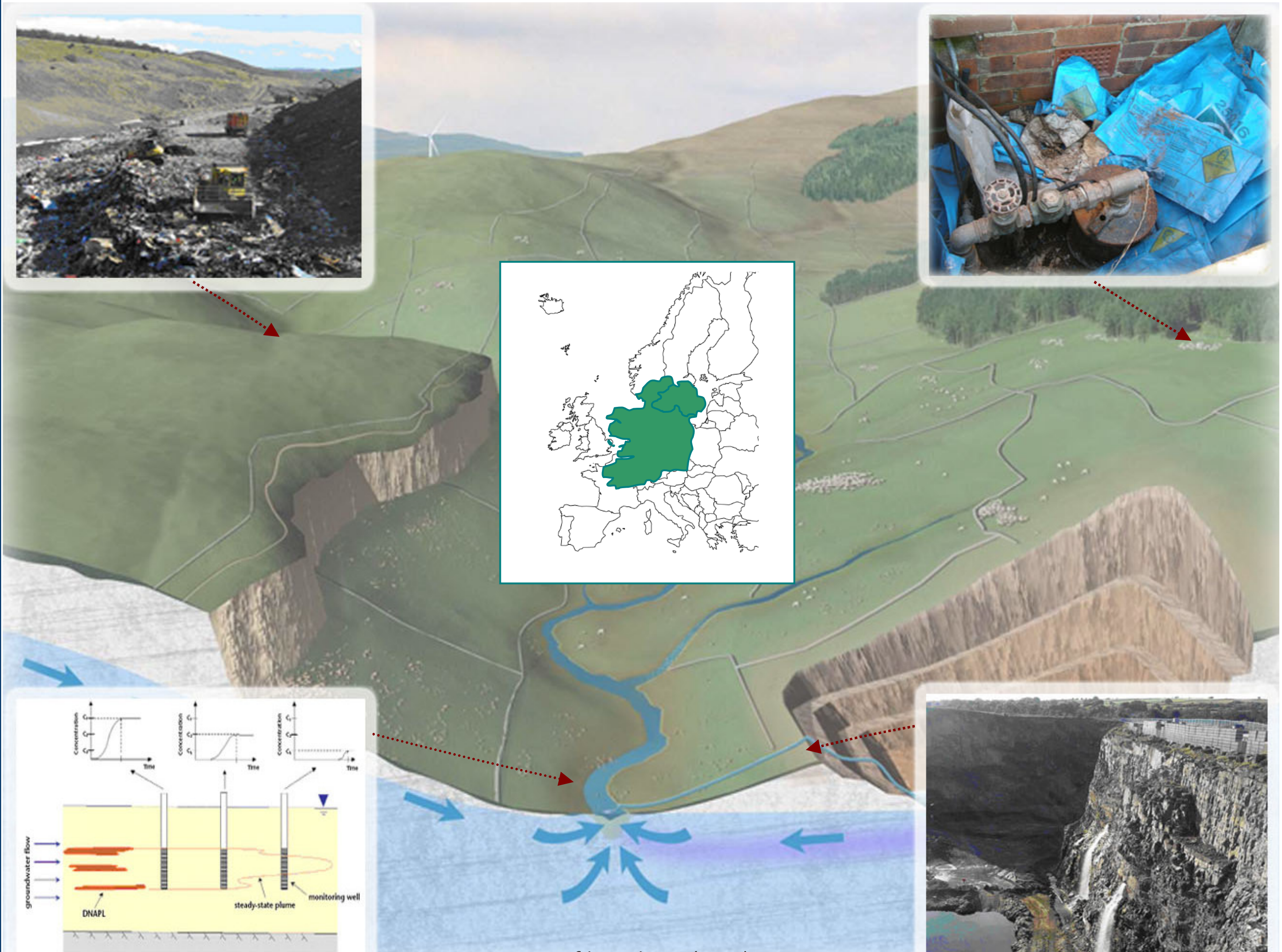
INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS – Irish Group

‘Evolving Hydrogeology’

Managing Groundwater



www.wfdvisual.com (2005)

Proceedings of the 31st Annual Groundwater Conference
Tullamore, Co. Offaly, Ireland

12th and 13th April, 2011

www.iah-ireland.org

INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS
(IRISH GROUP)

Presents

'Evolving Hydrogeology'

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Tullamore Court Hotel,
Tullamore,
Co. Offaly

12th & 13th April, 2011

INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IRISH GROUP)

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

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

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

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

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

2011 Conference Objective

The 2011 Conference will be of great benefit to hydrogeologists, local authority engineers, consultants, planning officials, environmental scientists, public health officials, and many other professionals.

This year is the 31st Anniversary of the Annual IAH (Irish Group) Conference, with the theme 'Evolving Hydrogeology'. The two-day event will start with a keynote presentation given by the President of IAH International, Mr Willi Struckmeier, on the IAH's role in the evolution of hydrogeology. Session 1 will deal with the ways in which practitioners are improving and applying our understanding of surface water and groundwater as an integrated resource with emphasis on modelling. Groundwater flooding mechanisms and flood mapping in Ireland are also discussed. The second half of Day 1 continues with Session 2 exploring the issues surrounding groundwater contamination from unregulated landfill sites, with perspectives from the Regulator and consultancy. The first day finishes with Session 3 on managing contaminated groundwater, with focus on different remedial options, regulatory approaches and case studies on remediation in Ireland.

Day 2 will begin by looking at groundwater development in the extractive and geothermal industries with an initial presentation on mine dewatering from an international perspective. Following this, development of geothermal energy; how it works, the international perspective and its applicability and current status in Ireland is discussed. The conference will close by looking at the management of groundwater resources with a talk on groundwater nutrient patterns in intensive agricultural catchments, followed by a presentation from the National Federation of Group Water Schemes on the issue of water metering and reducing abstraction pressure on groundwater sources.

2011 IAH (Irish Group) Committee:

President:	Teri Hayes, WYG Environmental
Secretary:	Jenny Deakin, Trinity College Dublin
Burdon Secretary:	Morgan Burke, Stream BioEnergy
Treasurer:	Catherine Buckley, ARUP
Northern Region Secretary:	Paul Wilson, GSNI
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Education & Publicity Secretary:	Anthony Mannix, EPA
Conference Secretary:	Shane Bennet

2011 Conference sub-committee:

Matthew Craig, Environmental Protection Agency; Niall Mitchell, RPS; Pat A. Groves; Colin O'Reilly, Envirologic; Orla McAlister, Tobin Consulting Engineers.

For more information and contact details please refer to: *www.iah-ireland.org*

The IAH would like to sincerely thank ARUP and White Young Green International for their help with Conference administration.

Proceedings cover designed by Pat A. Groves with main background image sourced from WFD Visual (Water Framework Directive Visualisation tool: *www.wfdvisual.com*) courtesy of Scotland & Northern Ireland Forum for Environmental Research (SNIFFER). Other photo sources: Development of a steady-state plume: An illustrated handbook of DNAPL transport and fate in the subsurface, Environment Agency, 2003: R&D Pub. 133, Fig. 13; Limestone quarry, Co. Roscommon: Caoimhe Hickey, (GSI); EU map, available online at: *www.europe-map.org;* Pat A. Groves.

The proceedings for the 31st Annual Groundwater Conference 2011 will also be made available digitally on the IAH-Irish Group website within the next three months.

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The IAH (Irish Group) would also like to acknowledge the support of the following members and organisations whose staff have worked on the committee of the IAH-Irish Group throughout the year and helped to organise the 31st Conference:

WYG Ireland part of the WYG group
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Geological Survey of Northern Ireland

ARUP

‘Evolving Hydrogeology’
31st Annual Groundwater Conference

International Association of Hydrogeologists –Irish Group
Tullamore Court Hotel, Tullamore, Co. Offaly: Tues 12th & Wed 13th April, 2011

Programme Day 1, Tuesday 12th April

8:15 – 9:30 *Conference Registration; Tea, Coffee, & Exhibits*

INTRODUCTION

9:30	Welcome and Introduction Teri Hayes - President IAH Irish Group (WYG Environmental)
9:45	Keynote speaker: ‘The role of the International Association of Hydrogeologists (IAH) in the Evolution of Hydrogeology and Water Management’ - Willi Struckmeier (President IAH International)

SESSION 1: INTEGRATED GROUNDWATER MODELLING

10:15	‘Integrated groundwater and surface water modelling - benefits realisation’ - Jan van Wonderen (Mott MacDonald)
10:45-11:15	*Tea and coffee*
11:15	‘Integrating surface and sub-surface water flow simulations for improved climate change impact assessments on the groundwater system’- Okke Batelaan (Free University, Brussels)
11:40	‘Groundwater flooding mechanisms’ - Kieran O’Dwyer (J B Barry and Partners Ltd.)
12:05	‘Mapping groundwater flooding in the Republic of Ireland’ - Rachel Hardisty (Mott MacDonald) Discussion, Q&A
12:50 – 14:00	*Buffet lunch in Tullamore Court Hotel*

SESSION 2: GROUNDWATER MANAGEMENT OF UNREGULATED LANDFILLS

14:00	‘EPA Code of Practice for Unregulated Waste Disposal Sites - Guidance for Investigations’ - Jim Moriarty (EPA)
14:25	‘The new EPA code of practice matrices for scoping site investigations and assessing groundwater risk’ - Darragh Musgrave (WYG) Discussion, Q&A
15:05	Student Poster Presentations
15:30 – 16:00	*Tea and coffee*

SESSION 3: MANAGING CONTAMINATED GROUNDWATER

16:00	‘Chlorinated hydrocarbons – different remedial options and regulatory approaches’ - Olivia Hall (Regenesis) and Kevin Forde (URS)
16:25	‘Groundwater remediation of chlorinated ethenes – implementation of a pilot study in an Irish context’ - Eleanor Burke (Malone O’Regan)
16:50	‘Enforcement of Contaminated Land and Groundwater: The road ahead’ - Kevin Motherway (EPA) Discussion, Q&A
17:30	*The final panel discussion on Day 1 will be followed by a wine reception in the Tullamore Court Hotel sponsored by* ***InSitu Inc.*** *followed by a BBQ meal at Hugh Lynch's Bar, Kilbride Street, Tullamore, sponsored by IAH (Irish Group).*

‘Evolving Hydrogeology’
31st Annual Groundwater Conference

International Association of Hydrogeologists –Irish Group
Tullamore Court Hotel, Tullamore, Co. Offaly: Tues 12th & Wed 13th April, 2011

Programme Day 2, Wednesday 13th April

9:00 – 9:30 *Tea, Coffee & Exhibits*

SESSION 4: DEVELOPMENT IN THE EXTRACTIVE & GEOTHERMAL INDUSTRIES

09:30	‘An international view on mine dewatering’ - Paul Heaney (RPS Aquaterra)
09:55	‘Geothermal energy utilisation - an international perspective’ - Riccardo Pasquali (GeoServ)
10:20	‘Geothermal developments in Ireland’ - Gareth Ll. Jones (Conodate, Geothermal Assoc. Ireland)
	Discussion, Q&A

11:00 – 11:30 *Tea & Coffee*

SESSION 5: MANAGEMENT OF GROUNDWATER RESOURCES

11:30	‘Groundwater nutrient patterns in two intensive agricultural catchments’ - Per-Erik Mellander (Teagasc)
11:55	‘Reducing abstraction pressure on groundwater sources: the lessons of universal metering in the Group Water Scheme sector’ - Barry Deane (National Federation of Group Water Schemes)
	Discussion, Q&A
12:35	Conference closing address: Shane Bennet (Conference Secretary - IAH Irish Group)
13:00	*Buffet lunch in Tullamore Court Hotel*

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KEYNOTE SPEAKER

THE ROLE OF THE INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IAH) IN THE EVOLUTION OF HYDROGEOLOGY AND WATER MANAGEMENT

W.F. Struckmeier
IAH President 2008-2012

ABSTRACT

The International Association of Hydrogeologists (IAH) looks back on a bright history of 55 years of existence. Since its foundation in 1956 during the 20th International Geology Congress in Mexico City IAH has grown from a small, rather Europe-centred association of geologists who wanted to give the emerging science of hydrogeology a more prominent role within the geological sciences, to a truly international non-governmental organisation specialised for groundwater with more than 3,800 members worldwide, in more than 135 countries.

In 2000 this unique international groundwater association has been registered in the U.K. as a charitable organisation with a board of directors (council) elected every four years by its members. The council of IAH comprises the president and secretary general as well as 10 vice-presidents, of which one vice-president is responsible for science and another for membership, plus eight regional vice-presidents representing the membership on the various continents and sub-regions.

The mission of IAH is to further the understanding, wise use and protection of groundwater resources throughout the world. The priorities therefore, focussed on:

- *providing a premium professional forum of scientific excellence in supporting its members and the groundwater community,*
- *raising awareness about groundwater and advocating on the importance, wise use and management of groundwater resources on all levels.*

Both focal priorities go together, but of course the professional base has to be laid first, before IAH increased its role in groundwater advocacy and raising awareness.

This paper describes the evolution of the IAH and the impacts it has made in hydrogeological sciences as well as in global water policies and to the society at large.

INPUT OF IAH FOR THE EVOLUTION OF HYDROGEOLOGY

The themes of the IAH congresses and symposia organised over more than fifty years clearly reflects the evolution of hydrogeology and the priority areas in which IAH tried to influence hydrogeological sciences and the wise use of groundwater worldwide (see Table 1).

Table 1: IAH Congresses and Symposia

Year	*Place*	*Theme*
1952	**Alger, Algeria**	**International Geological Congress (IGC)**
1956	**Mexico City, Mexico**	**IGC**
1957	Paris, France	Various themes of hydrogeological interest
1958	Liège, Belgium	Various themes
1959	Madrid, Spain	Various themes
1960	**Copenhagen, Denmark**	**IGC**
1961	Roma, Italy	Various themes
1962	Athens, Greece	Various themes
1963	Belgrade, Yugoslavia	Various themes
1964	**New Delhi, India**	**IGC**

1965	Hannover, Germany	Various themes
1966	Bad Salzuflen, Germany	Mineral and Thermal Waters
1967	Istanbul, Turkey	Various themes
1968	**Prague, Czechoslovakia**	**IGC**
1969	Budapest, Hungary	Various themes
1970	Krefeld, Germany	Various themes
1970	Palermo, Italy	Various themes
1971	Tokyo, Japan	Various themes
1972	**Montreal, Canada**	**IGC**
1972	Karlovy Vary, Czechoslovakia	Various themes
1973	Bordeaux, France	Hydrogeochemistry
1973	Madras, India	Development of Groundwater Resources
1974	Opatia, Yugoslavia	Problems of Hydrogeology, Engineering Geology and Geophysics
1974	Montpellier, France	Various themes
1975	Porto Alegre, Brazil	Various themes
1975	Huntsville, USA	Karst Hydrogeology
1975	Palermo, Italy	Various themes
1976	Alexandria, Egypt	Arid Lands Irrigation in Developing Countries
1976	Bowling Grenn, USA	Hydrologic Problems in Karst Regions
1976	**Sydney, Australia**	**IGC**
1976	Budapest, Hungary	Hydrogeology of Great Sedimentary Basins (with IAHS)
1976	Athens, Greece	Thermal Waters, Geothermal Energy and Volcanism in the Mediterranean Area
1976	Anaheim, USA	Land Subsidence
1977	Birmingham, U.K.	Optimal Development and Management of Groundwater
1978	Prague, Czechoslovakia	Groundwater Pollution by Oil Hydrocarbons
1978	Cieplice Spa, Poland	Hydrogeochemistry of Mineralized Waters
1978	Granada, Spain	Mine Water and Undergraound Construction
1978	Basel, Switzerland	Drinking-Water Protection Areas
1979	Dortmund, Germany	Artificial Groundwater Recharge
1979	Vilnius, USSR	Methods for Evaluation of Ground-Water Resources
1980	**Paris, France**	**IGC**
1981		
1982	Prague, Czechoslovakia	Impact of Agricultural Activity on Ground Water
1983	Noordwijkerhout, Netherlands	Methods and Instrumentation for the Investigation of Groundwater Systems (IHP, IAHS)
1983	Koblenz, Germany	Groundwater in Water Resources Planning (with IHP)
1984	**Moscow, USSR**	**IGC**
1985	Tucson, USA	Hydrogeology of Rocks of Low Permeability
1985	Cambridge, U.K.	Hydrogeology in the service of man
1986	Karlovy Vary, Czechoslovakia	Integrated Land Use Planning and Ground-Water Protection Management
1987		
1988		
1989	**Washington, USA**	**IGC**
1989	Hannover, Germany	Hydrogeological Maps as Tools for Economic&Social Development
1990	Lausanne, Switzerland	Water Resources in Mountainous Regions (with IAHS)
1991	Tenerife, Spain	Aquifer Over-exploitation
1992	**Kyoto, Japan**	**Environmental Hydrogeology**
1992	Beijing, China	Groundwater and Environment
1993	Oslo, Norway	Hydrogeology of Hard Rocks

1994	Adelaide, Australia	Shallow Groundwater Systems
1995	Edmonton, Canada	Managing Man's Activities on Groundwater
1996	**Beijing, China**	**IGC**
1997	Nottingham, U.K.	Groundwater in the Urban Environment
1998	Las Vegas, USA	Gambling with Groundwater, Aquifer-Stream Relations
1999	Bratislava, Slovakia	Hydrogeology and Land Use Management
2000	**Rio de Janeiro, Brazil**	**IGC**
2000	Cape Town, South Africa	Groundwater: Past Achievements and Future Challenges
2001	Munich, Germany	New Approaches to Characterising Groundwater Flow
2002	Mar del Plata, Argentina	Groundwater and Human Development
2003		
2004	**Florence, Italy**	**IGC**
2004	Zacatecas, Mexico	Groundwater Flow Understanding: From Local to Regional
2005	??, Poland	Nitrates in Groundwater
2006	Dijon, France	Darcy's Legacy in a World of Impending Water Shortage
2006	Beijing, China	Groundwater – Present Status and Future Task
2007		
2008	**Oslo, Norway**	**IGC**
2008	Kampala, Uganda	Groundwater Response to Changing Climate
2008	Toyama, Japan	Integrating Groundwater Science and Human Well-being
2009	Hyderabad, India	Hydrogeology of Hard Rock Terrains (with IAHS)
2010	Krakov, Poland	Groundwater Quality Sustainability
2011	Pretoria, South Africa	Groundwater: our source of security in an uncertain future
2012	**Brisbane, Australia**	**IGC**
2012	Niagara Falls, Canada	Confronting Global Change

In the first 20 years the main focus of IAH activities was laid upon the advancement of science. Almost 10 commissions were formed with international membership, and they contributed to the scientific meetings of the International Geological Congress held every four years, or of IAH Congresses and Symposia held in between. From the proceedings of these early meetings it can be seen that the principal fields of interest related to

- Investigation and characterisation of aquifers,
- Water balance studies of groundwater resources and reserves,
- Hydrogeological mapping,
- Karst hydrogeology,
- Mineral and thermal waters,
- Applied hydrogeology for engineering and mining,
- Additional themes of hydrogeological relevance, chiefly geophysical methods.

It is quite logical that during the fifties to the seventies, when national economics and welfare showed enormous growth rates, the main emphasis of hydrogeological scientists and practitioners was to conduct investigations about the availability and suitability in order to assure high quality groundwater supplies and protect the water resource base for various purposes, such as drinking, domestic and industrial use and irrigated agriculture. In addition, the complex hydrogeological conditions in karst regions were investigated in detail.

A large number of hydrogeological maps were initiated in the sixties, and the joint IAH Commission of Hydrogeological Maps and thematic Sub-Commission of the Commission for the Geological Map of the World (CGMW) took a leading role in the harmonisation and standardisation of hydrogeological maps on all continents. The map series of the International Hydrogeological Map of Europe, at the scale of 1:1,500,00 still serves as a model for thematic maps throughout the world and the guidebook on hydrogeological maps (Struckmeier & Margat, ICH, 1995). This theme of hydrogeological mapping continued in the 1990's and 2000's when geo-information systems (GIS) and hydrogeological data bases were increasingly used, now also coupled with 3D-underground hydrogeological modelling.

In the seventies and eighties, water quality issues and the protection of groundwater resources from pollution became a major theme for the work of IAH Commissions and in IAH meetings around the world. On the one hand, intensive agriculture was seen as a source of non-point source contamination, on the other hand the search for safe depositories of dangerous red waste gave rise to numerous studies and investigations of non-aquiferous strata and in areas where there seemed to be a potential for secure underground storage of hazardous substances. Protecting areas of groundwater abstraction sites became also an issue of international discussion.

Well logging, pumping test evaluation and hydrogeological modelling of groundwater flow and transport processes became also very popular in hydrogeology, and IAH commissions and working groups organised several related symposia and published a number of pertinent publications.

Although the application of hydrogeological science for socio-economic development used to be an important perspective in all IAH congresses and symposia, groundwater management issues became an increasingly important field of activity for hydrogeologists in the eighties. The 18th IAH congress in Cambridge 1985 dedicated to “hydrogeology in the service of man” and the Symposium on “integrated land use planning and groundwater protection management” in Karlovy Vary in 1986 are excellent examples of the evolving priority, to better use hydrogeological knowledge, skills and tools for an improved management of groundwater resources. The issue of groundwater management has since become an essential part of each of the following congresses and symposia of IAH, and this has also largely fostered the IAH priority of advocating for groundwater worldwide.

A number of new themes in hydrogeological science strongly related to socio-economic development cropped up chiefly in the past twenty years, such as managed aquifer recharge, hydrogeology and the environment, groundwater and climate change, and transboundary aquifers. Most of these themes have been dealt with in depth during pertinent congresses and symposia of the IAH, partly in association with other partners such as UNESCO, the International Association of Hydrological Sciences (IAHS) or other regional and national partners.

PUBLICATIONS OF IAH CONTRIBUTING TO ADVANCEMENT OF HYDROGEOLOGY

There is a wealth of publications in which IAH members and other scientists attending IAH congresses and symposia have published innovative ideas and new findings about hydrogeology and groundwater resources.

In the early phase of IAH until the early eighties, numerous proceedings of IAH congresses and symposia were published and frequently sent to all IAH members free of charge. However, as the membership increased and printing and mailing costs boosted, the IAH had to find a more cost effective way in communicating hydrogeological science to its members and the science community.

A new series of books named “International contributions to hydrogeology (ICH)” was founded in agreement between IAH and the Heise Publishing Company in Germany. It was amended by another series called “Selected papers in hydrogeology (SP)” as well as a new regular journal that started as “Journal of Applied Hydrogeology” which was later converted into the premium “Hydrogeology Journal” for which a long-lasting contract between IAH and the Springer-Verlag (Berlin/Heidelberg, Germany) was concluded in 1996.

The IAH book series ICH and SP were transferred in the mid 90’s to Balkema and later to Taylor & Francis Publishers. 26 books and monographs of the series “International contributions to hydrogeology” and 4 “selected papers” have been published as soft-cover books by the Heise-Verlag between 1984 and 1995. Since the mid 90s both series are published by Balkema rsp. Taylor &

Francis as hard cover editions (ICH volumes 18-26, SP volumes 5-16). Members of IAH can purchase the book at more than 50% discount.

The "Hydrogeology Journal (HJ)" published by Springer has become a premium journal under the very efficient editorship of Dr Clifford Voss (US Geological Survey). It is included in the IAH membership fee and goes free of charge to all members of IAH, now in its 19^{th} volume (2011), in eight individual numbers (approx. 2000 pages) per year. The scientific papers and reports of the hydrogeology journal have steadily increased in number and quality over the years, making HJ an outstanding journal with a high scientific impact (1.4) and excellent quality, standing and visibility.

Numerous additional monographs and reports elaborated under strong IAH participation have been published outside the IAH serial publications, e.g. in many of the UNESCO groundwater publications originating from the intensive cooperation within the International Hydrological Programme (IHP) of UNESCO.

