.

Vose D (2001) *Risk Analysis: A Quantitative Guide*, 2nd Ed. J. Wiley & Sons Ltd.

Bruce Misstear and Paul Hynds,
Department of Civil, Structural and Environmental Engineering,
Trinity College Dublin.

Groundwater Related Research

Department of Civil Structural and Environmental Engineering, Trinity College Dublin

On-site wastewater treatment research

A three year EPA funded project is ongoing entitled, "*the effective distribution of on-site wastewater effluent into percolation areas via distribution boxes and treatment by reed beds compared to attenuation of pollutants in sandy subsoils*". This project is aiming to address research questions raised during the previous research project into on-site treatment carried out by the Department which had looked in detail at four sites receiving both septic tank and secondary effluent with subsoils of T-values ranging from 15 to 52. The current project is studying two sites over a longer period both with subsoils of T-values below 5, one of which is receiving septic tank effluent, the other receiving secondary treated effluent from a packaged plant. The idea of on-site effluent being discharged into more freely draining sandy soil (T-value 1 to 5), although allowed in the current EPA guidelines, seems to attract a degree of scepticism both from local councils, practitioners and other bodies who have an intuitive feel that the effluent is percolating too fast. Hence, the project is particularly focusing on bacteria and virus attenuation with depth in the subsoil. Another major part of the project is to test the efficiency of different distribution devices both in the laboratory under regulated conditions and also out on site receiving both qualities (septic tank and secondary) of on-site effluent. Finally, the project is looking at the performance on the sites of subsurface horizontal wetlands whereby again, one is receiving septic tank effluent and the other is receiving secondary treated effluent. In addition a third site is under investigation for comparison using a packaged reed bed acting as a tertiary treatment process for the on-site wastewater.

Several other smaller research projects are also being carried out in the field of on-site wastewater treatment. A statistical comparison of the different BS5950 subsoil descriptors (CLAY, SILT etc) against their respective range of T-values has been compiled from a database of over 600 site assessments. The use of recycled glass for on-site treatment processes is being studied, for example as an alternative media for filters systems as well as the potential for mixing different quantities of the glass into the soil used in raised mound treatment systems in order to promote improved and more consistent percolation characteristics. Research has also recently been carried out on the phosphate removal performance of different native Irish sands for use in sand filters or applications for example, such as sacrificial filters for constructed wetlands etc. Finally, work is ongoing into the design of an optimum distribution manifold for the pressurised dosing of on-site wastewater onto a sand filter process.

For further details on these projects contact:
Laurence Gill
Email: gill@tcd.ie

Environmental Engineering Research, School of Civil Engineering Queens University Belfast

Radiocarbon Dating of Young Groundwater for Aquifer vulnerability and sustainability

This project is focused on dating young groundwaters for aquifer vulnerability and sustainability using 14C. He has been developing protocols for the direct absorption of 14CO2 (as a carbamate) for analysis by Liquid Scintillation Counting. Calibration and validation is underway using IAEA-C3 activity standards and also via a standard carbonate used in the CSIRO isotope Analytical Service Lab. A working standard from sea limpets (Patella vulgata), collected in the east coast of Northern Ireland, has been made for the Direct Absorption Line in the Environmental Tracers Laboratory (ETL). Comparisons will be made with other young dating indicators (e.g. CFCs and 3H-3He) through research collaborations being developed with the Geological Survey of Denmark & Greenland and Lawrence Livermore National Laboratory (USA). Suitable experiment areas are being investigated in Donegal Co., Ireland and the province of Granada, Spain in collaboration with Donegal County Council and IGME (Spanish Geological Survey) respectively.

Environmental Engineering Research, School of Civil Engineering Queens University Belfast

NITRABAR Project

The release of nutrients, including nitrates, to surface water and groundwater remains a big issue in agricultural land management in many parts of Europe. With the introduction of the Water Framework Directive (WFD), the issue of nitrates in the environment has become an even bigger challenge. The WFD aims to ensure that all inland and coastal waters within defined river basin districts reach good chemical and ecological condition by 2015. Reducing nitrate levels in the environment is therefore an important part of achieving this objective.