THE IMPACT OF IAH IN AWARENESS RAISING AND ADVOCACY FOR GROUNDWATER

In addition to the strong influences IAH has undoubtedly had and is still exercising on the science of hydrogeology by its meetings and related publications as well as the Hydrogeology Journal, the role IAH plays as a premium international non-governmental organisation (INGO) specialised on groundwater has increased enormously over the past decades. IAH has become an appreciated partner for UN-WATER, the joint panel of all water-related activities of currently 28 organisations of the United Nations, e.g. UNESCO, FAO, IAEA, WMO and many others. IAH is also a member of the World Water Council (WWC) organising the World Water Forum and it is partner of the Global Water Partnership (GWP). So from its original scientific roots within the geological community, marked by its affiliation to the International Union of Geological Sciences (IUGS), the IAH has evolved to a truly interdisciplinary player for the global water agenda, where it successfully advocates for groundwater and defends the particular role of groundwater in the Integrated Water Resources Management (IWRM) concepts.

The increasing importance of groundwater in global water meetings is underpinned by various actions of the IAH, such as the production of pertinent information material, e.g. brochures about the role of groundwater for livelihoods or the 50^{th} anniversary brochure of IAH, and a number of world maps showing the groundwater resources or transboundary aquifers, but it is also related to presentations and contribution to discussions of many representatives of the association, namely its officers serving in the IAH council, commissions and working groups and in the national and regional chapters of IAH, but also by the IAH membership at large.

Finally, a number of guidelines and policy briefs underpinned by IAH but specifically geared at politicians, managers and executives in the water sector have been prepared by the groundwater management advisory team (GW-MATE) of the World Bank headed by Stephen SD Foster, former president of IAH.

CONCLUSION

It is evident that the International Association of Hydrogeologists (IAH) played a vital role since its start in 1956, but mainly during the last decade of the 20^{th} century for the evolution of the science of hydrogeology. Thanks to the work of IAH and its commissions and working groups in association with numerous scientific meetings organised in the name of IAH or fostered by IAH members, a wealth of new ideas and innovative approaches towards hydrogeology have been published and discussed. This paved the way for the evolution of hydrogeological science in many parts of the world.

The unique role of the IAH as the largest international NGO specialised on groundwater in advocating for groundwater in the global water agenda has been underpinned by numerous publications and actions of representatives of IAH at major global or regional water meetings and for a, such as the World Water Forum, the Stockholm World Water week or the African Water Week.

There is no doubt that IAH has greatly advanced on the scientific, socio-economic and political level in fulfilling its mission to further the understanding, wise use and protection of groundwater resources throughout the world. However, we must maintain our impact at all levels in order to secure a sustainable groundwater resource base for mankind and the environment in times of continuous global changes, particularly the demographic evolution, land use changes and the challenges of climate change.

REFERENCES

IAH Publication series 1989-2010: International contributions to Hydrogeology (ICH) and Selected Papers on Hydrogeology (SP): www.iah.org/publications_books.asp

International Hydrogeological Map of Europe, scale 1:1.5 Million: www.bgr.bund.de/ihme1500

GW-MATE Briefing Notes:
web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTWAT/0,,contentMDK:21760540~menuPK:4965491~pagePK:148956~piPK:216618~theSitePK:4602123,00.html

SESSION I

INTEGRATED GROUNDWATER AND SURFACE WATER MODELLING – BENEFITS REALISATION

Jan van Wonderen
Mott MacDonald

ABSTRACT

Groundwater models became commonly used tools for groundwater assessment, management and planning since the 1970's. Although models were technically sound and able to represent the complexity of real groundwater systems, models were often developed as a one off. Models were constrained by computer capacity in terms of processing power and visualisation of model results. Advanced computer hardware now allows for detailed modelling and GIS and other visualisation and data processing facilities have greatly enhanced the value of models as advanced management tools. The integration of groundwater and surface water approaches enables the impacts of groundwater abstraction and/or groundwater recharge on surface water features to be quantified. Nowadays, models are often used to assess the impacts of natural and anthropogenic influences on wetlands and groundwater dependent terrestrial ecosystems, thus highlighting the need to consider the environment is an important groundwater user. European legislation has influenced the use of a fully integrated approach to groundwater models for long term resource management. Integration relates not only to combining groundwater and surface water, but is also important in the context of integrated water resources management (IWRM). Technical and non-technical aspects need to be addressed to enable benefits realisation. Aspects such as communication, stakeholder participation and adequate knowledge management and sharing have become important. Benefits realisation has become an essential aspect of groundwater modelling studies in the UK. Benefits accrue from the whole model development process. Realising benefits is important in the context of cost benefit analysis, where costly investment in model development needs to reap substantial benefits.

INTRODUCTION

Regional-scale groundwater flow models are widely used throughout the world to aid in the management of groundwater resources and to increase understanding of the behaviour of groundwater and its interaction with surface water and the environment.

Historically, modelling has been largely case specific and there was little standardisation in terms of type of model code and model practice. Modelling studies were commonly undertaken by specialists, often linked to universities, water companies, regulators, stakeholders and others. The studies were largely target orientated and did not involve significant stakeholder participation during the modelling study. The models generally suffered from a lack of comprehensive data, due to problems of access to historical data and adequate data sharing protocols. The latter is common in many overseas countries.

Completed models were generally not handed over to the institutions that are responsible for water resources management and were often, once completed, not used again. The models remained static and were not subjected to gradual improvement as more data became available and understanding of the water resource system was improved.

Groundwater models are commonly recognised as the best means of representing the processes operating in a groundwater system. However, they require considerable resources to develop, both financially and in commitment from those with specialist knowledge of water resources and related issues. Experience has shown that if these resources are not committed then the finished model may be inadequate for the tasks required.

This paper presents an outline framework for the development of regional distributed integrated surface water and groundwater resources models and the realisation of benefits from the whole modelling process. Such models can become effective tools for integrated groundwater and surface water management and resource utilisation planning. The framework methodology is largely based on that developed by the Environment Agency (EA) in the United Kingdom, who acts as regulator and guardian of the water environment. The EA in turn has drawn on experience from the USA, the Netherlands, Germany and Australia.

The significance of adopting a clear and comprehensive framework for water resources modelling is in the use of the models for activities related to a large number of potential future business drivers. Such business drivers often result from European legislation. Model use could relate to sustainable resource utilisation, to assisting with water permitting, to environmental impact assessment, etc.

The framework also takes account of stakeholder involvement in modelling studies. Stakeholder involvement is essential for a number of reasons, most notably:

- Potential conflicts of interest can be avoided when the aim amongst all is to reach consensus on model findings.
- Large amounts of factual and tacit knowledge reside with stakeholders and it is in the interest of all to make use, as extensively as possible, of all available data and knowledge.
- Consensus on model findings will increase the chances that resource management decisions (based on model prediction scenarios) are acceptable to stakeholders.

USE OF MODELS IN WATER RESOURCES MANAGEMENT

GENERAL

The sustainable development of water resources requires appropriate strategies with respect to surface water allocation and groundwater abstraction management. Optimal and yet sustainable development of groundwater (without compromising environmental needs and groundwater quality) is a major challenge. It requires a comprehensive understanding of the dynamics of the groundwater system and its relationship with the surface water environment.

This understanding can be adequately formulated as a quantitative conceptual model of the system and once embedded within an appropriate numerical model becomes the key to effective resource management.

Methods available for groundwater resources assessment can vary considerably in complexity. They may range from simple lumped water balance equations to complex distributed groundwater models integrated with surface water systems.

Simple lumped water balance models are cheap, but often very approximate and do not always allow for a good understanding of the dynamic nature of the groundwater system. Distributed groundwater models are expensive, require an accurate and comprehensive database and also require considerable expertise at all stages of model development. There are, however, considerable advantages of using complex distributed models:

- Groundwater systems are spatially variable and dynamic in their response to time-variant influences such as climate and human interventions (such as for example groundwater abstraction and use of river water for irrigation). Distributed numerical models allow for inclusion of both spatial and temporal variability and can most accurately approximate the real groundwater systems.

- A pre-requisite for the development of distributed groundwater models is an in-depth assessment of all available data and knowledge and the development of a comprehensive conceptual understanding of the behaviour of the groundwater system, both in space and time.

- In such models, data should be seen in a broad context and thus include all data of relevance to water balance components included in model simulation.

- If used appropriately, distributed models allow for a systematic assessment of uncertainty and allow for more focused programmes of field investigations and monitoring aimed at reducing uncertainty. Understanding uncertainty will also lead to a better appreciation of the reliability of model predictions.

- The models, although costly in developing, can reap substantial benefits through:
  - Significant improvement of the knowledge of the mechanics and dynamics of the integrated groundwater and surface water system.
  - Rapid assessment of a large number of potential future resource development and management options.
  - Risk aversion, particularly when the models have been adequately calibrated, are based on an accurate and comprehensive database and on a sound conceptual understanding of the integrated groundwater and surface water system.
  - Contributing to water resources and environment functions of the regulator. For example, it could be used in the assessment of permit requests in relation to water resource availability, or to assess alternative abstraction and discharge scenarios.
  - As a tool to evaluate the need for field surveys and additional monitoring data; it can result in considerable time and cost savings.
  - Use of the model as a tool for conflict resolution in relation to water resource or environmental issues and this may avoid the need for costly litigation.

There is, however, a need for caution when deciding on the costly route of distributed model development. In particular:

- The phrase '*a model is only as accurate as the data that feeds it'* holds true in many cases. It is essential to realise that the accuracy of a model relies heavily on the presence of a comprehensive database and its availability to the model developers.
- The development of a good model requires on the one hand a high degree of specialisation in hydrogeology and numerical modelling and, on the other hand transparency and involvement of stakeholders.

Furthermore, the model development should not be a one-off exercise. It should be seen as the start of a process of continued groundwater resource evaluation which will result in a gradual strengthening of the model as a resource management tool.

WHAT IS MODELLING?

Modelling is a Process and not a Computer Application

The process is sometimes termed the 'modelling cycle' and includes components such as:

- scoping;
- investigation and testing;
- monitoring;
- analysis;
- conceptualisation;
- use of evaluation tools such as analytical or numerical models; and
- documentation.

Such components are repeated on a regular basis. This multi-cyclical process is often referred to as the 'whole life' approach to investigations and modelling. It implies a continuing process of developing and enhancing the knowledge of groundwater systems and their inter-relationship with the surface water system and the water dependent environment. The multi-cyclical modelling process could cover a period of many years.

The first modelling cycle includes the initial scoping and the development and delivery of the model in a number of technical stages as illustrated in Figure 1. This is then followed by regular updates, validation and possible re-calibration representing the subsequent cycles. The reason for starting a new cycle could be a mismatch between model performance and field observations found during the model verification. It could also be necessitated by the need for the model to address issues that were not included during the first cycle of model development.

THE PURPOSE OF MODELLING

The purpose of a groundwater model can be considered in the context of both 'tactical' and 'operational' water resources management.

The 'TACTICAL' use of groundwater models relates to a holistic and basin-scale approach to understanding the role of integrated groundwater and surface water systems and the influences exerted upon them (either natural or anthropogenic). This approach is described in Table 1.Tactical uses could also be seen as developing preparedness for adverse conditions.

The 'OPERATIONAL' use of groundwater models relates to groundwater management functions. These are summarised and further clarified in Table 2.

These tables contain a list of possible drivers for modelling projects, but they are not inclusive of all possible uses of groundwater flow models.

BENEFITS REALISATION

GOOD PRACTICE

Good practice is an important pre-requisite for optimising benefits realisation. This is not only in obtaining the highest cost-benefit ratio in financial terms, but also relates to benefits that cannot be easily expressed in such terms. The latter refers, for example, to improved relationship between the regulator and the stakeholders, or to an improved profile towards the general public.

UK guidance on regional groundwater modelling defines good practice as the adoption and the use of standards of work, work procedures and methods that result in a product that is:

- of the highest technical standard that can realistically be achieved within the constraints of available data and budget;
- acceptable to all parties (including the regulator and major stakeholders) as the most appropriate tool;
- easily usable by those who are in need of the model data and simulation results;
- flexible in terms of the ability to update, further improve and modify to suit other purposes;
- capable of realising the intended benefits; and
- likely to have a long shelf life.

It is very important to be aware that realisation of benefits from modelling does not only result from high technical standards, but that aspects of team building and management, project organisation and staffing, communication and participation, appropriate knowledge/data management, data sharing and knowledge dissemination are equally important.

STAKEHOLDER PARTICIPATION

Major stakeholders generally involve water companies, other water users such as farmers (particularly when groundwater is used for irrigation), environmental interest groups and the end users of model results. It is important that stakeholders (particularly the major ones) are involved with model development during the whole modelling cycle and in particular:

- involvement of stakeholders in project preparation and in the technical development, making optimum use of knowledge that resides with their technical staff;
- there should be pro-active communication with stakeholders, which is initiated by the project management; and
- the requirements of the end users (those who will make use of model information and simulation results) need to be clearly identified through appropriate communication and participation of those end users in the model development process.

The benefits of stakeholder and end user participation cannot be under-stated. Local knowledge from stakeholders not only contributes to a better model, it also provides ownership of model development. Through participation, it also contributes to conflict minimisation, particularly if consensus on model results can be obtained.

COMMUNICATION AND PARTICIPATION

Benefits cannot be easily realised without well thought-out communication and participation strategies and with the appropriate implementation of such strategies. Communication and participation relate to the internal interaction between the modelling team and the functions that benefit from the model, and also between the regulator and the external stakeholders.

'Buy in' and 'ownership' are extremely important outcomes of good communication and participation and most important to successful benefits realisation. The following ground rules for interaction between people with differing technical background and experience should be embedded into the communication and participation strategies:

- **Account for the importance of people's knowledge and opinions** – this is very relevant as it makes people feel they can contribute.
- **Respect for all staff members regardless of age, gender and status** – respecting all staff members without distinction of gender, age and status, contributes to a rise in the level of participation.
- **Encourage participation in all of the actions –** when invitations to participate in activities are made, recognition of the importance of their knowledge and contribution should be made clear. In this way they feel confident about their contribution and rate it of high importance.
- **Provide clarity about all actions –** clarity should always be stimulated as a means to achieving understanding and successful outcomes of actions.
- **Avoid raising false expectations –** this is a very important rule and success is partly a result of applying it at all times. The aims and objectives should always be made very clear so that false expectations are not raised.

BENEFITS REALISATION

Benefits can be obtained throughout the model development process and are thus not limited to model simulation results only. Experience in the UK has shown that knowledge gained and presented during the development of a conceptual model is of great value to the various functions within the Environment Agency. The regional groundwater modelling studies aim at quantifying such benefits in financial terms, which is important for showing the value of the investments in modelling. During the 5-Yearly Review of modelling in the UK, completed in 2006, method statements were prepared that showed the potential contributions of the modelling process to the various drivers such as for example the Water Framework Directive (WFD). Figure 2 illustrates some of those links.

The emphasis on the non-technical aspects of the modelling process has resulted in the realisation of substantial benefits to both stakeholders and end users within the Environment Agency. There is a growing awareness of the benefits and this also clearly demonstrates that well-planned investment in the model development process is worthwhile.

Figure 1: Stages of a Groundwater Modelling Project

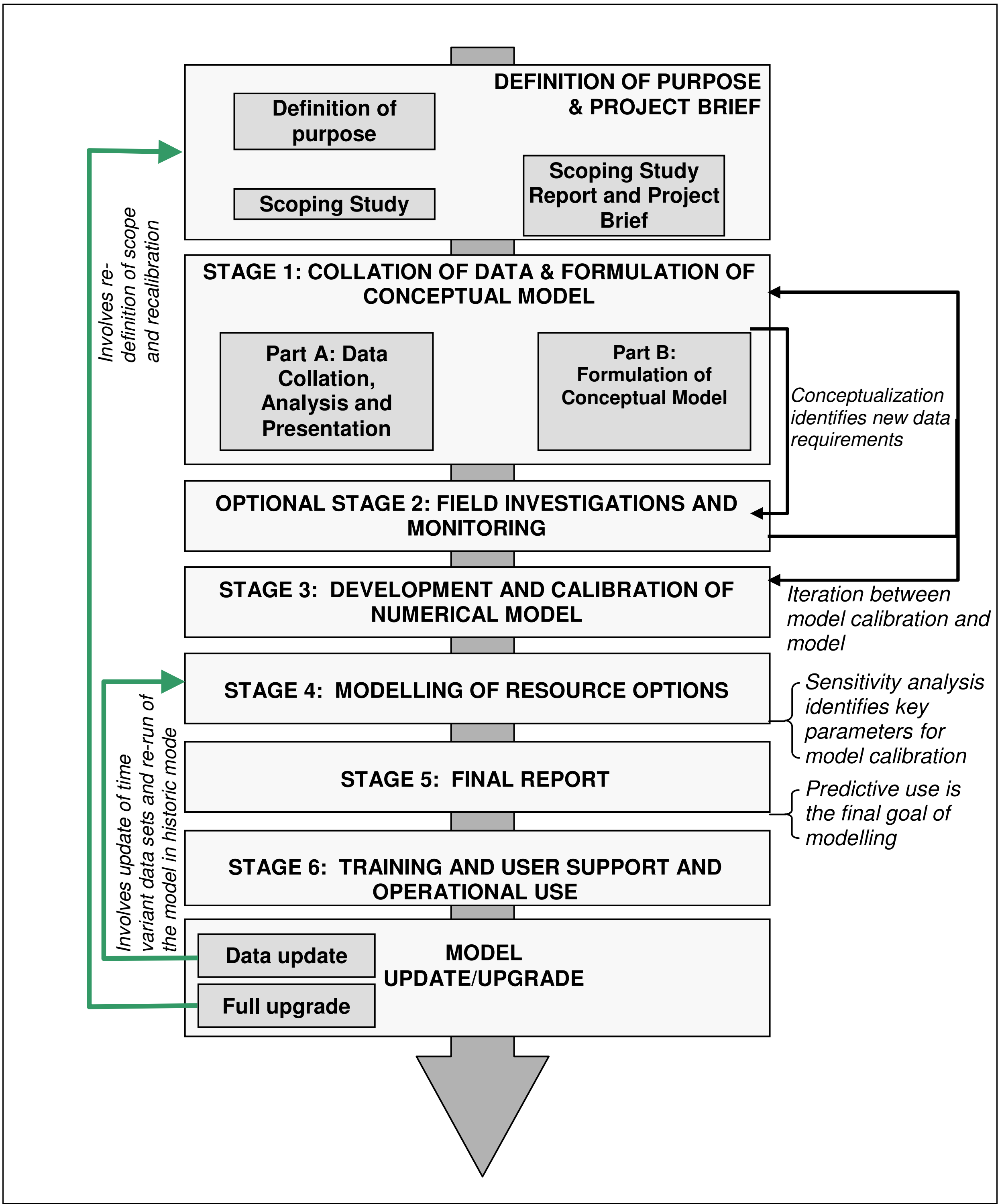


Figure 2: Model Benefits Links - WFD

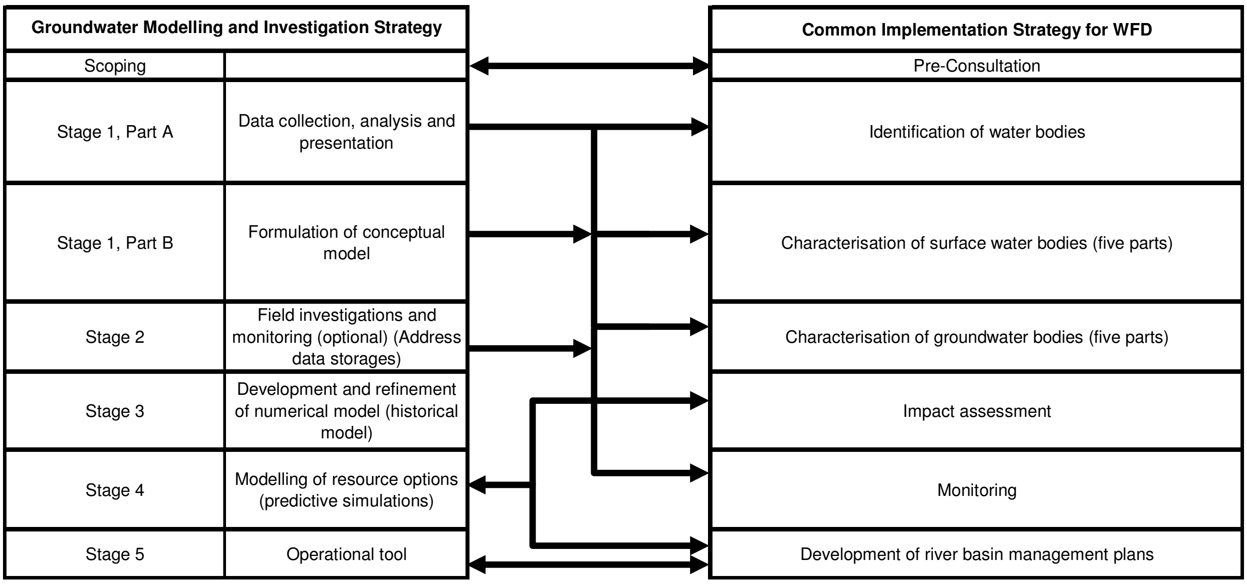


Table 1: Tactical Use of Groundwater Flow Models

Use	**Clarification**
Review of water resources management plans	This relates largely to the evaluation of the limits of sustainable water resources development
Local impact assessment	This relates to use of the model to assess impacts of different groundwater management options on users, springs, river flows and wetlands
Forecast of water supply yield for prevailing groundwater conditions	To establish the current resource state and from that determine the optimum groundwater use for the immediate future
Forecast of response of groundwater to drought	The use of the model helps in drought forecasting and thus the development of appropriate drought plans
Forecast the need for mitigation measures	This is linked to the previous use and relates to the use of models in assessing mitigation needs such as use of river water and cutback/cessation of abstraction
Forecast operational yield of artificial groundwater storage and recovery (ASR) schemes	To assess the net gain in the short and long term
Assess the implications of climate change	This relates to assessing the impact of climate change on groundwater resource systems
Assess the implications of land use change	This relates to the impact of land use change on the groundwater resource system
Design of an ‘optimum’ groundwater monitoring network	Models allow for evaluation of the ‘value’ of monitoring facilities

Table 2: Operational Use of Models

Function	Drivers	Clarification
Strategic Water Resources Planning	River basin management plans	Models are essential to assist in river basin planning and are required wherever sustainability approaches (such as for example reduced groundwater abstraction) are likely to be contested.
	Environmental impact assessments	Groundwater models can be used to assess the impact of groundwater abstraction on environmentally sensitive areas such as rivers, wetlands and groundwater dependent terrestrial ecosystems. Such assessments often relate to small-scale areas and regional models can be used to set the boundary conditions for local-scale modelling. More refined modelling processes may be required to gain more confidence in impact assessments.
Operational Management of Groundwater	Abstraction permitting	Because of their regional coverage, models can play an important role in abstraction permitting. Better informed decision making will lead to improved acceptance of decisions made by the permitting authority.
	Water availability forecasts	Abstraction up to the full permitted rates is sometimes required under adverse climatic conditions, particularly drought periods when surface water is in short supply. As for permit limit determination, models can play an important role in this duty.
Monitoring	Asset management of monitoring network and design of monitoring networks	The cost of monitoring can be very high, yet monitoring data is essential to accurate groundwater resource evaluation and thus to effective resource management. Models are very useful in analysing how important certain data are to the accuracy of model predictions. Models therefore help to design monitoring systems that maximise model accuracy and minimise costs.
Groundwater Quality	Framework for groundwater quality investigations	Groundwater quality is generally closely linked to groundwater flow and the input and output components of groundwater systems. Regional groundwater flow models can be seen as a first step in the evolution to more comprehensive flow and contaminant transport models.
	Groundwater protection zones	Time-variant groundwater models are reliable tools to asses the dynamic nature of groundwater protection zones.
	Diffuse pollution	Regional groundwater flow models are powerful tools to assess groundwater movement with time. They can form the basis for diffuse pollution modelling.
	Contaminated land	Regional groundwater models provide a good insight into the potential fate of pollutants originating from the contaminated land sites. More sophisticated modelling, probably at more localised scale, would be needed to obtain a more in-depth understanding of pollutant transport from localised contaminated land.

INTEGRATING SURFACE AND SUB-SURFACE WATER FLOW SIMULATIONS FOR IMPROVED CLIMATE CHANGE IMPACT ASSESSMENTS ON THE GROUNDWATER SYSTEM

Jef Dams[1] and Okke Batelaan[1, 2]
[1]Dept. of Hydrology and Hydraulic Engineering, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium and [2] Dept. of Earth and Environmental Sciences, K.U.Leuven, Celestijnenlaan 200e-bus 2410, 3001 Heverlee, Belgium

ABSTRACT

Global land-use and climate changes are increasingly threatening water resources worldwide. Fast urbanization and altered climatic conditions are significantly influencing the hydrological cycle both on a global and on a local scale. Until recently hydrological impact assessments primarily focused on flood events. However, current climate change simulations predict a decreasing future water availability in large parts of the world, including Belgium. In order to assess the impact of droughts on the water availability the groundwater system is crucial. The majority of the previous model studies oversimplified the groundwater system as they focused on flood prediction. In this research we integrated a surface and sub-surface water model. In this way we are able to assess the impact that global changes have on the surface water balance further on the groundwater system. The methodology was tested on a lowland catchment in Belgium. Results show that the groundwater level is predicted to decrease from September to January when comparing the climate change scenarios developed for the period 2071-2100 with the reference period 1961-1991. However, because of higher groundwater recharge during winter, the total annual groundwater reserves of the basin decrease only slightly due to climate change. Groundwater discharges in turn are expected to decrease during late summer and autumn while simulations for winter and early spring fluctuate around the groundwater discharge simulated for 1960-1991.

INTRODUCTION

Climate models predict for North-West Europe a significant rise in potential evapotranspiration (PET) while the precipitation is expected to increase during winter but to decrease during summer (Bagius, 2009). Since changes in PET and precipitation directly influence groundwater recharge, groundwater resources and fluxes will be affected. Given the strategic importance of groundwater as a source of drinking water (WWAP, 2009) and for the existence of groundwater dependent terrestrial ecosystems (GWDTEs), protected by the Groundwater Directive in Europe (EU, 2006), it is important to assess the impact of climate changes on these resources.

In earlier studies on the impact of climate changes on hydrology, the focus has been primarily on flood events. As a result, the impact of climate changes on groundwater systems is not studied extensively until now but is gaining interest over the last decade. Especially, the impact of climate change on groundwater recharge has received attention so far by applying methods with various degrees of complexity ranging from simple linear to distributed physically based hydrological models (Hendricks Franssen, 2009). Generally, these models are steady state models, which means they simulate changes for an average condition, or apply yearly or seasonal time steps (Scibek and Allen, 2006; Woldeamlak *et al*., 2007). Only recently, van Roosmalen *et al.* (2009), Toews and Allen (2009) and Goderniaux *et al.* (2009) applied a physically based model using a high temporal resolution.

In order to properly assess the impact of climate change on the groundwater system there is a need for an improved integrated surface and groundwater modelling approach. In this research we couple a WetSpa surface water model with a MODFLOW sub-surface water flow model to improve the impact assessment of climate change on the groundwater system. This model integration allows for the analysis of the intra-annual response of a groundwater system to climate changes. These intra-annual changes determine the groundwater resources as well as site conditions of GWDTEs (Naumburg, 2005). The climate for the reference period, 1960-1991, is compared with climate scenarios, predicted for 2071-2100. Due to the high variability of climate change predictions between different climate change models, an ensemble of twenty-eight climate change scenarios is chosen from the European project PRUDENCE (Christensen and Christensen, 2007). By applying this ensemble of climate change models we obtain uncertainty bounds on the impacts of the climate change on the groundwater system. We limit the study to climate change impacts, disregarding other expected changes such as land-use change (Dams *et al.,* 2008).

The focus in this paper is on the sensitivity of a groundwater system in Belgium to climate change. The groundwater system comprises 581 km², is part of the Scheldt basin and serves in this study as a type case of an extensive sedimentary aquifer system with important water resources and ecological functions. We applied a spatial-temporal distributed approach to model the climate change impact on groundwater recharge, head and flux.

STUDY AREA

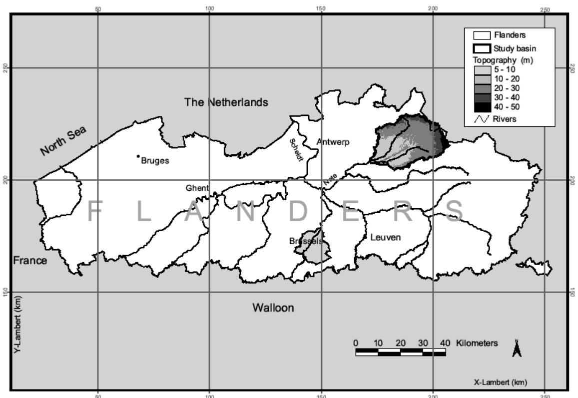


Figure 1: Location of the study area

The study area is located in Belgium about 60 km north-east of Brussels and comprises the basin of the Kleine Nete, about 581 km² (Fig. 1). The elevation above sea level ranges from 3 to 48 m, the average elevation is about 24 m, the average slope 0.4%. Interfluves are slightly elevated, the valleys broad and swampy. The dominant soil texture is sand, though in the valleys some loamy sand, sandy loam and sandy clay is present. The region has a temperate climate characterized by a warm summer and a cool winter with little snowfall. Precipitation is distributed almost equal over the winter and summer period. The average annual precipitation during the period 1960-1991 was 828 mm with a standard deviation of 136 mm. The long term average annual potential evapotranspiration (PET) is 664 mm with a standard deviation of 47 mm. Sandy deposits of Miocene, Pliocene and Pleistocene form a high productive aquifer with a depth of roughly 200 metres (Wouters and Vandenberghe, 1994). The land cover in the study basin consists mainly of agricultural fields including meadows (60%), coniferous and mixed forest (20%) and urban areas (10%). Groundwater is extensively used in the basin; in total there are 565 wells, which extract a total of 54,291 m³/day of which about 30,200 m³/day is extracted by a public drinking water company.

The Kleine Nete basin comprises several areas with an important ecological function; some of these areas are part of the European Natura2000 network, set up for the protection of Europe's most vulnerable habitats. Several of these habitats depend largely on good hydrological conditions: oligotrophic and mesotrophic waterbodies, Northern wet heaths, Shady woodland fringes, Atlantic Quercus robur – Betula woods, Alnus-Fraxinus woods of rivulets and springs, etc.

METHODOLOGY

CLIMATE CHANGE SCENARIOS

The groundwater characteristics for the reference period 1960-1991 are compared with climate scenarios for the period 2071-2100. Climate change scenarios are obtained from the PRUDENCE database and combine several General Circulation Models: ECHAM4/OPYC, HadAM3H, HadAM3P, ARPEGE and HadCM3and Regional Circulation Models: RCAO, RACMO, HIRAM, CHRM, HadRM3P, REMO, ARPEGE, CLM and PROMES (Christensen and Christensen, 2007). All scenarios applied in this research are based on the A2 and B2 world views (Nakicenovic et al., 2000). For each of the 28 scenarios PET and precipitation are simulated.

INTEGRATED SURFACE - GROUNDWATER MODELLING

To understand complex natural systems, scientists have always had the tendency to focus on a part of the system with detailed description of the physical processes. Even within hydrological research there are many specializations focusing on for example surface hydrology, water quality, eco-hydrology, hydrogeology, etc. The most important scientific advancement in the field of hydrology during the last decades has been the development due to computer models. These models allow one to simulate with a certain complexity the hydrological processes at a location where data is available. Because of the specialized research focus many of these models focus on one aspect of the hydrological cycle only, while simplifying other processes.

Recently, hydrological models are often applied to assess the impact of global changes such as land-use change or climate changes on the hydrology. With respect to the impact assessment of these global changes on the hydrological system there is an increasing need for models that integrate all processes that could play a role. The further integration of different compartments of the earth system is required to understand for example feedback mechanisms between these systems. In this research we aim to assess the impact of climate change on the groundwater system, including its temporal dynamics. Therefore, it is required to integrate the surface water system with the groundwater system. We choose a coupling of the WetSpa, surface water model with a MODFLOW groundwater flow model.

WetSpa

The WetSpa model (Water and energy transfer between Soil plant and atmosphere) is a GIS-based distributed hydrological model originally developed by Wang *et al.* (1996) and adopted for flood prediction and water balance simulation at catchment scale by Liu *et al.* (2003). The model is physically based and simulates hydrological processes of precipitation, interception, excess rainfall, soil moisture storage, interflow, percolation, evapotranspiration, groundwater storage and discharge continuously in both time and space for which the water and energy balance is maintained on each raster cell. The simulated hydrological system consists of four control volumes: the plant canopy, the soil surface, the root zone, and the saturated groundwater aquifer (Figure 2).The model utilizes hydro-meteorological data and three basic digital maps: topography, land-use and soil type to derive the model spatial parameters with the help of ArcView scripts. The main outputs of the model are river flow hydrographs and spatially distributed hydrologic characteristics. Due to its fully distributed nature, it is a suitable model for integrating the vast amount of spatially and temporally distributed data for impact analysis studies.

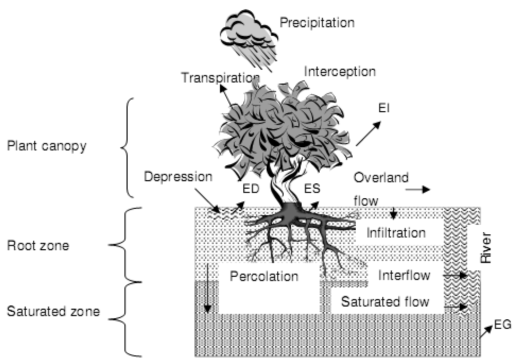


Figure 2: Hydrological processes considered in WetSpa model (Solomon, 2007).

The WetSpa model was calibrated using the measured river discharges and estimated baseflow at the catchment outlet. Model efficiencies for the validation period (1997-2001) are 73%, 62% and 72% for the Nash-Sutcliffe coefficient, model efficiency for low flows and model efficiency for high flows, respectively. These efficiencies show that the model is performing well both for high and low flow. The estimated baseflow from the WetSpa model was compared with the baseflow derived from an automated baseflow filter (Arnold and Allen, 1999). Looking at the baseflow filters as observations, the baseflow estimated with WetSpa has a Nash-Sutcliffe efficiency of 87%.

MODFLOW
In this project, MODFLOW (Harbaugh and McDonald, 1996) is used for simulating groundwater flow. MODFLOW is an extremely versatile finite-difference groundwater model that simulates three-dimensional groundwater flow through a porous medium. MODFLOW solves the general form of the 3-D groundwater flow equation, which is derived by combining Darcy's law with a water balance equation and subjected to initial and boundary conditions:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t}$$

where K_{xx}, K_{yy} and K_{zz} are hydraulic conductivities along the x-, y- and z-coordinate axes [LT^{-1}], h is the hydraulic head [L], W is a volumetric flux per unit volume that accounts for pumping, recharge, or other sources and sinks [T^{-1}], Ss is the specific storage [L^{-1}] and t is time [T].

Important boundary conditions of MODFLOW are defined by the Recharge, Drain and River packages. The Recharge package, a specified flux boundary condition, is applied to simulate a specified flux distributed over the top of the model. Within MODFLOW, these rates are multiplied by the horizontal area of the cells to which they are applied to calculate the volumetric flux rates. The River package specifies a head-dependent flux boundary condition for rivers, canals and lakes. If the head in the cell falls below a certain threshold, the flux from the river to the model cell is set to a specified lower bound. The watershed boundaries of the model are set to no-flow boundaries. The drainage from ditches and small streams are simulated with the DRAIN package.

The MODFLOW model is calibrated using 10,226 head observations, measured between 1992 and 2001, from 113 observation wells more or less equally distributed over the basin. A steady state version of the groundwater model is calibrated on the river conductance, drain conductance and horizontal hydraulic conductivity. When reasonable results are obtained the calibration is continued on the transient model. The final result has an average BIAS, between observed and simulated hydraulic heads, of -0.03 m, a mean average error of 0.59 m and a root mean square error of 0.81 m.

WetSpa and MODFLOW integration
The integration of the WetSpa and MODFLOW models is done through the adaption of the boundary conditions of the MODFLOW model according to results of the WetSpa simulations. With respect to the groundwater recharge the integration is straightforward. The spatially distributed groundwater recharge simulated with WetSpa for every time step is incorporated in the MODFLOW Recharge package. In this approach, for every stress period MODFLOW reads the groundwater recharge map.

Besides the groundwater recharge, the hydraulic head in the open water bodies also has an important impact on the groundwater flux. As WetSpa is a hydrological model and is not coupled to a hydraulic model, river heads are not directly available. However, a relation exists between the simulated flow in the river and the hydraulic head of the river. A simplified methodology is applied to estimate the river head values in each 50 meter transect of the River during each stress period. From a hydraulic model of the major rivers in the basin average hydraulic head profiles were calculated for different discharges at the basin outlet. Depending on the discharge at the outlet simulated by WetSpa for that stress period a specific hydraulic profile is selected for the upstream river head and incorporated into the MODFLOW model.

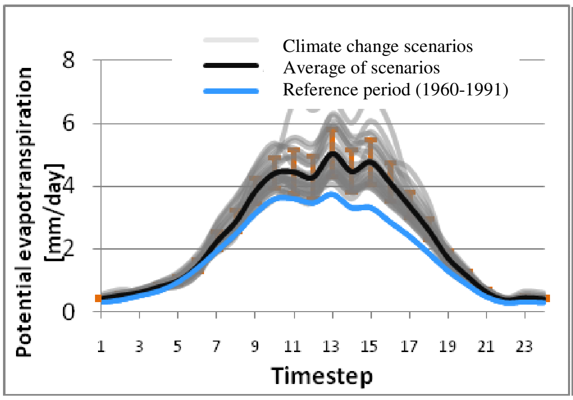
The Wetspa and MODFLOW coupling allows one to assess propagation of changes in the surface water system to the groundwater system. Changes in the surface water could for example be introduced by land-use or climate change. Furthermore, advantages of the applied integrated methodology include the relatively fast calculation time and simplicity to apply the methodology. Both the simplicity and speed are a consequence of the one-directional exchange of data, from WetSpa to MODFLOW. The disadvantage of this one-directional exchange is that the groundwater system which is simulated with a simple linear reservoir approach in the WetSpa model is not updated with the more accurate groundwater flux information obtained from MODFLOW.

RESULTS

CLIMATE SCENARIOS

Evapotranspiration and precipitation are the major climatic factors influencing groundwater recharge. Figure 3 illustrates the impact of the climate change scenarios on the inter-annual dynamics in potential evapotranspiration (PET) following the 28 climate change scenarios. The graphs in Fig. 3 and 4 connect the half monthly PET and precipitation amounts (mm/day), respectively, averaged for the 32 years considered, simulated for the reference period (blue line), the scenarios (grey lines) and the average of all scenarios (black line). Orange bars show the standard deviation of the different scenarios.

From Fig. 3 we read that during winter the PET is low and is not expected to change significantly for the future scenarios. During summer, however, all scenarios project an increase in potential evapotranspiration with on average 1 mm/day and a standard deviation between the scenarios of 0.75 mm/day.



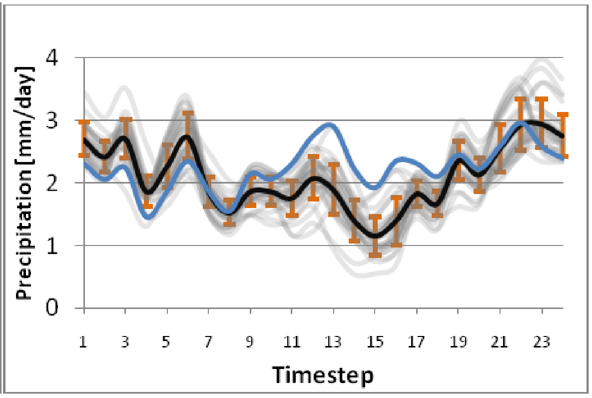
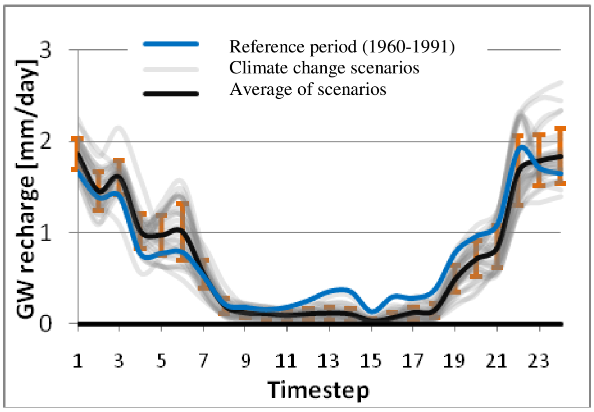


Figure 3 & 4: Average intra-annual variability of PET (Fig. 3) and Precipitation (Fig. 4) for the reference climate (1960-1991), climate scenarios (2071-2100) and the average of the climate scenarios.

During the reference period (1960-1991) the average precipitation was 821 mm/year. The average future precipitation predicted by the climate change scenarios is 767 mm/year, with a standard deviation of 36 mm/year between the different scenarios. Generally, an increase in precipitation is projected for the ‘winter’ months (roughly November – April) while a decrease is projected for the ‘summer’ months (Fig. 4). On average the scenarios predict around 100 mm less precipitation during ‘summer’ and about 50 mm more for ‘winter’. Although all simulated scenarios follow roughly the same trend, there is a relatively large spread in the predicted amount of future precipitation.

GROUNDWATER RECHARGE AND HEAD



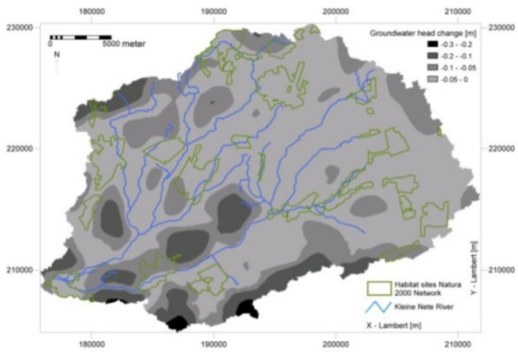


Figure 5: Average intra-annual variability of groundwater recharge for the reference climate (1960-1991), climate scenarios (2071-2100) and the average of the climate scenarios & Fig. 6: Change in average groundwater head over the same timeframe considering the average of the climate scenarios.

Figure 5 illustrates the intra-annual dynamics of groundwater recharge simulated for the reference (blue) and climate change scenarios (grey) estimated by WetSpa. Orange bars show the standard deviation from the different future climate scenarios. Similarly with precipitation, the groundwater recharge decreases from April to November and increases from December to March. During the period 1960-1991 the average simulated groundwater recharge is 291 mm/year. The average future groundwater recharge predicted by the WetSpa model is 271 mm/year.

Figure 6 shows the difference between the average groundwater heads of all future scenarios and the current average groundwater map. Due to a convergence problem of the MODFLOW model with scenario CNRM-DE6, this scenario was excluded in all further analyses. From Fig. 6 it is clear that the lowest change in average groundwater head occurs in the valleys. The largest changes occur near the ridge and near the borders of the catchment where the groundwater head drops up to 0.3 m. On average the groundwater head declines with 7 cm, from 2.07 m to 2.14 m below topography with a standard deviation between the different pixels of 4 cm and between the different scenarios of 5 cm.

DISCUSSION AND CONCLUSIONS

The developed methodology couples the hydrological model WetSpa with the groundwater flow model MODFLOW. Validation results show the ability of the WetSpa and MODFLOW model to estimate the groundwater recharge and groundwater head, respectively. This study is one of the first that applies such a hydrological–groundwater flow coupling under highly transient conditions. Additionally, the traditional coupling including only the groundwater recharge, applied for example by Woldeamlak *et al.* (2007) and Scibek and Allen (2006), was extended by applying the river heads from the main rivers, estimated from the WetSpa model, in the RIVER package of the MODFLOW model. Similar to Van Roosmalen *et al.* (2009) it is observed that our groundwater flow model captures the dynamics over time quite well, even though the mean simulated and observed values may differ considerably. However, because in the context of this paper we are mainly interested in comparing future scenarios with the current state, getting the groundwater dynamics right is more vital than obtaining the correct groundwater depth.

The uncertainty of the future precipitation and PET is high; to account for this uncertainty it is chosen to work with an ensemble of 28 different climate change scenarios, obtained from the PRUDENCE database. The results show a significant spread between the different scenarios. It is important to be aware of this uncertainty and look at the results as projected trends rather than exact changes.

In our study area, climate changes seem to result in a significant decrease in groundwater recharge. This decrease in groundwater recharge leads to an important decrease in groundwater head and flux. Analyses show that especially the yearly, lowest groundwater levels decrease, while the highest groundwater levels stay more or less constant. Model simulations also show that groundwater discharge will be influenced by climate change. Both groundwater discharge frequency and flux are predicted to decrease, especially in areas currently receiving relatively little groundwater discharge. As the groundwater discharge is a controlling factor for some protected natural habitats in the study basin, the predicted decrease could result in a loss of valuable vegetation types in the study area.

From this study it can be concluded that predicted changes in the groundwater system are highly variable in space and time. In future climate change impact assessments of the groundwater system, both time and space discretization should be well considered. To receive more insight knowledge on the impact of climate change on the groundwater system, similar studies should be applied to different catchments to incorporate both the spatial variability of the climate change and the effect of the basin characteristics.

Further research should examine how models could be improved for assessing the impact of climate change on the groundwater system, e.g. including vegetation growth, physically based ET calculation, hourly time discretization, further coupling of surface-subsurface processes without increasing the data requirements and computation time too extensively.

REFERENCES

Arnold J.G. & Allen P.M. Automated methods for estimating base flow and groundwater recharge from streamflow records. *J. of Amer. Water Res. Assoc.* 35, 411-424 (1999).

Bagius, P., Roulin, E., Willems P. & Ntegeka V. Climate change scenarios for precipitation and potential evapotranspiration over central Belgium. *Theor. Appl. Climatol*. 99, 273-286 (2009).

Christensen J.H. & Christensen O.B. A summary of the PRUDENCE model projections of changes in European climate by the end of this century. *Clim. Change* 81, 7-30 (2007).

Dams J., Woldeamlak S.T. & Batelaan O. Predicting land-use change and its impact on the groundwater system of the Kleine Nete catchment, Belgium. *Hydrol. Earth Syst. Sci.* 12, 1369-1385 (2009).

European Community. Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of Groundwater against pollution and deterioration. *Official Journal of the European Union* 372, 19-31 (2006).

Goderniaux P., Brouyere S., Fowler H.J., Blenkinsop S., Therrien R., Orban P. & Dassargues A. Large scale surface-subsurface hydrological model to assess climate change impacts on groundwater reserves. *J. Hydrol.* 373, 122–138 (2009).

Harbaugh A.W. & McDonald M.G. *MODFLOW-2000, the US Geological Survey modular groundwater model – User guide to modularization concepts and the groundwater flow process.* (USGS Open-File Report 00-92, Virginia, US, 2000).

Hendricks Franssen H.-J. The impact of climate change on groundwater resources. *International Journal of Climate Change Strategies and Management* 1, 241–254 (2009).

Liu Y.B., Gebremeskel S., De Smedt F., Hoffmann L. and Pfister L., 2003. A diffusive transport approach for flow routing in GIS-based flood modelling. *Journal of Hydrology*, 281, 91-106.

Nakicenovic N. et al. *IPCC Special Report on Emissions Scenarios* (eds Nakicenovic, N. & Swart, R.) (Cambridge Univ. Press, Cambridge, UK, 2000).