NITRABAR is a European Commission LIFE Environment Project to demonstrate a highly efficient, reliable and cost-effective treatment system for nitrates derived from agricultural practices. The treatment system consists of a Permeable Reactive Barrier (PRB). Essentially, a PRB involves the placement of a reactive material below the ground through which groundwater flows and reacts with contaminants (such as nitrate) or changes them to less harmful ones.

It is expected that this approach will achieve an 85% reduction in the nitrate level in waters passing through the system. The project aims to demonstrate the application of the NITRABAR system in the agricultural setting and enable others to replicate the system throughout Europe.

Investigation of the Biological Processes of Natural Attenuation of Carbon Disulphide

Carbon disulphide, CS_2, is a toxic, dense non-aqueous phase liquid (DNAPL) that has been used commercially since 1880. In August 2006, CS_2 had been identified as a contaminant of concern in greater than 10% of sites listed on the US Environmental Projection Agency's "National Priorities List" of the most hazardous waste sites in the USA and a number of CS_2 contaminated sites have been identified within the UK.

The hazards associated with CS_2 arise because its (1) toxic nature (prolonged and repeated exposure to CS_2 can affect both the central and peripheral nervous systems and cause serious neurological and psychological impairments) and (2) the danger of fire and explosions, (CS_2 is highly volatile, has a wide flammability range and low ignition temperature). A number of techniques for remediation of CS_2 have been developed which include source destruction and pathway interception (Dulsey et al. (2001), Kalin et al. (2005)), however it appears that no investigations into natural attenuation of CS_2, for contaminated land cleanup, have been carried out.

Natural attenuation is described as "the effect of naturally occurring physical, chemical and biological processes, or any combination of these processes to reduce the load, concentration, flux or toxicity of polluting substances in the groundwater" (Carey et al., 2000). Regulatory bodies are increasingly accepting monitored natural attenuation (MNA) as a viable means of managing the risks posed by contaminated groundwater at appropriate sites and biodegradation has been recognised as the most important destruction mechanism during natural attenuation of organic compounds.

This research project focuses on investigating the biologically mediated processes of natural attenuation of CS_2, through laboratory based microcosm studies, with the aim of informing the use of MNA to remediate CS_2 contaminated sites.

Carey, M.A., Finnamore, J.R., Morrey, M.J. and Marsland, P.A., 2000. Guidance on the assessment and monitoring of natural attenuation of contaminants in groundwater. R&D Publication 95. Bristol, UK: Environment Agency.

Dulsey, R., Mausner, M., Bybee, G., Mercurio, B., Fahrenthold, P., Hazard, J. and McGhee, C., 2001. Method for oxidative destruction of carbon disulfide in soil. US Patent. 405/128.5 edn. US: B09B 3/11.

Kalin, R.M., Myles, P. and McGeough, K., 2005. Carbon disulphide sources, risks and treatment: An emerging contaminant of environmental concern? G. A. Boshoff and B. D. Bone, eds. In: Permeable Reactive Barriers, 14-16 March 2005, IAHS Press pp 82-92.

Environmental Engineering Research, School of Civil Engineering Queens University Belfast

Position Specific Isotope Analysis (PSIA)

The main aim of this PhD research is to design and develop a prototype system for Position Specific carbon Isotope Analysis (PSIA). The atoms of a molecule that are involved in the reactions of synthesis, transformation and degradation undergo isotopic fractionation and thus are likely to have characteristic isotopic signatures. These are, however, sometimes, masked in the stable isotope signature of the "whole molecule" (provided by Compound Specific Isotope Analysis) by the presence of non reacting atoms. Position Specific stable Isotope Analysis is the investigations into isotope variations at the intra-molecular level via isolation of elements or groups of interest. The system is developed to be used for the analysis of environmental forensic and conventional forensic samples. It is hoped that it can unveil differences or links between molecules that are not seen at the bulk or molecular level and that it can provide new insight on the pathways and mechanisms of contaminants degradation.

Investigating the sources of persistently high nitrate on surface water quality in Northern Ireland. The role of stable isotopes and radon as investigative tools.