Naumburg E., Mata-Gonzalez R., Hunter R., Mclendon T., & Martin D. Phreatophytic vegetation and groundwater fluctuations: A review of current research and application of ecosystem response modeling with an emphasis on Great Basin vegetation. *Environ. Manage.* 35, 726–740 (2005).

Scibek J. & Allen D.M. Modeled impacts of predicted climate change on recharge and groundwater levels. *Water Resour. Res.* 42 doi:10.1029/2005WR004742 (2006).

Toews M.W. & Allen D.M. Simulated response of groundwater to predicted recharge in a semi-arid region using a scenario of modeled climate change. *Environ. Res. Lett.* 4, 035003 (2009).

van Roosmalen L., Sonnenborg T.O. & Jensen K.H. Impact of climate and land use change on the hydrology of a large-scale agricultural catchment. *Wat. Resour. Res.* 45, W00A15 (2009).

Wang Z.M., Batelaan O. and De Smedt F., 1996. A distributed model for water and energy transfer between soil, plants and atmosphere (WetSpa). *Physics and Chemistry of the Earth,* 21(3): 189-193.

Woldeamlak S.T., Batelaan O. & De Smedt F. Effects of climate change on the groundwater system in the Grote-Nete catchment, Belgium. *Hydrogeol. J.* 15, 891–901 (2007).

World Water Assessment Programme. *The United Nations World Water Development Report 3: Water in a Changing World.* (UNESCO, Paris, France & Earthscan, London, UK, 2009).

GROUNDWATER FLOODING MECHANISMS

Kieran O'Dwyer
J B Barry and Partners Ltd.

ABSTRACT

The implementation of the EU Floods Directive requires flood risk from groundwater sources to be considered. There is little known of groundwater flooding in Ireland. The OPW floods database contains very few records of specific groundwater flooding events. This paper reviews the principals of groundwater flow and how an aquifer responds to changes in conditions resulting from extreme or prolonged rainfall events. The conditions leading to groundwater flooding are a dynamic response of the aquifer to adjust to these changes. The water level in the surface water feature to which the groundwater provides baseflow dictates water level in the aquifer. A series of groundwater flooding scenarios (natural and manmade) are described together with the mechanisms that create the conditions conducive to groundwater flooding.

INTRODUCTION

Directive 2007/60/EC on the assessment and management of flood risks entered into force on 26 November 2007. This Directive now requires that Member States undertake Catchment Flood Risk Assessment and Management Studies (CFRAMs) to assess if catchments and coastlines are at risk from flooding and to map the flood extent and assets and humans at risk in these areas, and to take adequate and co-ordinated measures to reduce this flood risk.

These studies require the following types of flooding to be addressed:

- Fluvial
- Pluvial
- Coastal
- Groundwater

It is clear that an integrated approach is required. Historically, hydrology and hydrogeology have been regarded as two distinct disciplines and only scant attention has been paid to interactions between groundwater and surface water. Groundwater modelling predicts the groundwater regime and surface models predict the surface water regime. However, the two are intrinsically interconnected and the influence of one on the other is often not fully understood or addressed.

This paper will focus on the groundwater flooding element and endeavours to provide an understanding of the factors and conditions which are required in order for groundwater flooding to occur. It will also highlight the areas where the response of groundwater and surface water can mutually influence each other after extreme rainfall events. Various scenarios are presented where groundwater emergence can result in flooding.

GROUNDWATER FLOW PRINCIPLES

When considering the likelihood of groundwater flooding it is important to understand the factors that control groundwater flow. Groundwater flooding is a <u>response</u> to particular events rather than a steady state scenario with constant inputs.

RECHARGE

The volume of groundwater that is available to flow through the aquifer is dependent on the amount of precipitation that can enter an aquifer. Recharge is the component of precipitation that infiltrates downward to recharge the aquifer. The quantity of this component is dependent on the rate of infiltration which is in turn dependent on the composition of the overburden material (i.e. there is a limit to the rate of recharge). Extreme precipitation events of short duration will result in a very high proportion of surface runoff while the rate of recharge will be similar to that during much less extreme events. Extreme short duration rainfall events can have a major impact on the flows in streams and rivers. However, it is prolonged rainfall events that impact most on groundwater flow. The intensity of precipitation may be less but there is more constant recharge to the groundwater environment.

Vulnerability mapping may be used to provide an indication of the relative rate of recharge to aquifers. Rates of recharge for a precipitation event can vary over an aquifer depending on the composition of the overburden material.

GROUNDWATER FLOW

The recharge that enters the aquifer flows through the permeable strata until it discharges as baseflow to surface water features (lakes, rivers, streams, sea). Groundwater can also emerge at specific locations such as springs. Baseflow contribution to surface water flow is very small during flood events.

The groundwater flow regime is dictated by simple hydraulic principles which become complex when considered in a dynamic context.

Darcy's Law is used as the basis to describe the flow of groundwater through an aquifer.

$$Q = -KA\frac{dh}{dl}$$

Groundwater flow is often considered in terms of a steady state scenario which provides a generalized concept of the flow regime. However, with groundwater flooding we need to consider the response of the flow regime to changes in these variables.

Q is the flow through the aquifer and is dependent on the recharge. The flow through the aquifer will be greater during winter months when the recharge is higher.

K is the hydraulic conductivity of the aquifer and can be considered as a measure of the ease with which groundwater can flow. In hydrogeology the product of the hydraulic conductivity and the aquifer thickness provides a characteristic called transmissivity which can be used to estimate the volume of flow through an aquifer.

Hydraulic gradient (*dh/dl*) is denoted as *i.* This can be considered as the pressure required to push a specific flow of groundwater through an aquifer. A change in the groundwater level at a point will result in a change in the hydraulic gradient. After periods of high recharge the quantity of groundwater that needs to flow through the aquifer increases. The hydraulic gradient increases in order to respond to this need. Similarly, after periods of little or no recharge the quantity flowing though the aquifer is less and the hydraulic gradient needed is less steep. This is reflected in the seasonal variation in groundwater levels. The range in fluctuation will be a function of the hydraulic conductivity and aquifer thickness (transmissivity), storage and recharge. The hydraulic gradient can also vary in response to changes in the water level in the water body to which it provides baseflow. If the water level in the receiving surface water channel rises the hydraulic gradient pushing the groundwater to the river as baseflow changes. This can lead to a reversal in the direction of flow. More importantly, it results in a backwater effect away from the river as the groundwater builds up in response to the rise in the free boundary at the river. This backwater effect will lead to a rise in the water level back up the aquifer until the gradient that is the pressure is sufficient to drive the groundwater through the aquifer to discharge again in the river as baseflow.

Storage: The storage available within the aquifer and overburden is another consideration in the understanding of groundwater flooding. A rise in the water table is a reflection of water going into storage.

In groundwater flooding, the response of this sensitive hydraulic system results in the water table increasing to the extent that it intercepts the ground surface.

GROUNDWATER FLOODING

Groundwater flooding occurs when the water table at a location (point or diffuse) rises to such an extent that groundwater emerges at the ground level (or in subsurface structures) where it is not normally experienced. Elevated groundwater level (piezometric surface) above the ground level is a pre-requisite for groundwater flooding to occur.

In Ireland data and records of groundwater flooding are sparse. The lack of records (apart from turlough flooding) would suggest that this is not a major issue.

It should be noted that the emergence of groundwater as a result of a rise in the water table does not necessarily result in flooding. For the emergence to be classed as a flooding event the groundwater must spread out over an area. Seasonal springs are not considered as flooding incidents as there is usually a channel that will convey the discharge to a water course. Similarly, ephemeral streams at the headwaters of catchments will flow in predefined channels and do not result in flooding. The concern is where the emergence of groundwater results in inundation. Therefore, the surface drainage pathways must be considered when assessing flooding risk.

When the groundwater emergence has no clear surface pathway to a surface water feature groundwater flooding occurs. Turloughs are an excellent example of this. After a heavy rainfall event the water table rises until a discharge occurs, usually at the low point in a depression. Ponding will occur as the water table continues to rise until a level is reached that provides sufficient pressure to drive the groundwater flow within the aquifer beneath or until the ponding reaches a level whereby it can escape overland via pathways or channels to a watercourse.

EXISTING GROUNDWATER FLOODING RECORDS

The OPW maintain a database of flooding data collected from Local Authorities, Regional OPW staff and other sources. While there is a field in the dataset that describes the source of the flooding, the descriptions are very general and do not specifically identify groundwater flooding events. The exception to this would be flooding where the source is described as a turlough which is a feature of karst limestone aquifers and have a clear groundwater dimension. The GSI do have a database of turloughs and a detailed study was undertaken in connection with flooding in the Gort area of County Galway.

Another description used is “low lying ground” which could be descriptive of groundwater flooding due to a high water table but is just as likely to refer to fluvial or pluvial flooding.

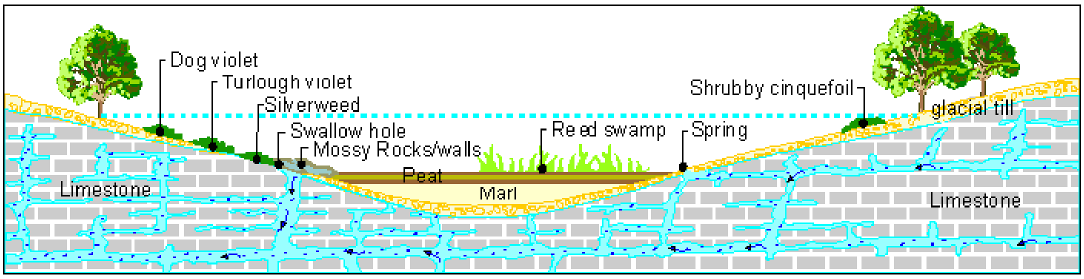
Apart from flooding due to turloughs it is very difficult to distinguish whether there is a groundwater component to flooding events in low lying ground as there is usually a more obvious and significant fluvial or pluvial component.

GROUNDWATER FLOODING SCENARIOS

The dynamics of groundwater flooding is dependent on the type of aquifer and its hydrogeological characteristics will define whether and how groundwater flooding could potentially occur. There are a number of mechanisms or combination of mechanisms by which the groundwater level can rise to the extent that groundwater emergence will occur.

a) Turlough Flooding (Karst Aquifers)

These are found in karstic limestone environments predominantly in the west of Ireland and are seasonal lakes which flood in response to rainfall recharge. They are generally located in low lying areas where the water table is high. Flooding in these environments can last for extended periods. The flow system is a complex interaction between the surface and groundwater regimes. Excessive recharge during prolonged extreme rainfall results in the water level rising and aquifer storage being exceeded; the aquifer will reach throughflow capacity resulting in overflow (discharge) at low points where the water table reaches ground level. These aquifers usually have low storage and rapid recharge pathways. The most significant flooding associated with turloughs has been in the Gort area of Galway.



b) Unconfined Sand/Gravel Aquifers

These aquifers are unconfined and consist of saturated sands and gravels. There is a natural high water table level close to ground surface. Extreme rainfall causes the water level (which is normally close to the surface) to rise to the extent that the sand/gravel deposit is saturated and the aquifer fills up, and the water table breaks the surface in localised low lying areas. In local low lying depressions this results in flooding. It should be noted that these areas would also be prone to pluvial flooding. The natural drainage of these deposits is good and flood recedes quickly.

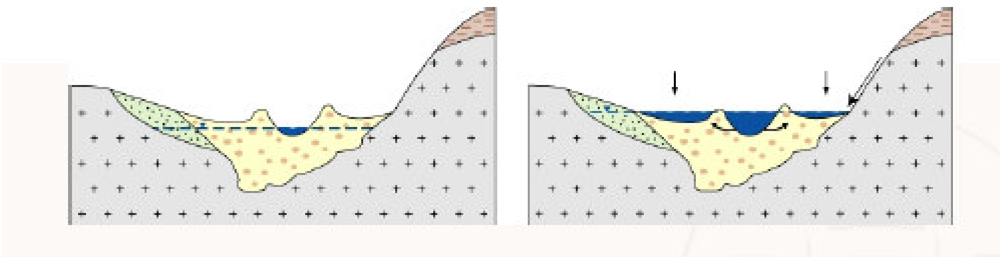
c) Unconfined Alluvial Sands and Gravels

These permeable deposits are found in flood plains close to natural surface drainage channels and the flooding is coincident with fluvial flooding. The mechanisms that can change the hydraulic gradient within the groundwater body resulting in flooding can occur simultaneously.

- River flood levels: The water level in the river controls the groundwater gradient. High runoff to the river as a result of extreme rainfall will cause the water level to rise naturally in response. The response of the water level in the river will be faster than the response of the water level in the aquifer. The increase in head at the river will cause a back up in the groundwater flow as the groundwater needs a steeper gradient for throughflow and this can result in the water table breaking the ground surface in low lying areas resulting in flooding. This backup effect and the increase in hydraulic gradient can result in areas which are topographically higher than the flood water level in the river becoming flooded by groundwater due to the water table breaking the ground surface. River water levels can also be increased when in-bank storage is utilised as part of a flood defence system.

- Increase in recharge: Rainfall infiltration volumes recharging the aquifer will increase after extreme prolonged rainfall. In order for the aquifer to facilitate the throughflow of this increased quantity, an increase in the hydraulic gradient is required. Because a steeper gradient is required and the water level in the watercourse to which the baseflow discharges is the control, there will be a rise in groundwater level away from the river. The magnitude of the rise will increase with distance. In flat terrain the increase in gradient can result in the water table intercepting the ground surface resulting in an emergence of groundwater at that point.

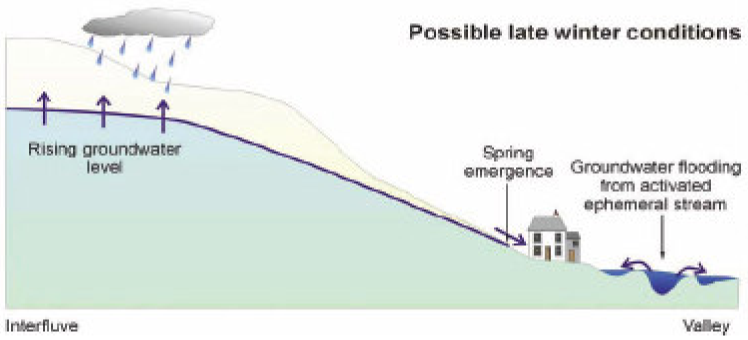
- High in-bank river levels or extreme tidal condition: This type of groundwater flooding is most commonly associated with alluvial floodplains with high permeability soils. If the water level in the river is raised the flow can be reversed resulting in water flowing from the river into the aquifer thus increasing water levels as it goes into storage. The secondary effect of this will be the adjustment in the hydraulic gradient within the groundwater body which will exacerbate the problem. The rate of response is a function of the permeability of the soil. Conditions conducive to groundwater flooding can be created as a result of certain flood defence assets where high flood levels are contained within embankments and the water level in the river is allowed to rise above the surrounding ground level.



The free draining nature of these deposits means that if groundwater flooding occurs it will recede rapidly after the surface water flood levels recede. These areas will be coincident with areas that are designated as having a high risk of fluvial flooding.

d) Upland Groundwater Flooding

After prolonged heavy rainfall (recharge) the quantity of groundwater that has to pass through the aquifer increases. This will result in a steepening of the hydraulic gradient as the aquifer fills to higher than normal levels and the overflow (spring lines) will be at higher elevations. The headwaters of streams will also emerge at higher elevations. If there is an absence of drainage channels groundwater flooding can occur. However, groundwater flooding of this type is unusual as the topography is usually steep and therefore there is high surface water runoff. Water courses are therefore subject to flashy floods anyway. The water table is usually at some depth and therefore there is considerable storage available before overflow takes place.



e) Chalk Aquifers

This is a major type of groundwater flooding in the UK in the chalk aquifer which is characterised by:

- Very large seasonal variations in groundwater levels.
- The porosity of the Chalk matrix.
- High Recharge.
- Absence of defined surface water drainage channels.

We have no similar types of aquifer in Ireland.

f) Basement Flooding

Flooding of basement occurs when the groundwater table rises to a level above that of the invert level of the basement. If the construction of the basement is not watertight water will seep in and due to the depth there is no gravity drainage path to surface channels available. If no sump pumping system is incorporated there, water level in the basement will rise until it is the same as the groundwater level outside the walls.

All basements must be designed in accordance with British Standard BS8102:1990. This British Standard defines four grades of basements ranging from Grade 1: Car parking where some seepage is allowed to Grade 4: Archives and stores – totally dry environment.

Basement flooding is often associated with other sources such as surface water from the street, backing up of storm or sewer pipes and so forth. Water can often build up in the backfill outside the walls. This is not considered to be groundwater flooding.

g) Man-Made Restrictions on Groundwater Flow (includes Flood Defences)

Many flood defence projects incorporate piling systems in flood defence walls. These can effectively seal out the water bearing strata of shallow unconfined aquifers. While the objective is to prevent flow from the river into the aquifer during flood conditions the impacts of the restriction of groundwater flow under normal conditions is often not fully examined. Piling systems can effectively dam the flow of groundwater that discharges to the river as baseflow. This has the potential to back up and cause flooding during non-extreme conditions on the land side of the defences. In reality, the seepage to or from the river will be very small in comparison to the flood flow. Any defence assets that propose to use deep piles should assess the risk of groundwater flooding as a result of the construction.

h) Rebound after Mine/Quarry Dewatering

Some of the major quarries in the country require constant pumping to maintain dry working conditions. When the operation ceases there will be a recovery in the water table to pre-development conditions.

i) Discharge from Artesian Wells

Wells tapping into artesian conditions can overflow continuously at considerable discharge rates if not properly capped. While it may appear that the discharge is being conveyed away by the natural drainage and topography, flooding can take place some distance away where the natural drainage network overflows due to lack of maintenance or capacity.

With the exception of the turlough type groundwater flooding, there is very little known regarding the occurrence of groundwater flooding in Ireland. The understanding is further complicated by the fact that there is often a groundwater flooding component of what are categorised as fluvial events and it is not distinguishable. As a result many groundwater flooding events are probably regarded as fluvial.

SUMMARY

Data and studies of groundwater flooding in Ireland are sparse. Apart from turlough flooding there are little or no records of specific groundwater flooding incidents. The response of the groundwater flow regime to extreme and prolonged rainfall events is complex and is a combination of the reaction of the aquifer accommodating an increase in throughflow together with its response to dynamic variations in the head conditions in the surface waters to which it ultimately discharges.

Pre-requisites for groundwater flooding are:

- The groundwater table to rise above the ground surface. This is most likely in areas where the water table is high (lowland alluvial deposits) or where there is considerable fluctuation in water levels in response to changes in recharge (upland areas).
- Permeable deposits at surface that discharge at a rate that will result in flooding.
- Topographic or channel conditions that are insufficient to convey the discharge (resulting in inundation).

The principal groundwater flooding scenarios that may be of concern in Ireland are:

- Karst (turlough type flooding).
- Basement flooding.
- Groundwater flooding in floodplains due to restrictions in natural groundwater flow paths by civil engineering structures such as piling systems associated with surface water flood defences.

Many flooding events will have a groundwater and a surface water component. Consequently, flood risk assessment and prediction will require an integrated approach. However the present fluvial and pluvial risk maps will encompass areas where groundwater flooding may occur.

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MAPPING GROUNDWATER FLOODING IN THE REPUBLIC OF IRELAND

R.A.L.Hardisty[1], S.Beeson[1] and G.Poole[2]
[1] Mott MacDonald
[2] OPW

ABSTRACT

The hazard of groundwater flooding in the Republic of Ireland has been assessed and a preliminary nationwide groundwater flood hazard map has been produced. The map shows the outlines of floods defined by applying a new methodology, which was developed for the Office of Public Works to take account of the unique karstic nature of the hydrogeological environment in the Republic. The methodology is based on a consideration of physical variables and hydrogeological environments in the Republic as these control the amount, location and extent of groundwater floods. Information used in the mapping includes: evidence provided by groundwater experts; reports held on a database of flood events; digital images from aerial photography; satellite images of historic floods; and topographical elevations derived from a digital terrain model.

INTRODUCTION

The European Floods Directive (2007/60/EC) aims to assess and manage the consequence of flooding from all sources on human health, the environment, cultural heritage, economic activity and infrastructure. Under this directive the competent authority of each member state is required to undertake Preliminary Flood Risk Assessments (PFRAs) by December 2011. The competent authority in the Republic of Ireland is the Office of Public Works (OPW).

Prior to 2010 the assessment of flood risk for PFRAs in the Republic was largely with respect to fluvial, pluvial and coastal flooding. OPW recognised that the issue of groundwater flooding needed to be addressed, particularly as this form of flooding is common in the west and north-west. This led to the development of a methodology to assess groundwater flooding in the Republic and the creation of a nationwide preliminary map of the hazard. Future work will comprise the identification of receptors and the definition of risk and consequence with respect to groundwater flooding.

GROUNDWATER FLOODING IN EUROPE

A literature survey of groundwater flooding in Europe was carried out in order to examine the responses of other European countries to meeting their obligations with respect to the Floods Directive. Little information was found from outside the UK, despite the fact that hydrogeological environments in some countries would appear to be conducive to groundwater flooding.

In England and Wales, the main body of work has comprised studies [Jacobs, 2004, 2006 and 2007] relating to DEFRA's `Making Space for Water' consultation [DEFRA, 2005]. Other studies (see for example Morris *et a*l [2007] and MacDonald *et al* [2008]) have also been completed. Groundwater flooding mechanisms have been considered and mapping procedures have been developed.

GROUNDWATER FLOODING IN THE REPUBLIC OF IRELAND

BACKGROUND

The Geological Survey of Ireland's (GSI) Groundwater Section has identified 27 Rock Unit Groups (RUGs) on the basis of geological characteristics that have hydrogeological relevance. Furthermore, the GSI has developed a system of bedrock aquifer classification that characterizes the groundwater flow regime and resource potential of the 27 RUGs as follows:

- Regionally Important (R) Aquifers (karstified bedrock dominated by diffuse or conduit flow, fissured bedrock and extensive sand and gravel)
- Locally Important (L) Aquifers (moderately productive bedrock, karstified bedrock and sand and gravel)
- Poor (P) Aquifers (generally unproductive bedrock).

The karstic nature of the hydrogeological environment in the Republic is unique within Europe. The degree of karstification ranges from slight to intense.

EVIDENCE OF GROUNDWATER FLOODING IN THE REPUBLIC OF IRELAND

A robust assessment of groundwater flooding in the Republic requires an evidence-based understanding of the hydrogeological environments where flooding mechanisms may, or do, occur. Both positive evidence (the known occurrence of floods) and negative evidence (the known absence of floods) have been considered. Use has been made of a wide range of information, including reports on flooding in karstic limestone environments referred to in discussions with experts at the GSI and Trinity College Dublin (TCD), and the interrogation of a database of over 5,000 flood events held by the OPW [Adamson, 2009].

The evidence indicates that the vast majority of extensive, recurring groundwater floods originate at turloughs. These groundwater-fed, seasonal lakes are unique to the Republic. *Sensu stricto*, they are groundwater floods but, in fact, they are only recognised as such under exceptional conditions when they expand beyond their normal seasonal extents. A total of 482 turloughs have been recorded by the GSI. The majority are in the west and north-west of the Republic on the Pure Bedded Limestones RUG. This is a regionally important karstified aquifer dominated by conduit flow. The locations of turloughs with respect to this and other aquifer categories are shown in Figure 1.

Turloughs are associated with two main regions: the lowland karst of the western lowlands in and around the counties Clare, Galway and southern Mayo; and the upland karst in the west, north-west and locally in the midlands. Turloughs also occur elsewhere at a few scattered locations.

Groundwater flooding is particularly prevalent in the western lowlands near the town of Gort and between the River Fergus and Lough Bunny south-west of Gort.

The floods near Gort are associated with a very well developed, complex, interconnected karstic drainage system. The turloughs in this area are well studied; see for example, Mac Dermot [1991, 1995] and Daly [1992, 1993]. An extreme flood event near Gort in late 1994 to early 1995 prompted a major study by Southern Water Global [1997] for the OPW. Another extreme event, in late 2009, is documented by TCD with photographic evidence (including that of water levels at Thoor Ballylee, located north-east of Gort), data downloaded from loggers installed in the turloughs at Blackrock and Lough Coy, and commentary.

The hydrogeological environment between the River Fergus and Lough Bunny is different from that near Gort and has not been studied in such detail. Karstification is less evident and there are fewer turloughs. Nonetheless, groundwater floods can be extensive and historic floods have occurred at similar times to those near Gort.

EXISTING APPROACHES TO MAPPING GROUNDWATER FLOODING IN THE CONTEXT OF IRISH AQUIFERS

Four approaches have been developed for mapping groundwater flooding in England and Wales: groundwater emergence maps; groundwater flood susceptibility maps; the definition of areas susceptible to groundwater flooding; and groundwater flood risk maps. None of these approaches can be applied to the Irish situation because they require detailed groundwater level data and aquifer systems where groundwater flow directions are controlled by local hydraulic gradients, neither of which is present for Irish karstic environments.

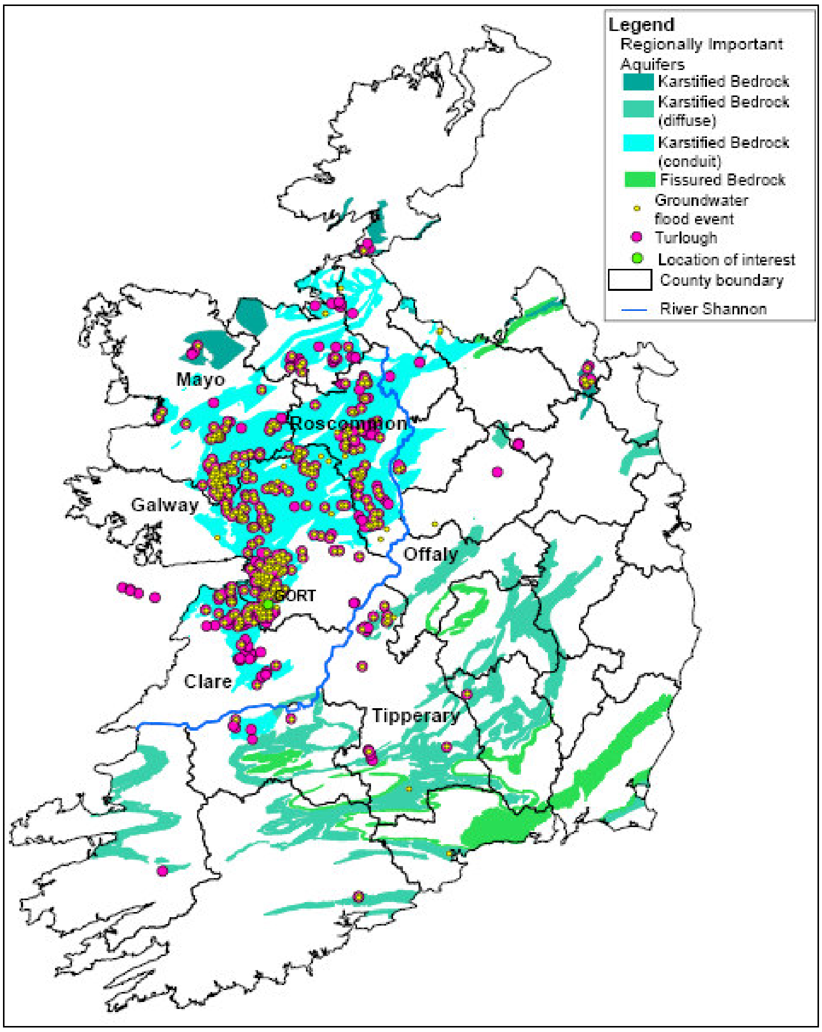

Figure 1: Turloughs and Groundwater Flood Events in the Republic of Ireland

MAPPING GROUNDWATER FLOODING IN THE REPUBLIC OF IRELAND

Two approaches to mapping the groundwater flooding hazard in the Republic were considered but rejected because either there was no supporting evidence or because there was a lack of data. The approaches were: the use of areas of extreme and high aquifer vulnerability as surrogates for groundwater floods; and the mapping of areas encompassing springs and likely areas of shallow groundwater.

The methodology developed to map areas of potential groundwater flooding in the Republic uses information regarding the presence and absence of groundwater floods. It comprises three inter-linked stages, which differ from each other in terms of the amount and quality of existing information.

STAGE 1 –MAPPING GROUNDWATER FLOODS IN THE WEST AND NORTH-WEST

There are three different types of karstic drainage in the west and north-west of the Republic and the availability of information regarding groundwater floods varies across the region: from reports, data and numerical modelling results for the area near Gort, to virtually no information in the upland karst region. These differences have influenced the approaches developed to map the groundwater floods.

The methodology for mapping the groundwater floods in the area near Gort is based on the outlines of floods shown on historic images for February 1990 and in the winter of 1994–1995, on photographic evidence, data downloaded from loggers installed in the turloughs at Blackrock and at Lough Coy, and commentary provided by TCD for the severe flood event in late 2009. An example of the flood map near Gort is shown in Figure 2 (the various turloughs are identified on the figure).

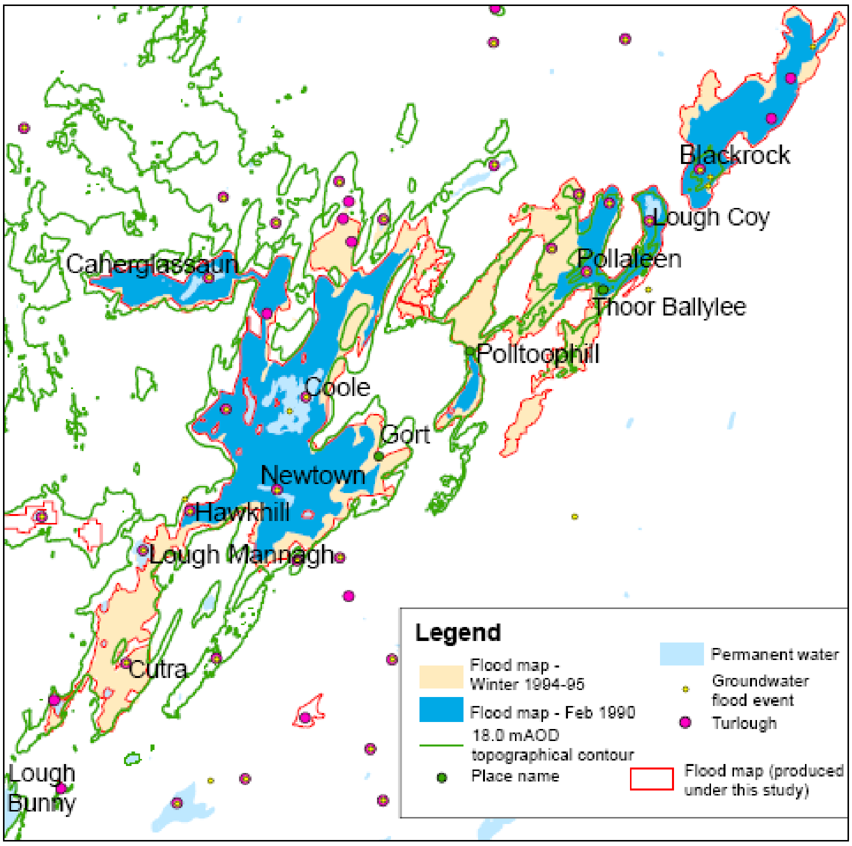

Figure 2: Mapping Groundwater Floods near Gort (Stage 1)

In summary, the level of the groundwater flood in late 2009 was similar to that in the winter of 1994–1995 at Blackrock and at Thoor Ballylee, but increased progressively down hydraulic gradient so that it was about 0.70 m higher at Caherglassaun turlough in late 2009 compared with previously. The maximum level of the flood at Thoor Ballylee is estimated to have been 18.0 mAOD. There is a time lag of about nine days between the peak level at Blackrock on 24/11/09 or 25/11/09 and the peak level at Caherglassaun on 03/12/09 or 04/12/09.

For the initial version of the flood map, the 18.0 mAOD contour derived from DTM tiles was drawn and compared with the two flood images. The contour coincides with the outlines of the images near Thor Ballylee Tower but does not coincide elsewhere in the turlough system. It encloses too small an area up hydraulic gradient at Blackrock and too large an area down hydraulic gradient relative to the historic flood images. This is because it takes no account of the regional hydraulic gradient nor variations in ground elevations. Basing the flood map on the 18.0 mAOD contour is clearly inappropriate.

Therefore, the flood map of the area near Gort is drawn to coincide with the outline of the flood image in the winter of 1994–1995 except where photographic evidence and logged data of the flood extent in late 2009 at Blackrock, Lough Coy, Thoor Ballylee and Caherglassaun indicates a different outline. Examples of the revised flood outlines are given in Figure 3.

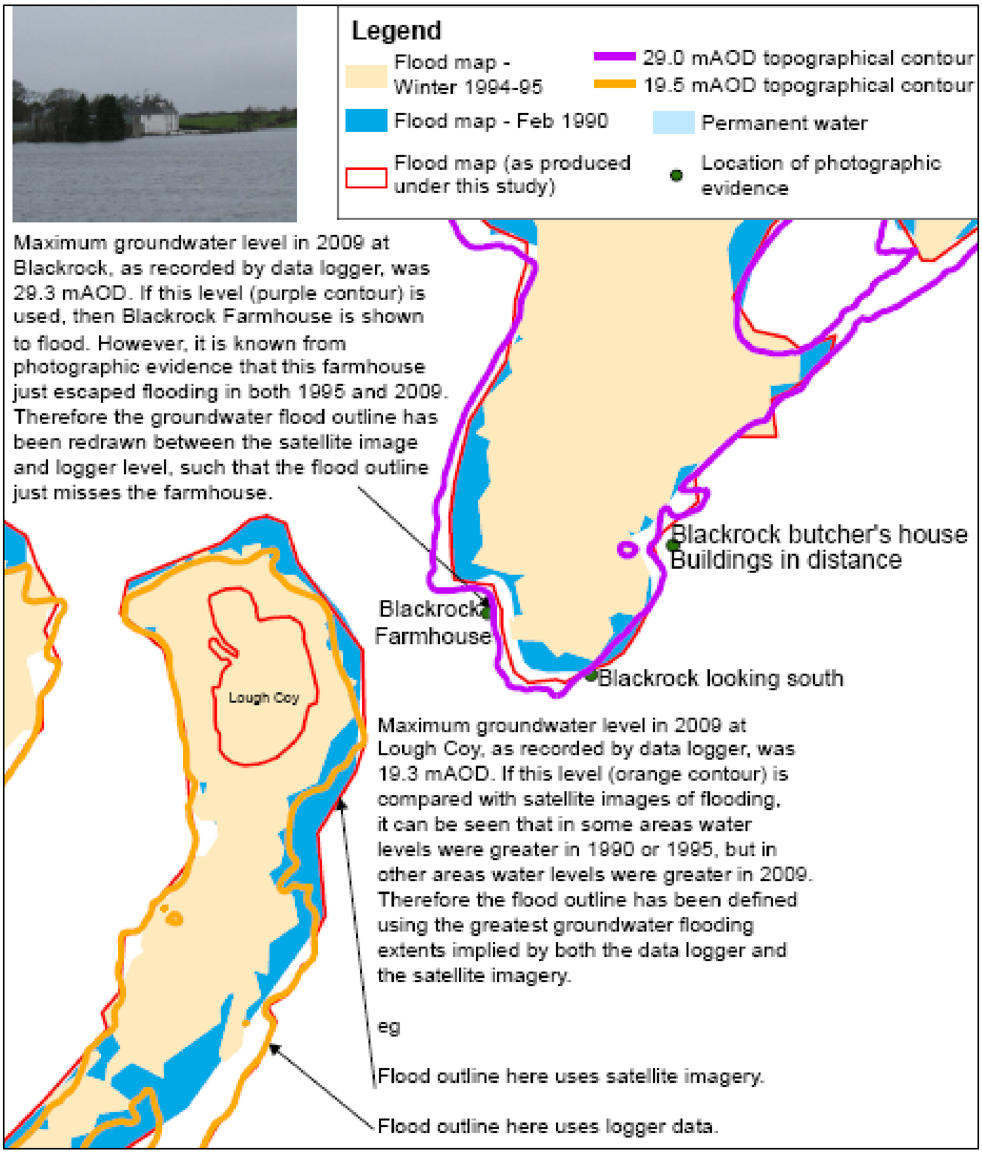

Figure 3: Adjustments to Groundwater Flood Outlines Near Gort (Stage 1)

The methodology for mapping the groundwater floods in the area between the River Fergus and Lough Bunny uses the image for 04/12/09 and assumes that the extent of flooding in late 2009 was at a maximum on this day.

There are more streams, more permanent groundwater fed lakes and far fewer turloughs in the area between the River Fergus and Lough Bunny than in the area near Gort. Groundwater flooding is known to occur, both at genuine turloughs and some permanent lakes. Images obviously cannot distinguish between groundwater and surface water floods. The decision was made that individual floods have the potential to be groundwater, with the exclusion of those located solely on peat. The outlines of permanent water bodies within groundwater floods are excluded from the preliminary map since these are not floods (the flood map around permanent water bodies has the appearance of rings).

The methodology for mapping the groundwater floods in the upland karst region uses two available images on 24/02/01 and 30/11/09. These are for a corridor along the River Shannon from Lough Bofin south to the northern two-thirds of Lough Derg and including eastern areas of Counties Roscommon and Galway, north-western Country Tipperary and western County Offaly.

The flood event on 30/11/09 was more extreme than that on 24/02/01. Therefore, the image of 30/11/09 is used to define the maximum extent of groundwater flooding in the region.

Again, an examination of the hydrogeology of various flooded areas was necessary in order to decide whether these were groundwater or surface water derived. Subsoils on both sides of the Rivers Suck and Shannon are predominantly peat. Sand and gravel aquifers are not present. This indicates that the hydrogeological environment, in which the specific groundwater flooding mechanism associated with floodplains can operate, is not present. Therefore, it was assumed that the floods in late 2009 on both sides of the rivers were surface water derived and not groundwater.

Most of the region covered by the image of 30/11/09 that lies outside the river valleys of the Suck and Shannon is underlain by the Pure Bedded Limestones RUG. Limestone tills or peats overlie the bedrock except in a few patchy areas. The decision was made that any floods distinguished by being located solely on peat and not associated with a turlough were surface water derived. All other floods are assumed to be groundwater derived.

The final version of the map prepared under Stage 1 shows the extent of the most severe groundwater flood to have occurred in the area near Gort in the last 50 years or so. Maximum flooding in the other areas may not have occurred at the same time. Consequently, the map is not date-specific and a return period for the most severe groundwater flood to have affected the other areas cannot be specified.

STAGE 2

Historic images of floods are unavailable for much of the Republic. Stage 2 therefore defines maximum groundwater flood outlines around those turloughs that lie outside the coverage of the available images and for which there is little or no other information. The flood outlines are drawn by assuming that flood levels are 4.0 m above the base elevations of the turloughs. This is the median difference between the base elevations of 85 turloughs that lie within the coverage of the images and the corresponding flood levels shown on the images.

Differences between flood level and turlough base vary between 0.1 m and 14.5 m. It was anticipated that floods associated with turloughs located in elevated areas would have greater differences than those associated with lower elevations. However, this is not the case. Possible reasons for this are inaccurate DTM contours, and flood extents at high elevations that are not maxima (i.e. the image of 30/11/09 does not show the full extent of groundwater floods in regions outside the area of Gort).

Given the variability of the computed differences, realistic constraints were applied as follows:

- if the +4.0 m contour gave an unrealistically large flood then the contour closest to +4.0 m that gave a realistic size was followed instead;
- if two or more turloughs were located close together such that their +4.0 m contours intersected, then the outlines around these turloughs were merged into one;
- if the contours in the vicinity of a turlough did not form an enclosed shape around it, then the flood was assumed to extend down gradient in an approximately oval shape;
- permanent water bodies shown on the Teagasc subsoils map were excluded.

The approach is illustrated in Figure 4a for Moran's and Ballytrasna turloughs. The +4.0 m contour gives an unrealistically large flood extent which would include more than half the area shown on the figure. The more reasonable contour of +3.0 m has been selected instead.

Sensitivity analysis was carried out using the extreme case of the 90 percentile difference (9.3 m) instead of the median difference. The approach is illustrated in Figure 4b for Gardenfield/Ardacong turlough. In this case, the flood extent defined by the 90 percentile difference would include most of the area shown in the figure. The largest reasonable contour (+5.0 m) has been selected instead.

Many of the resultant floods using the 90 percentile difference are so extensive that there would be evidence of them in the form of reports, photographs, etc. No such evidence exists. This suggests that the use of the median difference, constrained where necessary, is reasonable.

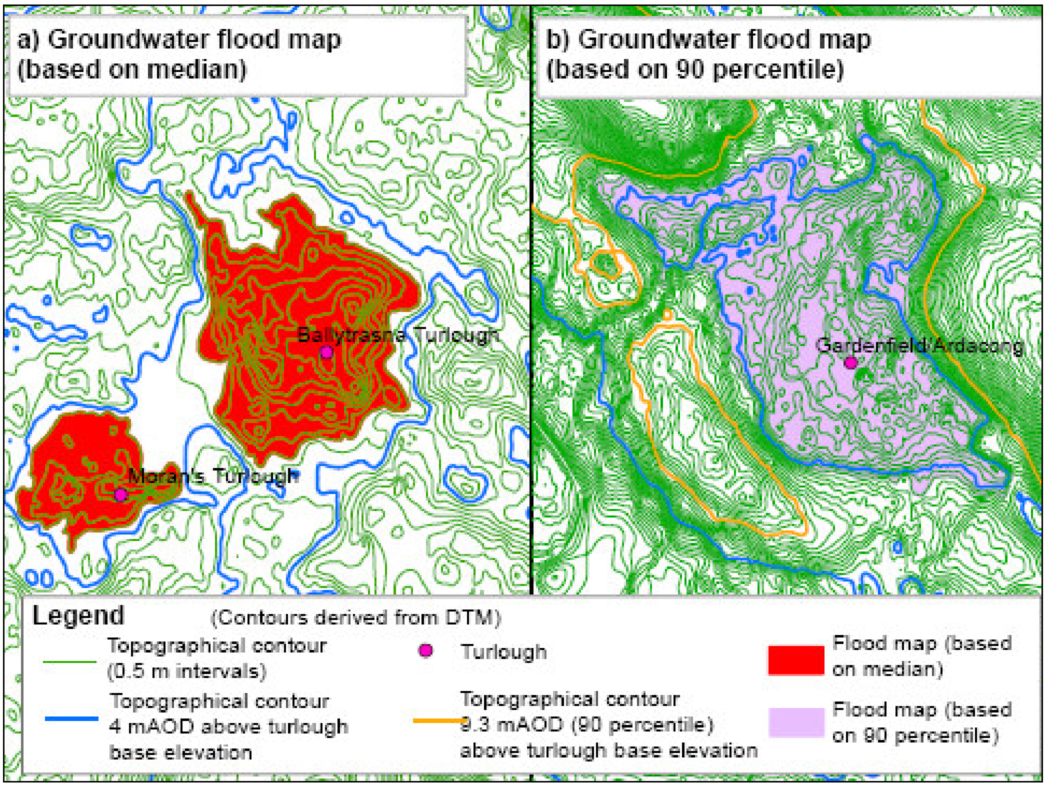

Figure 4: Mapping Groundwater Floods in Areas not Covered by Images (Stage 2)

STAGE 3

There are 37 flood events associated with turloughs on the OPW's database for which there are easily accessible reports containing useful information such as details of the flood extent, its location and photographs. The reports were used where possible to corroborate or adjust the maps defined using Stages 1 and 2 of the methodology. In many cases the reports did confirm that the maps were reasonable.

Groundwater flood levels are likely to vary across the country because the amount and intensity of rainfall, and hence recharge, decrease significantly from west to east. It is anticipated that flood levels in the east will be less than those in the west. Aerial photographs of the 24 turloughs located in the east were visually examined as part of Stage 3. Features attributable to groundwater flooding were identified and used to check flood outlines drawn during Stage 2. Most flood levels associated with the turloughs have been significantly reduced as a result.

CONCLUSIONS

A preliminary map of the groundwater flooding hazard in the Republic of Ireland has been produced as part of the first requirement of the Floods Directive to undertake preliminary flood risk assessments by December 2011. The map shows the outlines of groundwater floods as defined using the methodology which was developed for this project. It is shown in Figure 5.

ACKNOWLEDGEMENTS

The authors wish to thank the OPW for permission to publish this paper. The views expressed are entirely the authors' own and not necessarily those of the OPW. The authors also gratefully acknowledge the contributions from: Monica Lee, Taly Hunter Williams and Caoimhe Hickey (GSI); Paul Johnston, Bruce Misstear and Owen Naughton (TCD); the EPA; and MERTIT.

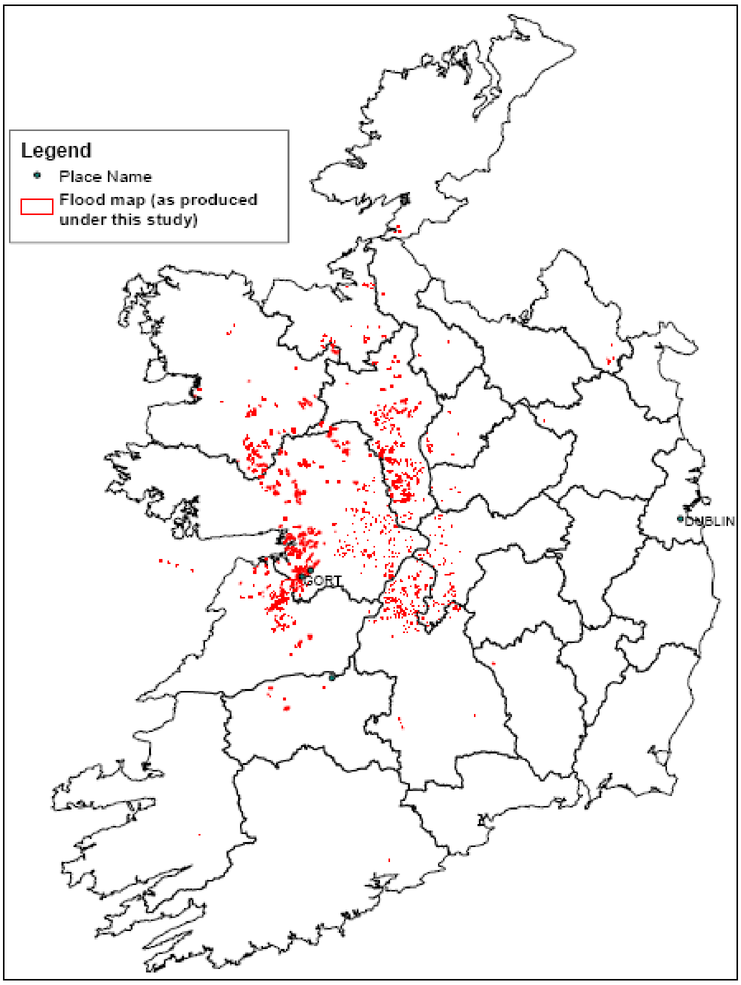

Figure 5: Preliminary Groundwater Flood Hazard Map

REFERENCES

Adamson, M. (2009). Determining Areas of Potentially Significant Risk in Ireland. Unpublished OPW report.

Daly, D. (1993). Notes on Field Trip to Lowland karst Area, Gort, Co Galway. Unpub. GSI report.