Although the EU Nitrates Directive has implemented measures to control nitrate within Northern Ireland's freshwater there still continues to be persistently high levels of nitrate within the rivers. This research project aims to look at the source types of these persistent nitrates using stable isotopes, $\delta^{15}N$ and $\delta^{18}O$. Radon and CFCs will be used to identify if the nitrates are originating in the groundwater and then entering the rivers within the base flow. If this is the case there will be a time lag from the nitrate entering the groundwater and its subsequent entry into the river. The effect of urban and rural groundwater on nitrate levels within a river will be studied. The role of soils, in particular peaty soils, in lowering nitrate levels will be considered; this is a particular concern as organic rich soils are prolific in Northern Ireland.

For further details on any of these projects contact:

Dr. Ulrich Ofterdinger,
Environmental Engineering Research, School of Civil Engineering,Queens University Belfast.

Department of Earth & Ocean Sciences, National University of Ireland, Galway

At the Department of Earth & Ocean Sciences at NUI, Galway two groundwater related research projects are underway. Tiernan Henry is working on the structural controls of groundwater flows in the Tynagh area of east Galway. The project is focusing on developing an understanding of the groundwater regime in the area (not just in the vicinity of the old mine) and will involve a well sampling component (to be undertaken this summer). Historical flow data and water management records from the mine are being accessed to gauge the nature, type and magnitude of water makes in the mine, during the development, operational and post-closure phases. Rachel Cave and Tiernan Henry have been working on assessing the interaction of groundwater and estuarine water in the Kinvarra area of south Galway over the past two years. They have compiled data on groundwater discharge to the estuary as well as assessing the nitrate, nitrite and phosphate concentrations in the water. Rachel is developing a profile of the flow patterns of fresh and saline water in the estuary. As part of this work, Ronan O'Toole, who is now with the GSI, completed a coastal survey from Kinvarra to Doolin recording the locations and - where possible - the magnitudes of groundwater discharges. A project team with researchers from TCD and UCC has been assembled and funding has been sought to install monitoring equipment in the area and to complete onshore and offshore geophysical surveys to assess the ecological impacts of groundwater discharges in the coastal zone.

For further details on these projects contact:

tiernan.henry@nuigalway.ie
rachel.cave@nuigalway.ie

Cork City Council & Department of Geology, University College Cork

Docklands Geothermal Feasibility and Environmental Impact Study

Cork Docklands are set in a beautiful location to the east of the City Centre and cover an area of 166 hectares of land on both banks of the River Lee, with 4 kilometres of waterfront. In Docklands there will be 352,722m^2 (approximately 5,900 units) for residential uses and 351,567m^2 for non-residential uses. The Cork Docklands Development Plan sets out a 20 year vision for a new urban quarter characterized by high quality design, residential, employment and leisure opportunities, sustainable development and a superb quality of life in a high-density urban setting.

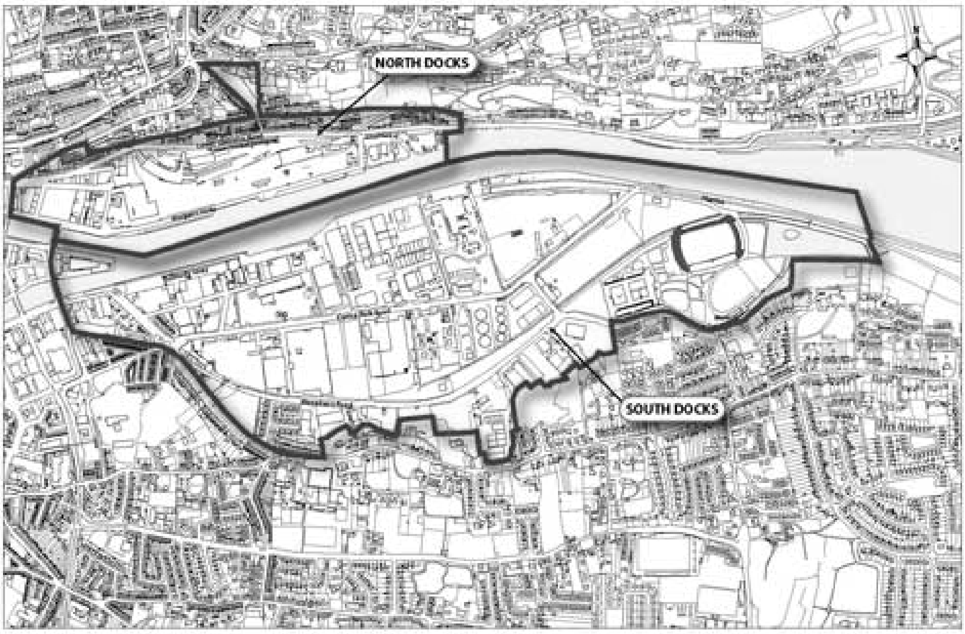
In order to reduce CO_2 emissions to comply with Kyoto Protocol and to take advantage of renewable energy, the Environment Directorate and Docklands Directorate of Cork City Council have appointed Cork City Energy Agency, in conjunction with the Geology Department in UCC, to undertake a ground water research study to determine the feasibility of using the potential geothermal resource beneath the Docklands area to heat the buildings. Two 30m deep boreholes have already been drilled and the quality, quantity and temperature of the ground water in Docklands will be assessed. As there will be large scale development of houses and buildings constructed in the Docklands, it is recognised that large abstractions of groundwater for geothermal energy may have an impact on the aquifer, so the environmental impact of the ground water pumping will also be investigated. Groundwater flow modelling software will be employed to assess the behaviour of the aquifer beneath the Docklands in response to continuous large abstractions of groundwater for geothermal heating.