Daly, D. (1992). A report on the Flooding in the Gort-Ardrahan Area. Unpublished GSI report.

DEFRA (2005). Making Space for Water. Taking forward a new Government strategy for flood and coastal erosion risk management in England.

Jacobs (December 2007). Making Space for Water, Groundwater flooding records collation, monitoring and risk assessment (ref HA5), Consolidated Report, for Environment Agency (EA).

Jacobs (November 2006). Making Space for Water, Groundwater flooding records collation, monitoring and risk assessment (ref HA5), Extended Report (Chalk Aquifers), for the EA.

Jacobs (March 2004). Strategy for Flood and Erosion Risk Management: Groundwater Flooding Scoping Study (LDS 23).

Johnston, P. (December 2009). Turlough Flooding 2009. Unpublished TCD photographs and text.

Mac Dermot, C. (1995). Water Levels in the Gort Area 1994 – 1995. GSI Occasional Report 95/1.

Mac Dermot, C. (1991). Water Levels in the Gort Area 1971 – 1977. Unpublished GSI report.

MacDonald, D.M.J. *et al* (2008). Improving the understanding of the risk from groundwater flooding in the UK. In FLOOrisk 2008, European Conference on Flood Risk Management, Oxford, UK, 30th September to 2nd October 2008. The Netherlands, CRC Press.

Morris, S.E., Cobby, D., and Parkes, A. (2007). Towards groundwater flood risk mapping. *GJEGH*, Vol 40, pp.203-212.

Southern Water Global (September 1997). An Investigation of the Flooding Problems in the Gort-Ardrahan Area of South Galway, for OPW.

SESSION II

EPA CODE OF PRACTICE FOR UNREGULATED WASTE DISPOSAL SITES – GUIDANCE FOR INVESTIGATIONS

Jim Moriarty
Manager, Environmental Enforcement (Waste), Office of Environmental Enforcement, EPA

ABSTRACT

The Environmental Protection Agency (EPA), at the request of the Minister for the Environment, prepared a Code of Practice (COP) on Environmental Risk Assessment at unregulated waste disposal sites. The COP followed a Ministerial Direction (WIR 04/05) of the 3rd May 2005 and was issued in April 2007. The COP provides a framework for local authorities to compile an inventory of historic waste disposal sites and to have environmental risks at these sites assessed.

Since its publication, the COP has been enshrined in Irish law through the December 2008 Waste Management (Certification of Historic Unlicensed Waste Disposal and Recovery Activity) Regulations SI 524/2008. These regulations provide for the regularisation of closed landfills by an authorisation system administered by the EPA. Central to this is the completion of site investigations to provide information necessary to assess risk and inform remediation options.

The nature and extent of investigations necessary to provide the necessary information is set out in Chapter 5 of the COP. The EPA has prepared a set of matrices that provide guidance for both the exploratory and main site investigations required at closed landfills. The investigations are informed by the SPR linkages and facilitate a targeted investigation. In this way, a cost-effective investigation can be completed that provides the information necessary to assess the risk posed by the closed landfill.

It is envisaged that the application of the matrices, which are available on www.epa.ie, *will assist local authorities in completing risk assessments at closed landfills and prepare high-quality applications for certificates of authorisation for submission to the EPA.*

NOTES

THE NEW EPA CODE OF PRACTICE MATRICES FOR SCOPING SITE INVESTIGATIONS AND ASSESSING GROUNDWATER RISK

Darragh Musgrave
Regional Director - WYG Environmental – Cork Office

ABSTRACT

The Environmental Protection Agency (EPA) published the Code of Practice (COP) on 'Environmental Risk Assessment for Unregulated Waste Disposal Sites' in April 2007. The COP document is primarily aimed at giving local authorities a framework for completing risk screening on unregulated waste disposal sites and also giving detailed and thorough guidelines on what is required in the Exploratory and Main Site Investigation (SI) phases at these landfills in order to inform their remediation and authorisation. These new SI Matrices are designed to complement the COP document and more graphically present and summarise the information in Chapter 5 – Site Investigations and Testing. They are aimed at assisting in the planning of the site assessment work, to give guidance in the application of various site investigation techniques and to help focus the work to quantify the risks for the Source-Pathway-Receptor (S-P-R) linkage(s) identified for a particular site.

The two Matrices outline the various steps in the COP risk assessment process and give guidance on what SI techniques are considered mandatory, recommended, should be considered or not recommended for each of the 11 S-P-R linkages that must be evaluated for each site. The proper assessment of the groundwater regime at historic waste disposal sites is a critical element in the quantification of the leachate contamination pathway to potential receptors. It is envisaged that the use of the new Matrices, in conjunction with the COP, will assist local authorities in consistently completing cost effective, risk specific site investigations, that will be of the required standard to enable the EPA to issue Certificates of Authorisation for these historic waste sites.

INTRODUCTION

The Environmental Protection Agency (EPA), were directed by the Ministerial Direction (WIR 04/05), issued in 2005 under Section 60 of the Waste Management Acts (WMA) 1996 to 2005, to prepare the Code of Practice for the 'Environmental Risk Assessment for Unregulated Waste Disposal Sites' which was published in April 2007.

The Code of Practice (COP) provides a frame work for local authorities to compile an inventory of historic waste disposal sites and to have the environmental risk at these sites assessed. Chapter 4 of the EPA COP shows how to undertake Risk Screening and Prioritisation of 11 potential risks at each site and Chapter 5 sets out the nature and extent of Site Investigations (SI) and Testing necessary to provide the information required for the thorough environmental assessment of the site. Chapter 6 indicates this may include a quantitative risk assessment, depending on the risk classification for the site. The information from these works will be used in the application to the EPA for the site 'Certification of Authorisation'.

WYG has assisted the EPA in the design and preparation of a set of SI matrices which are based on the information in the COP but provide additional guidance for the preliminary, exploratory and main investigations required at closed landfills.

The matrices are designed to focus the site investigations to the particular environmental and human health risk(s) that have been identified by the initial COP risk screening scoring system for the individual landfill. They facilitate consistent and more targeted investigations, focusing resources on the particular risk(s) that are deemed to need assessment and quantification.

This paper describes the use of the new COP Matrices and looks at the assessment of groundwater risks from unregulated waste disposal sites.

COP ENVIRONMENTAL RISK ASSESSMENT METHODOLGY

The EPA COP follows the Source – Pathway – Receptor (S-P-R) linkages conceptual model for environmental management. This conceptual model approach is designed to identify the sites that pose the greatest risk to the environment and human beings and identifies the individual S-P-R linkages that have the highest risk associated with them.

The COP identifies that principal sources of contamination from a waste body are primarily either leachate and/or landfill gas. The identification of the type of waste is critical so the potential for leachate and its toxicity and the potential for landfill gas can be identified.

The leachate migration pathways that are considered in the COP are:

- Vertically to the water table or aquifer – groundwater is the receptor,
- Vertically to the aquifer and then horizontally to a receptor such as a well, spring or stream,
- Horizontally at the ground surface (or at a shallow depth) to a surface receptor, such as a river or stream.

Therefore the assessment of the aquifer status and vulnerability, groundwater flow regime and surface water drainage are key aspects of the determination of the migration pathways.

Sensitive receptors which are considered at risk of potential leachate migration to groundwater and are itemised in the COP, they include:

- Human Presence (private groundwater wells),
- Protected Areas (including groundwater dependent wetlands),
- Aquifer Category (groundwater resource potential),
- Public Water Supplies, (large groundwater wells)
- Surface water bodies, (rivers, lakes, estuaries).

Landfill Gas risk is considered through an evaluation of the subsoils and identification of any preferential flow paths and Human Presence is considered the main receptor.

The Risk Prioritisation system used in the COP defines eleven different Source, Migration Pathway and Receptor linkages which are individually scored to provide an indication of the relative environmental or human health risk that may be present on any individual site.

S-P-R linkages 1 to 7 require determination of vertical and horizontal groundwater flow characteristics in the scoring system so are critical elements of the risk assessment process. The highest S-P-R risk score of any linkage is taken to represent the risk classification of the site. Three Risk Classifications are used in the COP.

Class A – Highest Risk = greater or equal to 70% for any individual S-P-R linkage,
Class B - Moderate Risk = between 40 – 70% of any individual S-P-R linkage,
Class C – Lowest Risk = less than or equal to 40% for any individual S-P-R linkage.

The completion of an initial risk screening and development of a conceptual site model provides information on the scope of site investigations required to, as far as possible, enhance the model and quantify the identified risks so that decisions can be made on what measures are required to manage the risk in the long term. Remediation may involve breaking the pathway or the remediation strategy report required by the COP. This needs to identify the potential pollutant linkages and examine ways of breaking the linkages, removing the source or in some cases the monitoring of the receptor.

As per best practice, a phased approach is used in the EPA COP risk assessment methodology. This allows a structured, transparent and practical process to be followed. This aids decision making and enables the greatest amount of effort and resources to be targeted where the most vulnerable and sensitive receptors are identified or where significant uncertainty exists where there is potential for significant environmental damage to occur.

The COP outlines a number of phases of work which are required to assess the site specific environmental and human health risks of any historic unregulated landfill.

Tier 1 – Preliminary Investigations - based on desk study and site walkover survey this is a qualitative risk assessment from which an initial conceptual site model (CSM) is derived and critically for the COP methodology, involves Risk Screening and Prioritisation through the identification and scoring of the eleven S-P-R linkages and the ranking/prioritisation of the specific site and their risks (as mentioned above).

Tier 2 – Site Investigation and Testing – Divided in the COP into an initial 'Exploratory Investigation', the 'Main Investigation' and where necessary 'Additional Investigations' these investigations should focus on providing sufficient site specific information to determine whether S-P-R linkages exist, the significance of the linkages and the risk posed by the hazard. Site investigations need to be sufficient to create a robust conceptual site model and to inform the quantitative risk assessment and recommendations for remediation.

Tier 3 – Quantitative Risk Assessment – Can be Generic or Detailed depending on the potential risk determined for the site. Once completed, an evaluation of the overall risk of the site needs to be made and recommendations on how to alleviate the risks identified.

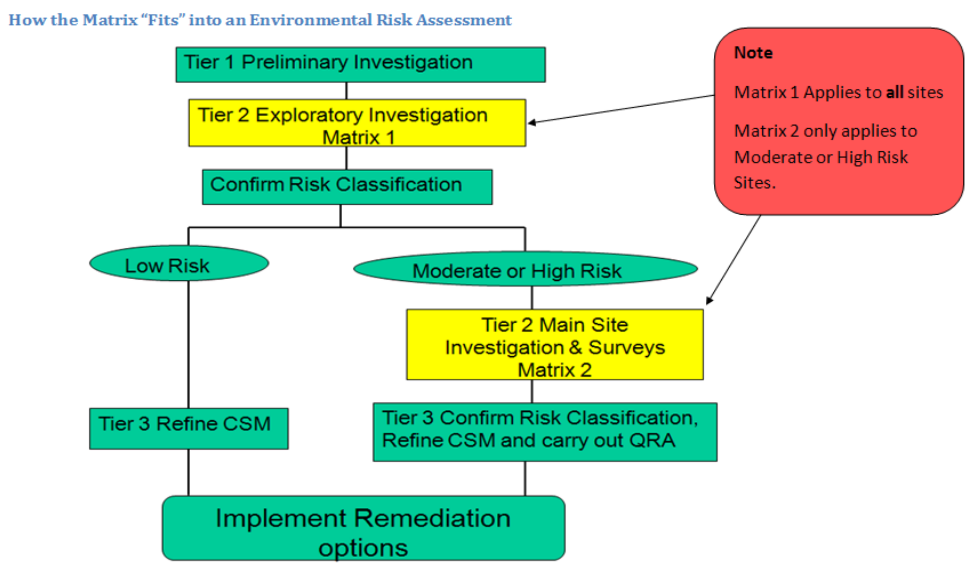

Figure 1: How the Matrices fit into the EPA COP Environmental Risk Assessment (Taken from the EPA Guidance document on how to read the COP SI Matrices).

THE NEW EPA COP MATRICES

The matrices are designed to support the consistent planning, scoping and completion of sufficient Tier 1 and Tier 2 investigations as required by the COP. They are presented in tabular format composed of a series of rows and columns and are developed in a way that allows site investigation requirements (in the rows), advice/guidance and recommendations (in the columns) to be assessed for each of the eleven S-P-R linkages on an individual basis.

The terminology in the matrices is consistent with that used in the COP and should be considered supporting/supplementary information to the main document so users should read and be familiar with the COP when they look to apply the matrices. Where necessary users should involve professionals experienced in landfill site investigations.

MATRIX 1

Matrix 1 gives guidance for the Tier 1 Preliminary and Tier 2 Exploratory Investigations and is required for **ALL SITES**.

The Tier 1 - Preliminary Investigation identifies and summaries the completion of the Desk Study, Walkover Survey and Conceptual Site Model (CSM) Phase and its completion is mandatory for all sites and for all 11 S-P-R linkages.

At this initial stage all available existing site information should be compiled and assessed in terms of developing as accurate a CSM for the site as possible.

Hydrogeological aspects of the site such as the type, depth and nature of the overburden, bedrock type, aquifer classification, potential presence of private and/or public supply wells should be researched. The Geological Survey of Ireland (GSI) and River Basin District Management Projects have regional

Geographical Information Systems (GIS) datasets of such information which enables such initial risk screening. National Parks & Wildlife Service (NPWS) databases of sensitive sites should be consulted and the need for ecological risk screening determined at this stage. Of particular interest to hydrogeological risks is the presence of groundwater dependent terrestrial ecosystems (GWDTE), such as fen habitats.

As much information as possible on the waste type should also be gathered at this stage and, when possible, interviews with previous site staff should also be considered.

Initial assumptions from the desk study should be confirmed by a site walkover survey which will aid in identifying pathways and receptors and also enable the accessibility of the site for Tier 2 works to be assessed.

After the initial conceptual model is completed, the 11 S-P-R linkages scored and the risk classifications determined the next step is to scope the Exploratory Tier 2 investigations.

The Tier 2 - Exploratory Investigations & Initial Sampling methodologies are outlined in the second portion of Matrix 1 and involve intrusive investigation of the site area and in particular the waste mass by excavating trial pits and/or trenches.

The exploratory investigations enable a physical assessment of the waste material, any capping material and the ground in which it is deposited to the determined. In terms of helping to quantify hydrogeological risks the depth and type of material under the waste may be accessible to the depth of the excavator and if bedrock is shallow then the vulnerability of the site can be accurately determined. Waste type and leachate presence/potential can be assessed as can the potential for landfill gas by the use of hand held gas monitoring equipment. The completion of Trial Pits & Trenches and assessment of the waste type is considered mandatory for all sites.

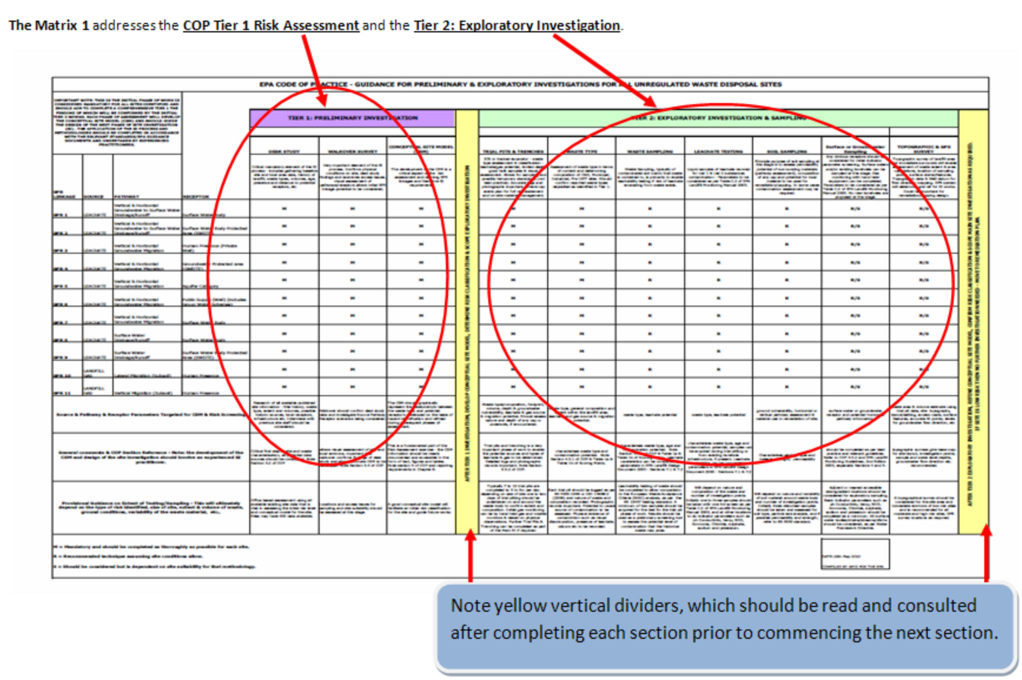

Figure 2: Matrix 1 – Tier 1 Preliminary and Tier 2 Exploratory Site Investigations (Taken from the EPA Guidance document on how to read the COP SI Matrices).

As per the COP, Matrix 1 recommends that waste, leachate and soil sampling is completed at this stage and if surface and/or groundwater features such as streams and boreholes are in proximity to the site then these should also be sampled, depending on their presence and relevance. No new boreholes are proposed at this stage.

Topographic and Global Positioning System (GPS) surveys of the site and relevant features are also recommended and should be considered depending on the size and nature of the site and initial risk classification. Accurate groundwater level data from at least three monitoring boreholes is important for the assessment of the saturated and unsaturated zone and calculation of hydraulic flow direction. GPS surveys are useful in accurately determining the distance to, and location of, potential receptors.

After the Tier 2 Exploratory investigation the conceptual site model should be refined and the Tier 2 Main Investigation scoped as necessary. If there is enough information known about the site that enables it to be scored and all 11 S-P-R linkages are determined as having low risk, (classifying the site as a low risk site), then no further site investigation work is deemed necessary and the remediation plan should be developed for the Certification of Authorisation application to the EPA.

MATRIX 2

Matrix 2 gives guidance for the Tier 2 Main Investigations, sampling and specialist surveys and is required for sites which are ranked as Moderate or High Risk from the screening and assessment process of the Tier 1 and Tier 2 Exploratory Investigations.

The second Matrix follows the same general format as the first with the individual S-P-R linkages with guidance and recommendations presented in rows and the different investigation and sampling techniques presented in columns.

The scoping of the Tier 2 Main Investigation and techniques to be used should be focused on the S-P-R linkages identified with the highest risk. In this way the main effort and focus of resources is on defining the S-P-R linkage considered to have the highest risk to the environment and/or human health.

If you take one S-P-R linkage and follow the row it occupies then the application of a particular technique is either:

- Recommended, (R) assuming site conditions allow,
- Should, (S), be considered, but dependent on the suitability of the methodology,
- Not Recommended (N), but may occasionally be suitable.

In this way the Matrix leads one towards what are considered the best ways in assessing the particular S-P-R Linkage identified as either a moderate or high risk. The last two rows of the spreadsheet identify the initial quantum of site investigation and sampling which should be undertaken, preferably as a minimum, in this assessment phase. As all sites are unique in their own way different techniques and scope of work are likely to be applied to different sites.

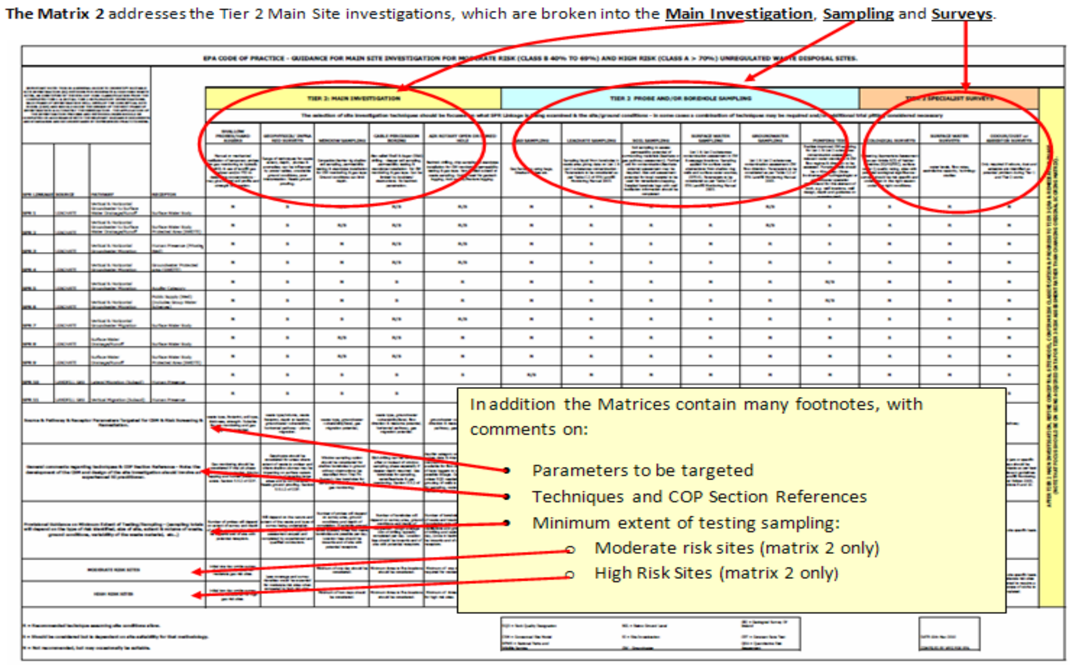

Figure 3: Matrix 2 – Tier 2 Main Investigations, Sampling and Specialist Surveys (Taken from the EPA Guidance document on how to read the COP SI Matrices).

For some sites more than one S-P-R linkage may pose a moderate and/or high risk and in this case a wider range of investigation techniques may need to be considered. Often the completion of some site techniques will provide data for the assessment of other linkages and sometimes easy adaptations to proposed infrastructure can allow them to be used in the assessment of more than one risk – as designing groundwater monitoring boreholes as duel groundwater and gas monitoring locations.

For the assessment of groundwater related S-P-R linkages the completion of some drilling such as Shell & Auger (S&A) and Air Rotary boreholes and leachate, soil and groundwater sampling is Recommended (R) or Should (S) be considered in all instances.

Pumping tests are recommended for the S-P-R 5 (Aquifer) and S-P-R 6 (public supply well) assessment and should be considered in the assessment of the other S-P-R groundwater risks. If not already engaged the involvement of a hydrogeologist is highly recommended for the scoping of the assessment of the groundwater/leachate/surface water related studies and especially pumping test works.

For the assessment of the potential risk to groundwater the site investigations are focused on determining the nature, thickness, age and type of waste, the thickness, type and permeability of the capping and overburden, type of bedrock, aquifer potential and classification, vulnerability, groundwater levels, gradients, permeability and flow direction.

Numbers of boreholes and sampling rounds will depend on the nature of the site and classification of the risk being assessed with higher risk linkages requiring more assessment than lower risk linkages. Chapter 5 of the COP recommends and refers to a number of guidance documents that should also be referenced in this regard.

It is important to remember that a detailed quantitative risk assessment may be required for the Tier 3 phase of works and the Tier 2 investigations need to provide sufficient data in terms of quality and quantity to allow for this and the recommendation of remediation techniques. Detailed Quantitative Risk Assessment may require completion of a contaminate fate and modelling exercise for the site.

After the completion of the Tier 2 Main Investigation and Sampling works the CSM is refined and the risk classification of the linkages is re-assessed. Note that if the data from the completed investigative works result in the risk classification being reduced to low then the Tier 3 quantitative risk assessment should be completed against generic criteria in order to quantify the risk and show that the risk is low.

The matrices are meant to give guidance as to what might be considered to be the minimum scope of work required to assess a particular S-P-R risk. Depending on the site setting and severity of the risk additional works such as more extensive drilling, further sampling, modelling and specialist surveys may be required to allow a comprehensive quantitative risk assessment to be completed.

EXAMPLE OF HYDROLOGICAL S-P-R LINKAGE ASSESSMENT

If after the mandatory completion of the scope of work outlined in Matrix 1 – (Tier 1 Preliminary Investigation and initial CSM followed by the Tier 2 Exploratory Investigation and refinement of the CSM), the scoring of the leachate source, groundwater pathways -vertical and horizontal and proximity of a public supply well receptor - indicate that the a site has a high S-P-R 6 risk rating (>70% Class A Site) then a Tier 2 Main Site Investigation is required.

Based on the guidance in Matrix 2 geophysics and S&A drilling should be considered while rotary drilling is recommended. For a high risk site a minimum of five S&A boreholes and/or three rotary boreholes are recommended as this will enable the depth and nature of the overburden, type and depth to bedrock, water levels, permeability's, ground water flow direction etc. to be defined and for monitoring boreholes to be established. This allows for groundwater levels and samples to be acquired as necessary in the future.

Automated groundwater level loggers can be put into boreholes to record groundwater levels continuously over time enabling the monitoring of groundwater levels on site and at the groundwater supply well. This will enable an assessment of the drawdown characteristics of the supply well and determination of its influences on the groundwater beneath the waste disposal site.

Leachate, soil and groundwater sampling is recommended by the Matrix and surface water sampling should be considered depending on the hydrological regime of the site.

A pumping test is recommended or should be considered and for a high risk site a step test and three day constant rate test is the proposed option. The pumping test would give site specific permeability and quantification of the aquifer status which will inform the risk assessment, (note that these tests are not designed to change the GSI classification of the aquifer used in the Tier 1 risk prioritisation/ranking score). There are risks of moving contaminates into aquifers and for the disposal of contaminated water on sites which also need to be considered. Therefore site specific information may alter the feasibility and practicality of doing pump tests on some sites while on other sites longer, or different, tests may be required to assess the hydrogeology of the site.

As none of the other S-P-R linkages were considered a risk at this site then the focus of the investigation was on assessing S-P-R 6 and investigations such as gas probing, window sampling, or specialist ecology or surface water surveys are not recommended and not deemed necessary for completion in order to resolve this particular risk.

ACKNOWLEDGEMENTS

The development of the COP SI Matrices was done at the request of EPA as part of a pilot project being completed by the Department of Environment Heritage and Local Government (DEHLG). The author would like to acknowledge the input of the various parties involved in the project. In particular Jim Moriarty and Pat Chan of the EPA who were instrumental in the development of the Matrices and for the assistance of his colleagues in WYG, especially Donal Marron and Donal Hogan.

REFERENCES

BS 5930:1999 Code of Practice for Site Investigations, British Standards Institution UK.

BS 10175:2001 Investigation of potentially contaminated site – Code of Practice, British Standards Institution UK.

EPA 1995, Landfill Manuals: Investigations for landfills, EPA Wexford

EPA 1995, Landfill Manuals: landfill Monitoring, EPA Wexford

EPA 1999, Landfill Manuals: Restoration and Aftercare, EPA Wexford

EPA 2003, Landfill Manuals: landfill Monitoring, (2nd Edition), EPA Wexford

EPA 2007 'Code of Practice for Unregulated Waste Disposal Sites'

Nathanail, J., Bardos, P., Nathanail, CP, 2002. Contaminated Land management Ready Reference 2002, Land Quality Press and EPP Publications

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STUDENT POSTER PRESENTATIONS

QUANTIFYING FLOWS ALONG POLLUTANT PATHWAYS IN IRISH CATCHMENTS

O'Brien, Ronan[1,2], Deakin, Jenny[1], Misstear, Bruce[1], Gill, Laurence[1], Johnston, Paul[1] and Flynn, Raymond[3]
[1]Department of Civil, Structural and Environmental Engineering, Trinity College Dublin
[2]Corresponding author obrienrj@tcd.ie
[3]School of Planning, Architecture & Civil/Environmental Engineering, Queen's University Belfast

ABSTRACT

The main hydrological pathways that may transport diffuse contaminants to rivers in Ireland are overland flow, interflow, shallow groundwater flow, and deep groundwater flow. The EPA STRIVE funded Pathways Project, being carried out by a research consortium involving QUB, UCD and TCD, is working towards a better understanding of hydrological pathway processes, water-borne contaminant fate and transport, and the subsequent impact of these contaminants on aquatic ecosystems in Irish catchments. Contaminants under investigation are phosphorus, nitrogen, sediments, pesticides and pathogens. The project is developing a Catchment Management Tool (CMT) to assist the EPA and River Basin District managers in achieving the objectives of the Water Framework Directive. One important element of the research is to quantify the proportion of the river hydrograph that is derived from each of the main pathways. One of the main modelling challenges is to achieve credible simulations in relatively small study catchments (sometimes less than 5 km^2). This will be addressed through use of physical and chemical hydrograph separation techniques, together with hydrological modelling of pathways using a semi-distributed, lumped and deterministic rainfall-runoff model, NAM. These techniques require collection of high temporal resolution rainfall and flow data, in order to constrain the pathway simulations. Contributions from each of the four pathways, combined with an understanding of the attenuation of the contaminants along those pathways, will inform the CMT to provide a more robust means of identifying the critical source areas discharging contaminants to rivers.

MANAGEMENT STRATEGIES TO REDUCE NITRATE LEACHING FROM SPRING BARLEY TO GROUNDWATER ON A VULNERABLE SOIL

Alina Premrov[1], Catherine Coxon[1], Richard Hackett[3] and Karl Richards[2]
[1]School of Natural Sciences, Geology, Trinity College Dublin
[2]Teagasc, Johnstown Castle, Wexford;
[3]Teagasc, Oak Park, Carlow

ABSTRACT

This study investigates the effect of three over winter green-cover treatments (naturally regenerated green-cover, mustard and no-cover) to reduce nitrate leaching from a spring barley system. The study was performed on free-draining soil underlain by a shallow sand and gravel aquifer in Oak Park, Carlow, from 2006 to 2009. The study consists of an unsaturated zone small-scale randomized experiment, and a shallow-groundwater large-scale experiment. The small-scale experiment includes over-winter green-cover treatments under conventional and reduced tillage, and is equipped with suction-cups (0.9m depth), whereas the large-scale experiment includes treatments only under conventional tillage, and is equipped with piezometers (4-5m depth). Generally high nitrate concentrations were observed in October and early November 2006 in both experiments (>30 mg NO_3*-N/L) [1, 2]. The largest decreases in nitrate concentrations were observed under the mustard cover-crop in each experiment. Already during the 2006/07 drainage season the small-scale experiment mustard / conventional tillage treatment significantly reduced cumulative N loss to the unsaturated zone at 0.9m, while both mustard and naturally regenerated green-cover / reduced tillage treatments also showed a reduction in N loss compared with no green cover [1, 2]. The large-scale experiment started to show reductions in the saturated zone concentrations under the mustard treatment compared with no green cover in early 2008 [2]. The results indicate that over-winter green-cover uptake of soil mineral N (either residual N following harvest or N mineralised over-winter) could be an important strategy for reducing nitrate leaching on vulnerable locations with free draining soil.*

References

[1] Premrov A., Coxon C., Hackett R. and Richards K. (2008) Strategies to reduce nitrate leaching from spring barley to groundwater on a vulnerable soil. Walsh Fellowship Seminar, RDS, Dublin, 2008.

[2] Premrov A., Coxon C.E., Hackett R., Kirwan L., Brennan D., Sills P., Staples V. & Richards, K.G. (2008) The effect of tillage method and over-winter green cover on nitrate leaching from spring barley. In: Agricultural Research Forum 2008. Tullamore, Co. Offaly. pages: 8.

USE OF STABLE ISOTOPE ANALYSIS (SIA) TO IDENTIFY AND TRACK ANTHROPOGENIC NUTRIENTS IN GROUNDWATER AND SUBMARINE GROUNDWATER DISCHARGE (SGD).

Foley, L. [1], Rocha, C. [1], Crowe, T.P. [2] and Grocke, D. [3]
[1]Biogeochemistry Research Group, School of Natural Sciences, Trinity College, Dublin 2, Ireland.
[2]School of Biology & Environmental Science, Science Centre West, University College Dublin, Belfield, Dublin 4, Ireland.
[3]Department of Earth Sciences, Durham University, South Road Durham DH1 3LE UK.

ABSTRACT

SIA has developed in ecological research as a tool to determine the contribution of different nutrient/contaminant sources to a common sink. SIA of contaminants, such as δ15N of nitrogen, provides a method for identifying the source of nutrients, and possibly tracking pathways of transport and reactivity of N-containing pollutants in groundwater.

However, pitfalls exist in the use of SIA, particularly in ecological research. Many researchers assume conservative transport of isotopic signatures and fail to consider the ability of reactions to alter such signatures, e.g. nitrification and volatilisation lead to δ15N-enrichment in the remaining substrate fraction of the N-pool so that it becomes δ15N-enriched relative to the original N source. Thus, biochemical transformations in transit may result in the isotopic signature of a contaminant (e.g. fertiliser) resembling that of a different contaminant (e.g. sewage), leading to inaccurate conclusions when determining the pollution source. Such reactions and processes must be considered and incorporated when using fractionation to attribute a position within the foodweb, and when using a N-fractionation-sequence within a foodweb to determine the N source.

In areas with conductive aquifers, such as karst aquifers, and a positive hydraulic head, groundwater may enter the marine environment via SGD. Thus, groundwater provides a vector for land-derived nutrients to the marine environment, usually the intertidal, with potentially significant environmental impacts on ecosystem functioning.

Preliminary investigations in Portugal demonstrate the potential for SIA in identifying the source of contaminants in groundwater and the benthic foodweb of the intertidal system to which they are delivered.

PHYSICAL CHARACTERISTICS & PESTICIDES IN GROUNDWATER ACROSS IRELAND: RESULTS OF THE EPA GROUNDWATER SURVEY 2007-2008

Sarah-Louise McManus[1], Karl G. Richards[2], Jim Grant[3], Anthony Mannix[4], and Catherine E. Coxon[1]
[1]Dept. of Geology, School of Natural Sciences, Trinity College Dublin, Dublin 2
(smcmanu@tcd.ie)
[2]Teagasc Environmental Research Centre, Johnstown Castle, Wexford, Co. Wexford
[3]Statistics and Applied Physics, Research Support Team, Teagasc, Ashtown, Dublin 15
[4]Environmental Protection Agency, McCumiskey House, Richview, Dublin 14

ABSTRACT

The aim of this study was to explore associations between zone of contribution (ZOC) physical characteristics and pesticide occurrence at 158 sites in Ireland sampled for pesticides in 2007-2008 as part of the Environmental Protection Agency's (EPA) national groundwater quality monitoring programme for the European Union (EU) Water Framework Directive (2000/60/EC).

Pesticide detections at each site (n=158) were classified into 3 levels. Occurrences greater than or equal to the EU drinking water standard (≥ 0.1 µg/L), greater than the analysis detection limit and below the EU drinking water standard (>0.01µg/L and <0.1µg/L) and values below the detection limit were identified from the 2007-2008 groundwater quality dataset. Associations between the most prevalent ZOC characteristics and pesticide occurrence were explored using Fisher's Exact Test (SAS, 2004) and significant associations were further analysed by logistic regression.

Site type (i.e. borehole / well / spring) was significantly associated with pesticide detections (p 0.01), with logistic regression suggesting that springs were more likely to have a pesticide detection (p 0.0076). Subsoil permeability did not show a significant association with pesticide detections (p 0.4634), but a classification of the subsoil types into acid versus basic subsoils showed a significant association (p 0.02), with logistic regression indicating that detections were more likely in basic subsoils including limestone tills and limestone gravels (p 0.0101). Aquifer type was also significantly related to pesticide detections (p 0.001): when aquifers were classified according to the Geological Survey of Ireland's system of hydrogeological characteristics, logistic regression showed that regionally important aquifers were more likely to have a detection (p 0.0007), while analysis using the Irish classification system of flow regime used for the Water Framework Directive has revealed that karstic aquifers have a greater probability of a pesticide detection (p 0.0002). Main flow lines through karstic aquifers to springs can allow pesticides to travel quickly through the subsurface without much interaction or attenuation in the soil, which normally suppresses pesticide mobility via sorption within the soil matrix.

GROUNDWATER AS AN ENVIRONMENTAL SUPPORTING CONDITION IN RAISED BOG WETLANDS

Regan, S. and Johnston, P.
Department of Civil, Structural and Environmental Engineering, Trinity College Dublin.

ABSTRACT

Peat bogs are traditionally considered to be relatively isolated hydrological systems with no direct linkage to a source aquifer. The isolation of a raised bog ecosystem from regional groundwater flow is primarily a consequence of its mode of development, where natural drainage is impeded by topography and geomorphology. Recent research on Clara Bog, Ireland, indicates a more complicated relationship between the peat body and the regional groundwater system. This interconnection has significant implications for restoration design.

Typical of most Irish raised bogs, peat overlies low permeability lacustrine clay, impeding downward movement of water. However, there are areas under the bog where this clay barrier is naturally absent, allowing the peat to rest directly on an underlying aquifer, a regional body of relatively permeable till subsoil. In the recent past the western tract of the bog has subsided significantly, up to 1.0 m locally, and as far as 600 m from the bog margin towards its centre. Consolidation of the peat substrate has altered hydrological conditions on the bog surface, thereby affecting its ecology.

Coincident with bog subsidence has been a localised drop in regional groundwater table. External drainage has created an enhanced hydraulic connection between the high bog and regional groundwater flow, resulting in vertical drainage from basal peat in the high bog. Both peat consolidation and groundwater level decrease have occurred in areas where lacustrine clay is absent. The inference is that maintenance of regional groundwater levels can be a critical support condition in the conservation of raised bog wetlands, and that restoration measures must be designed based on the bogs controlling hydrogeological processes.

CHARACTERISATION OF THE SHERWOOD SANDSTONE AQUIFER IN THE CONTEXT OF THE AQUIFER THERMAL ENERGY STORAGE SYSTEMS

McCabe, C. and Ofterdinger, U.S.
School of Civil Engineering, Queens University Belfast, David Keir Building,
Stranmillis Road, Belfast, BT9 5AG, United Kingdom

ABSTRACT

Ground source energy systems (GSES) are seen as environmentally friendly alternative to traditional heating and cooling systems that rely on fossil fuels. One such technology with a lot of potential is Aquifer Thermal Energy Storage (ATES). The UK has lagged behind continental Europe in the up-take of GSES and with the recent push towards a low carbon society, higher fuel prices and the adoption of the European Building Performance Directive (2002/91/CE) has led to the adoption of alternative environmentally, and sustainable technologies such as GSES. The Triassic Sherwood Sandstone aquifers are widely distributed throughout the UK and are the second most used group of aquifers after the cretaceous chalk aquifers. Groundwater from these aquifers has played an important role in the development of many UK cities such as Belfast, Birmingham, Leeds, Liverpool and Nottingham supplying potable and industrial water. As such there is a significant opportunity for the development of ATES systems in the Sherwood Sandstone. The mineralogy of the Sherwood Sandstone was analyzed. Geophysical and hydrogeological tests were conducted. Initial characterization suggests the Sherwood Sandstone Aquifer is suitable for ATES. Further work is needed to assess the recovery efficiency of ATES in Sherwood Sandstone.

SESSION III

CHLORINATED HYDROCARBONS – DIFFERENT REMEDIAL OPTIONS & REGULATORY APPROACHES

Dr Olivia Hall, Regenesis Ltd
Kevin Forde, URS/Scott Wilson

ABSTRACT

It is estimated that up to 1,500 facilities in Ireland, both licensed and unlicensed, use chlorinated hydrocarbons (CHCs) as a solvent in routine operations. This translates to the presence of up to 1,500 potentially contaminating CHC sites throughout Ireland.

The objective of this paper is to highlight the issues associated with the identification of CHC contamination and the challenges facing consultants and remediation practitioners is implementing remediation strategies to address CHC contamination in Ireland against a background of evolving regulatory requirements.

This paper presents an overview of the remedial approach at four CHC contaminated sites in Ireland where remedial works have been ongoing over the past decade, with particular reference to the changing regulatory regime over this time.

INTRODUCTION

Chlorinated hydrocarbons are a broad class of organic chemicals and are derived from a hydrocarbon molecule where one or more of the hydrogen atoms has been replaced by a chlorine atom. Chlorinated hydrocarbons (CHCs) are among the most frequently occurring contaminants in soils and groundwater. The physical and chemical properties of these compounds mean they have a wide range of industrial uses but also make them difficult to find or remove once they have entered the subsurface.

The most commonly used chlorinated solvents are perchloroethene (PCE), trichloroethene (TCE), 1,1,1 trichloroethane (TCA) and carbon tetrachlororide (CT). TCE was extensively used in metal fabrication and engineering, PCE in textile and leather degreasing and TCA in circuit board manufacture (Rivett, 2010). TCE and PCE have also been widely used in dry cleaning and electronic component manufacturing.

It is reported that one of the most significant constituents of point source contamination in Ireland at industrial sites is chlorinated solvents (Ford, 2010). It is estimated that there are in excess of 1,000 sites that are currently licensed under the Integrated Pollution Prevention Control (IPPC) Regulations, (EPA, 2011), though not all of these use CHCs. A further 400 sites are licensed under the Water Management Regulations (S.I. No. 395, 2004) and at least a further 100 sites have been identified to fall under the Solvent Regulations, (S.I. No. 543, 2002), (EPA/URS, 2006), totalling at least 1,500 potentially contaminated CHC sites that are likely to exist in Ireland.

THE SOLVENTS IN WATER PROBLEM

CHCs are a challenging groundwater problem for a variety of reasons. CHC’s as dense non-aqueous phase liquids (DNAPLs) are immiscible with water, but still sufficiently soluble to exceed drinking water standards by several orders of magnitude. The density of most chlorinated solvent DNAPLs ranges from approximately 1,100 to 1,600kg/m^3 and their viscosity typically ranges from approximately 0.57 to 1.0cP. DNAPL tends to exist at concentrations greater than 10% of the aqueous solubility of the solvent. Chlorinated solvents are therefore denser than water and typically less viscous than water, which can result in rapid rates of subsurface migration, far below the water table in many aquifers.

Historically manufacturers disposal recommendations for CHC's up to the 1970s, were to pour the solvents onto the ground (or in pits) to allow the solvents to evaporate, with or without ignition. Such disposal practices and inadvertent spillages have led to many DNAPL sources being present in aquifers, often at depths where other pollutants may never reach.

The exact pathway of downward migration is influenced by many factors, capillary pressure for example depends on interfacial tension, wettability and pore size or fracture aperture. The effects of capillary pressure explain much of the distribution and movement of subsurface DNAPL. Because the adhesive forces between the wetting fluid (water) and the solid surface (aquifer) are greater than the adhesive forces between the wetting (water) and non wetting fluid (DNAPL), the pressure head in the non-wetting fluid (DNAPL) must exceed the capillary force to displace the wetting fluid and enter or exit an opening. As a result macropores, large aperture fractures and coarse grained layers with relatively large openings are preferential pathways for DNAPL movement, (Payne *et al,* 2008).

In karst aquifers, for example, chemical dissolution has enlarged joints, bedding planes, and other openings that transmit water. Because the resulting karst conduits are commonly too large to develop significant capillary pressures, chlorinated solvents can migrate to considerable depth in karst aquifers as DNAPL's and as such present significant challenges to the remediation practitioner.

Upon release at the ground surface, the DNAPL will migrate both vertically and laterally, as illustrated in Figure 1. Residual DNAPL, in the form of disconnected blobs or ganglia or organic liquid is formed at the training end of the migrating DNAPL body. Residual DNAPL will form in both unsaturated and saturated media, and is held in place by capillary forces, (EA, 2003).

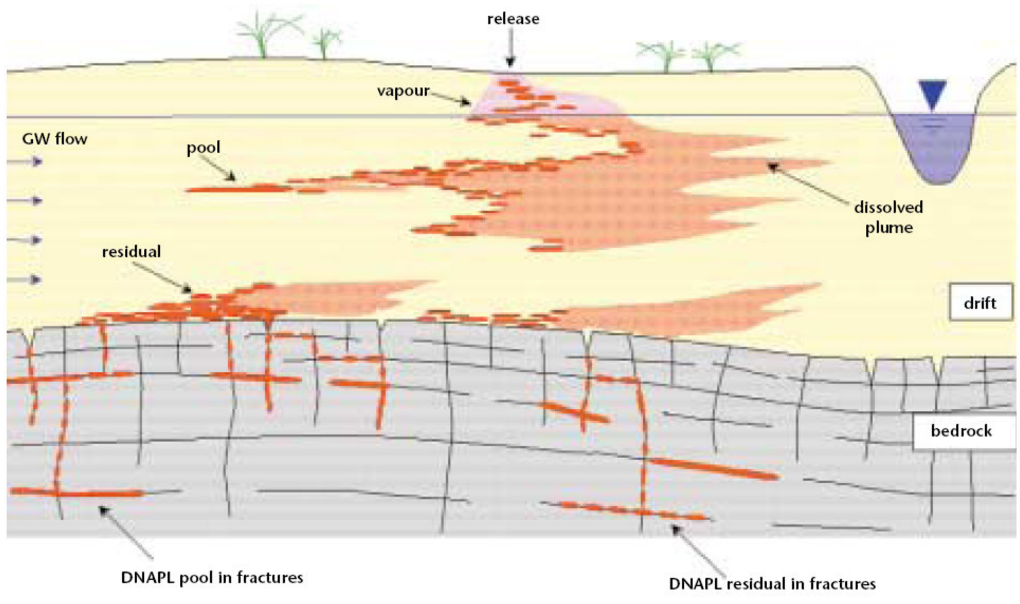

Figure 1: DNAPL Distribution in unconsolidated deposits (EA, 2003)

The amount of residual DNAPL retained by a typical porous medium such as silt, sand and gravel is typically between 5 – 20% of the pore space, (EA, 2003). Figure 2 presents a close up view of residual

DNAPL in saturated porous media. In most types of porous media, high hydraulic gradients or physical pumping will fail to mobilise residual DNAPL.

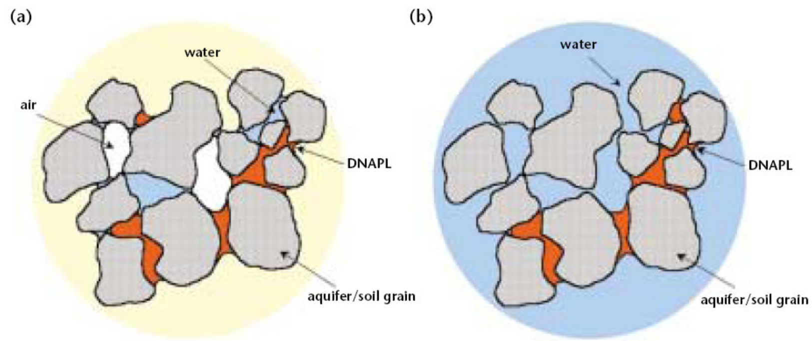

Figure 2: Residual DNAPL in (a) unsaturated medic and (b) saturated porous media (EA, 2003)

The residual DNAPL mass however will dissolve slowly into flowing groundwater, giving rise to a dissolved phase plume. Since most CHC's have relatively low solubilities and groundwater velocities are typically low, residual DNAPL may not be depleted for many decades and will continue to act as a source of further contamination over this time. As such a relatively small amount of chlorinated DNAPL has the potential to contaminate ground water over a significant area for decades or longer.

REMEDIATION OF CHC's

To data, a number of point sources of CHC contamination have been identified in Ireland, however, full plume delineation is rare and very costly and the number of sites where successful remediation has been carried out or ongoing is limited. To date, much of the remediation work done in Ireland on CHC sites have focused on containment or pathway control in order to break the source pathway linkage, as in Site 2 discussed below. However, groundwater pump & treat systems should be considered as containment or pathway control mechanisms only rather than active remediation, (Ford, 2010), and is considered to be a very inefficient costly means of achieving remedial goals in a reasonable timeframe.