To date, test boreholes have been drilled at UCC and the City Hall and all show elevated temperatures of 3–4°C above the norm. The slightly warm groundwater can be passed through a heat pump to further elevate its temperature and to extract heat for space heating purposes. There are already some sites within Cork City using the geothermal resource, including Lifetime Lab, the New Civic Offices at City Hall and the Lewis Glucksmann Gallery in UCC.

The results of the Docklands Geothermal feasibility and environmental impact study will determine the maximum volumes of groundwater that can safely be abstracted and will give detailed directions and suggestions to the developers in Docklands to meet the sustainable development plan of Docklands. In addition, the investigation will aid the location of reinjection wells for the spent water after it leaves the heat pump, which will assist in the control of aquifer beneath Cork City.

Xiang Cheng
Project Engineer
Cork City Energy Agency
Lifetime Lab,
Lee Road,
Cork

Ph: 021-4941509
Email: xiang_cheng@corkcity.ie



CORK DOCKLANDS - Local Area Plan Boundaries

IAH NEWS

The Annual Conference of the IAH (Irish Group) takes place in Tullamore, Co Offaly on Tuesday 24th & Wednesday 25th April 2007.

Technical Discussion Meetings*

Tuesday 5th June 2007
Joint IAH/Geothermal Association of Ireland Lecture
Aspects of the deep geothermal prospect in South Australia
Graham Beardsmore, Principal Consultant to Hot Dry Rocks Pty Ltd of Victoria, Australia.

Tuesday 2nd October 2007
Issues surrounding attitudes of public to scientists/engineers and recommendations on communicating scientific/technical information to the general public.
Mary Kelly
UCD

***Note – There is no meeting in May**.*

Departure of Newsletter Editor

The long time editor of the GSI Groundwater Newsletter, Mr Donal Daly, has left the GSI to take up a new position with the EPA.

Most readers will realise that there would not have been a Groundwater Newsletter without Donals input. We would like to take this opportunity to acknowledge his huge contribution to the establishment and running of this newsletter. We wish him well in his new position and look forward to his continuing contribution to the newsletter.

It is useful at this point to reference that important milestone - the first groundwater newsletter, introduced in 1986 (some grey hairs have appeared since then!), which aimed to *'bring together news, developments, reviews and opinions on all aspects of groundwater'* and *'to promote a proper appreciation of the value and importance of groundwater'*. Some forty five newsletters were successfully published and distributed delivering those aims.

Throughout that time articles have come from geologists, scientists, and engineers from both outside and within the Geological Survey.

We thank all contributors thus far for their efforts. We continue to encourage contributions from all disciplines and look forward to carrying on providing news, reviews and opinions on all aspects of groundwater.

Coran Kelly & Una Leader

CONTRIBUTIONS FOR THE NEXT ISSUE OF THE NEWSLETTER

Contributions for the next issue should arrive before 5th August 2007 to:

The Editor, GSI Groundwater Newsletter,
Geological Survey of Ireland,

Beggars Bush, Haddington Road, Dublin 4.

*****

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