Through the process of remedial options appraisal, remediation strategies are selected based on effectiveness, practicality, durability and likely cost and benefits. The following section summarises technologies that have been used to target either the source zone or both the source and aqueous phase plume and gives an indication of the effectiveness, practicality and durability.

GROUNDWATER PUMP & TREAT (P&T)

P&T involves the use of groundwater extraction wells to remove aqueous phase contamination and/or contain a DNAPL source zone. The extracted groundwater is typically treated ex-situ in a treatment plant before discharge to a watercourse, sewerage system or back to ground. Because of the long time required to desorb contaminants from aquifer solids, the long timescales associated with back diffusion from the aquifer matrix and the long time required to dissolved residual DNAPL, most pump and treat systems operate for many decades.

PERMEABLE REACTIVE BARRIERS (PRB)

At sites where groundwater plumes are shallow and readily accessible, a trench or funnel and gate type PRB can be constructed and filled with suitable reactive material, e.g. zero valent iron. The groundwater flows naturally through the permeable barrier, within which degradation occurs. Residence time needs to be sufficient to allow for contaminant reductions to occur within the barrier. PRBs tend to be costly engineering solutions and are not suitable where a contaminant plume is at any significant depth.

THERMAL TECHNOLOGIES

Thermal technologies such as steam flooding, in situ thermal desorption, six phase heading and microwave heating are relatively new technologies that rely on heat to vapourise and mobilize contaminants. High capital costs make these technologies inaccessible for many small to medium scale sites. In addition, it is difficult to predict the amount of mass removal that can be achieved at a particular site.

EXCAVATION

The physical removal of residual and pooled DNAPL from the source zone through excavation is often considered at sites where the extent of contamination is restricted primarily to unconsolidated deposits in the unsaturated zone. Increasing hazardous waste disposal costs make this option less viable. In addition, if DNAPL is present below the water table, the removal of contaminants from above the water table through excavation is unlikely to result in any improvement in groundwater quality.

Table 1

Contaminant	RegenOx™	Fenton's Reagent	Permanganate	Persulfate	Activated Persulfate	Ozone
Petroleum Hydrocarbons	A	A	B	B	B	A
Benzene	A	A	D	B	B	A
MTBE	A	B	B	C	B	B
Phenols	A	A	B	C	B	A
Chlorinated Ethenes (PCE, TCE, DCE, VC)	A	A	A	B	A	A
Chlorinated Ethanes (TCA, DCA)	A	B	C	D	C	B
Polycyclic Aromatic Hydrocarbons (PAHs)	A	A	B	B	A	A
Polychlorinated Biphenyls (PCBs)	B	C	D	D	D	B
Explosives (RDX, HMX)	A	A	A	A	A	A

Based on laboratory kinetic data, thermodynamic calculations, and literature reports.

Oxidant Effectiveness Key:

A = Short half life, low free energy (most energetically favored), most complete
B = Intermediate half life, low free energy, intermediate degree of completion
C = Intermediate half life, intermediate free energy, low degree of completion
D = Long half life, high free energy (least favored), very low degree of completion

CHEMICAL OXIDATION

Chemical oxidation can be used to chemically destroy aqueous phase contaminants in-situ. Oxidant effectiveness varies for different contaminants, as illustrated in Table 1. In addition, for oxidation to take place direct contact is required between the contaminant and the oxidant. Water is typically used as the transport medium for the oxidant and in general high volumes are required for treatment.

DUAL PHASE VAPOUR EXTRACTION (DPVE)

Dual-phase extraction is an in-situ technology that uses pumps to remove various combinations of contaminated groundwater, separate-phase product, and hydrocarbon vapour from the subsurface. Extracted liquids and vapour are treated and collected for disposal, or re-injected to the subsurface. Suitability of DPVE will depend on the site characteristics and chemical properties. Similar to P&T, treatment with DPVE requires time and is limited in what can be achieved i.e. low remedial target are difficult to achieve.

ENHANCED IN-SITU BIOREMEDIATION

Over the past three decades many products have been used in order to alter the redox conditions of the aquifer in turn promoting biodegradation of the contaminant. Under anaerobic conditions for example, the parent compounds PCE and TCE may be biodegraded via reductive dechlorination. Reductive dechlorination is described as the biologically mediated step wise replacement of chlorine with hydrogen, ultimately resulting in the formation of ethene, which itself poses no unacceptable risks. Abiotic and biological transformations for a selection of CHC compounds are illustrated below in Figure 3 below.

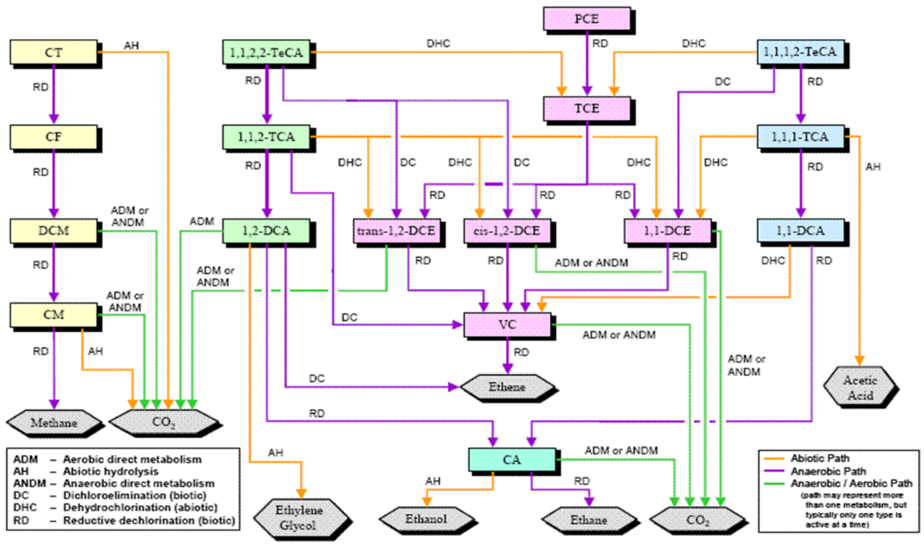

Figure 3: Abiotic & biological transformation pathways for selected chlorinated solvents.

Enhanced in situ bioremediation is commonly used to treat both dissolved phase plumes as well as being used in plumes with concentrations associated with the presence of DNAPL. It has become the remediation method of choice over the last few decades as it can be used to treat DNAPL down to very low levels of contamination and more recently through advances in electron donor distribution e.g. the development by Regenesis of 3D-Microemulsion, this approach has proven effective in complex geological settings e.g. bedrock with no physical free product removal required and minimal onsite disturbance or significant capital costs. It addition, the development of slow release products has allowed for ideal redox conditions to be maintained for extended periods of time with no onsite disturbance beyond the initial application, particularly relevant when remediation works are being undertaken at an operational facility. Enhanced bioremediation offers a low cost solution to what can be very large sites.

Regenesis have implemented enhanced bioremediation remediation strategies on over 4,000 sites worldwide and have collaborated with URS/Scott Wilson on almost 200 sites internationally, including sites in Ireland, in the UK, mainland Europe, Australia and the United States.

In the following sections of this paper, we have presented four case studies that illustrate the approach to CHC remediation in Ireland over the past decade. The remedial strategies and regulatory approach is illustrated to change over this time.

CASE STUDIES

As outlined in the preceding sections, the physical properties of CHC make them challenging problems both for investigation and remediation, particularly in the near-surface fractured bedrock aquifers that characterise much of Ireland.

Outline data is presented below on a number of industrial sites belonging to confidential multinational clients in Ireland where URS/Scott Wilson have encountered CHC contamination, principally TCE in fractured bedrock aquifers. The sites discussed vary both in the intrinsic properties of the bedrock aquifers (therefore exhibit differing assessment and remediation strategies depending on the setting) and in the regulatory frame work under which site assessment and remedial strategies were implemented (illustrating an evolution in the regulatory approach on the part of the EPA over time).

Site 1	Medical devices manufacturing IPPC-licenced South-east Ireland	TCE used as mould cleaner Losses due to leaking drains and historical storage/use practices	"Poor" Bedrock Metasediment Aquifer Low Permeability (<5e10^{-7} m/s) 600m to watercourse No housing adjacent to site No vapour risk to nearby commercial properties	Initial characterisation 1997–2004 Monitored Natural Attenuation accepted for 5 year period Anomalous TCE results in re-drilled well on 2008 (10-100 times higher) Major re-assessment of CSM and strategy ongoing, no soil source.
Site 2	Automotive component manufacture IPPC-licenced South-east Ireland	TCE use to degrease aluminium components Losses due to poor handling and unauthorised disposal practices	"Regionally Important" Volcanic Bedrock Aquifer High Permeability (10^{-4} m/s) Preferential plume migration controlled by anisotropic bedrock fracture pattern Aerobic aquifer conditions, little in-situ degradation of TCE 200m to watercourse, TCE detected in water course (key receptor) PWS impacted 1.5km down-gradient (decommissioned) No housing adjacent to site No vapour risk to nearby commercial properties (5 m clay soil)	Initial characterisation 2000-2002 Boundary hydraulic containment started 2003, no QRA or modelling, based on understanding of CSM CSM based on hydraulic testing, has proven robust >8 tonnes TCE recovered to date (Air Stripper with aqueous phase GAC @ 200m^3/day)) Off-site plume contracting. Bedrock source area not well defined. Client unwilling to trial alternative source reduction remedial methods (due to experiences in bedrock aquifers elsewhere), accepts long-term commitment to P&T

Site 3	Pharmaceutical manufacturing IPPC-licenced East	DCM used as solvent in chemical synthesis. DCM in solution with a range of other organic solvents (toluene, xylenes, MTBE, acetonitrile, tetrahydrofuran)	"Locally Important" Limestone Bedrock Aquifer and silty till sub-soils Anaerobic background conditions in aquifer, limits degradation of non-chlorinated compounds Weathered bedrock is key flow zone (bedrock $<10^{-7}$ m/s, weathered bedrock 10^{-5} m/s) 60m to watercourse (intermittent impact detected) No housing adjacent to site No vapour risk to nearby commercial properties	Characterisation ongoing since 1990s. Several changes of CSM and remedial approach Additional site investigation and risk assessment in 2009/10 leading to Remedial Options Assessment in 2010 and a recommended Preferred Option. Enhanced In-Situ Bioremediation is preferred strategy Currently negotiating pilot-scale test of injectable product (slow release oxygen) with EPA
Site 4	Pharmaceutical finishing and packaging IPPC-licenced East of Ireland	TCE historically used in heat transfer system Suspect losses due to defective containment in storage area	"Locally Important" Granite Bedrock Aquifer Main contaminant mass and migration in weathered bedrock zone. Moderate to Low Permeability ($<10^{-5}$ m/s) Aerobic groundwater system, little in-situ degradation of TCE 500m to watercourse No housing adjacent to site No vapour risk to nearby commercial properties	TCE issue detected during construction work in mid-2000s Extensive Site Investigation including coring, downhole geophysics, packer testing. QRA in 2008 indicated potential risks to on-site workers and off-site watercourse Remedial Options Appraisal conducted 2009 Enhanced In-Situ Bioremediation is preferred strategy Pilot-scale test of injectable product (HRC^{TM}) with EPA approval in 2009 – very effective, still active with anaerobic source area conditions 18 months later No accumulate on hazardous breakdown products (i.e. vinyl chloride) noted. Full scale remedial implementation has been authorised and is imminent

Sites 1 and 2 present an interesting contrast in terms of geological setting, one being in a high permeability, heavily exploited fractured rock drinking water aquifer and the other in a low permeability poor fractured rock aquifer. A Monitored Natural Attenuation strategy was initially negotiated at Site 1 on the basis of limited site investigation data and relatively low perceived risk, and would have continued had a damaged well not been replaced and much higher TCE concentrations been detected in the new well (within 3 m of the original well), illustrating the heterogeneity and difficulty in characterising fractured bedrock systems.

Site 2 was well-characterised, through phased investigation involving over 40 monitoring wells and the remedial system was implemented to mitigate proven risks (impact on two key receptors - a public water supply well and a surface water course). While no formal modelling or risk assessment has been performed for this site, the original CSM for Site 2 has proven very robust.

Remedial approaches for Sites 1 and 2 were initially negotiated with the EPA in the early-mid 2000s under a more informal licence enforcement regime and the level of technical justification proposed for these approaches was far less than would be required under current EPA requirements.

Sites 3 and 4 have both been investigated and proposed for remediation more recently (late 2000s) and the Agency has adopted a much more stringent approach in these cases than was the case for Sites 1 and 2. Phased, detailed site investigation has been required at both sites, with extensive Agency and third-party consultant review of results evident. In-situ bioremediation has proven to be a highly effective solution and following the success of the pilot works completed at Site 4, full scale in situ bioremediation treatment is imminent at this site. Likewise, in situ bioremediation is considered the most suitable remediation approach at site 3. A pilot testing programme is currently being negotiated for this site.

Evidence of a clear evolution of the EPA approach to contaminated land assessment is also seen in the formal process of site-specific risk assessment modelling, followed by Remedial Options Assessment and selection of a Preferred Approach, which has been required for Sites 3 and 4. A key priority on both sites in this process has been the clear identification of Remedial Goals and establishment of metrics and timescales for achievement of those goals prior to commencement of remediation, in contrast to the more fluid approach adopted for Sites 1 and 2.

In the absence of specific Irish guidance, the most common risk assessment approaches adopted in Ireland by contaminant land consultants in recent years have been based on modifications of the UK CLEA risk assessment approach (Environmental Agency, 2004).

CONCLUSIONS

Characterisation and remediation of contaminated ground water at the fractured bedrock sites that often characterise Irish CHC contaminated sites are hampered by the complex geology, the heterogeneous distribution and orientation of the fractures, and the movement of contaminants and fluids in fracture networks and rock matrices. Comparison of the approaches adopted at Sites 1 and 2 highlights the benefits of extensive site characterisation in developing robust Conceptual Site Models to underpin decisions on remedial actions.

While many treatment technologies exist which are capable of tackling CHCs, many are best suited to homogeneous, granular, unconsolidated aquifer settings and may struggle in the less predictable fractured rock setting that, at least in URS/Scott Wilson’s experience, account for the majority of groundwater CHC issues in Ireland.

In recent years, the evolution in regulatory requirements has led to a significant increase in the level of detailed site investigation, CSM development and justification of remedial techniques required by the EPA at IPPC-licensed facilities and contrasts with the approach in earlier years where limited site investigation led to the widespread adoption of pumping-based strategies at many sites, often with no clear objectives or defined endpoints. In contrast, in-situ bioremediation has proven to be an effective solution in these complex geological settings and successful pilot scale treatment provides additional confidence in this remediation approach.

Formal Irish guidance on environmental site characterisation and risk assessment of contaminated sites is lacking and current developments in this regard are welcomed, to harmonise the approach taken to contaminated site assessment and remediation.

REFERENCES

Environmental Agency (2003) An illustrated handbook of DNAPL transport and fate in the subsurface. R&D Publication 133.

Environmental Agency (2004) CLR 11: Model procedures for the management of land contamination (2004) R&D Report CLR 11, 192pp Environment Agency, Bristol, UK

Environmental Protection Agency (2011) Sum of IPPC license sites on the EPA website, www.epa.ie

Environmental Protection Agency & URS Ireland (2006) Solvents Regulations Ireland, Identification of Activities Covered by the Solvents Regulations in Ireland.

Ford, M. (2010). The Assessment & Prioritisation of Point Sources of Groundwater Contamination in Ireland. International Association of Hydrogeologists - Irish Group Proceedings of the 30th Annual Groundwater Conference, (pp. 9-16). Tullamore.

Payne F.C., J.A. Quinnan & S.T. Potter (2008). Remediation Hydraulics. CRC press.

Rivett, M. (2010). The legacy of chlorinated solvents in groundwater: an overlooked 1940s contribution. Royal Society of Chemistry - Environmental Chemistry Group Bulletin , 5-14.

Emissions of Volatile Organic Compounds from Organic Solvents Regulations 2002, S.I. No. 543 of 2002 (the Solvents Regulations)

Waste Management (Licensing) Regulations, 2004 (S.I. No. 395 of 2004)

Wiedemeier T.H., H.S. Rifai, C.J. Newell and J.T. Wilson (1999). Natural Attenuation of Fuels and Chlorinated Solvents in the Subsurface. John Wiley & Son

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GROUNDWATER REMEDIATION OF CHLORINATED ETHENES – IMPLEMENTATION OF A PILOT STUDY IN AN IRISH CONTEXT

Eleanor Burke
Malone O'Regan, 2B Richview Office Park, Clonskeagh, Dublin 14
Tel: 01 2602655 Email: eburke@morce.ie

ABSTRACT

This paper presents the findings of a remediation pilot study completed at a former industrial facility in Co. Laois. Historic operations at the facility included jewellery making, soap manufacturing and aerosol production. The facility, an Integrated Pollution and Control (IPC) licensed facility, was closed in 2000. During site decommissioning, investigative works identified elevated levels of chlorinated solvents in the groundwater beneath the site, in particular Trichloroethene (TCE). Monitored Natural Attenuation (MNA) was the remedial approach agreed with the EPA as part of the site owners exit strategy. In early 2007, the EPA requested that our Client assess alternative remedial strategies for the site. A remedial options appraisal was completed and the most technically viable remedial strategy was selected. A pilot study commenced in 2007, to validate the effectiveness of the chosen strategy, enhanced anaerobic bioremediation (reductive dechlorination). The pilot study consisted of applying a hydrogen releasing compound to the subsurface within a portion of the inferred source area onsite. Groundwater monitoring wells, located upgradient, downgradient and cross gradient, were monitored over an eighteen month period to observe the effects.

Enhancing reductive dechlorination using hydrogen donors effectively accelerates the breakdown of chlorinated solvent contaminants from the parent compound to its daughter products in this instance from TCE, to 1,1-dichloroethene (1,1-DCE), cis-1,2-dichoroethene (cis-DCE) or trans-1,2-dichloroethene (trans-DCE), vinyl chloride (VC) and eventually to ethene. During the pilot study and following application of the organic substrate i.e. a hydrogen releasing compound, a sharp decrease in concentration of the parent compound, TCE, was observed with concentrations decreasing from 20.374mg/l to <1mg/l measured at Day 19 post application. A corresponding increase in the daughter products was observed. The pilot study demonstrated that reductive dechlorination is a viable and effective remediation strategy for this site.

GENERAL INTRODUCTION

The site is located in Co. Laois and is bordered by a mix of residential, commercial and agricultural developments. The site was Greenfield prior to its development in the 1970s. Historic site operations included jewellery making, soap manufacturing and aerosol production. The site was licensed by the EPA in September 1998 under an Integrated Pollution and Control (IPC) Licence. In 1999 the site owners announced their decision to close the site and a gradual shutdown of operations took place between 1999 and the first half of 2000. Our Client purchased the site in 2000 and the site is currently unoccupied.

GEOLOGY

Quaternary Geology

The subsoil beneath the site comprises glacial tills (boulder clay) and sand and gravel deposits, which vary in thickness and occurrence across the site.

Bedrock Geology
The bedrock underlying the site is mapped as the Calp Formation which comprises of limestone with some shale. The bedrock is fractured in places, with the most highly fractured zone in the central portion of the site. Fractures have a moderate to steep dip (30º to 60º) which is similar to the orientation of the bedding planes. Some calcite and black mineralisation with similar orientation were identified at the site. The limestone bedrock has been locally dolomitised and has exhibited varying amounts of weathering and fracturing which control hydraulic conductivity in the formation.

HYDROGEOLOGY
The aquifer beneath the site is located within the Cushina Groundwater Body (GWB) which has an areal extent of $170m^2$. The aquifer of the Calp Formation in this area is classified as a locally important aquifer which is moderately productive only in local zones. In general, the Calp Formation is considered to have a low permeability in the order of 1m/d (Wright, 2000); however, high permeability is associated with fault zones.

The groundwater vulnerability beneath the site has been classed by the Geological Survey of Ireland (GSI) as 'high' with the exception of a small area in the northern portion of the site which is classed as 'Extreme' and 'Extreme with rock near surface or karst'.

The results of hydrogeological testing at the site indicate that the hydraulic conductivities ranged from 1.39x10-9m/s (0.00012m/d) to 2.08x10-4m/s (18m/d) with an average of 2.41x10-5m/s (2.08m/d). In general, the higher permeability values were associated with wells screened across highly fractured and weathered or dolomitised zones within the limestone. Groundwater beneath the site flows to the northeast towards the River Barrow which is located 500m from the site and is the primary environmental receptor of groundwater contamination in the area. It was established that all houses and industries within a 1 km radius of the site are served by public mains water supply. The measured hydraulic gradient across the site ranges from 0.003 to 0.005.

CONTAMINANTS
In accordance with the requirements of their IPC Licence, the former site owners undertook an investigation of the property to determine whether there were any residual impacts on the subsoil and groundwater as a result of 25 years of industrial activities on the site. This investigation revealed the presence of elevated levels of an industrial chlorinated solvent, namely Trichloroethene (TCE) in the groundwater downgradient of the factory building. TCE was commonly used in industrial and commercial activities in the 1970s and 1980s in particular as a degreasing agent for cleaning metal parts and also for dry cleaning. It is reported that TCE may have been used on the site from 1974 to the early 1980s. The contamination onsite resulted from site operations and waste management practices associated primarily with jewellery manufacturing although there were no reports of significant releases at the site. Maximum TCE concentrations reported in the inferred source area, located downgradient of the factory building, were in the region of 130mg/l in a sample collected from Borehole 401 in May 2000. Low level contamination was detected at depths of 75metres below ground level (mbGL) although the highest concentrations were generally observed at a depth of approximately 25-30mbGL. Low level concentrations of Tetrachloroethene (PCE) and chlorinated ethene daughter products were also observed.

ROLE OF THE REGULATOR
Monitored Natural Attenuation (MNA) was the remedial strategy approved by the EPA and implemented by the former site owner in 2000. It was considered at that time based on available data that the process of natural attenuation was already occurring. Malone O'Regan (MOR) has undertaken groundwater monitoring on site since 2001. Monitoring reports were submitted to the EPA after each monitoring event. These reports reveal the continued presence of TCE in the groundwater and although the plume size has remained stable over the monitoring period, the EPA were no longer willing to accept MNA as a

viable remediation strategy due to the slow degradation of the contamination. In January 2007 the EPA requested that our client consider alternative remediation. Following this request from the EPA, MOR commenced a detailed evaluation of possible alternative remediation technologies.

REMEDIAL OPTIONS APPRAISAL

Various remedial options were examined by MOR to determine their technical feasibility for use on this site including those listed in the Contaminated Land Report No. 11, more commonly known as CLR 11 (Environment Agency, 2004). The remedial options evaluated included:

Civil Engineering Methods	• Hydraulic Barrier • In-ground Barrier
Biological Methods	• Biosparging • Enhanced Anaerobic Bioremediation
Chemical Methods	• Chemical Oxidation
Physical Methods	• Dual Phase Soil Vapour Extraction (DPSVE) • Air Sparging • Permeable Reactive Barriers (PRBs) • Ex-situ Pump and Treat • Thermally enhanced remediation techniques

The remedial options were evaluated in terms of the initial cost of implementation, ongoing operational and maintenance costs, duration of treatment, disturbance of land and specific technical constraints. Some of these remedial options were easily discounted given the specific site characteristics. For example, given the depth of contamination, it was clear that PRBs, in-ground barriers or thermal treatment would not be effective solutions for this site. It was also considered that hydraulic containment would not be effective for this site as it is likely that groundwater flow within the bedrock aquifer rather than flushing due to infiltration is responsible for much of the mass transfer of contaminants.

Techniques that involve the use of air injection (e.g. biosparging and airsparging) were also discounted due to difficult application in bedrock conditions, the depth of contamination and also given the heterogenous subsurface conditions present which could result in some areas remaining untreated.

Any method involving the extraction of groundwater (e.g. DPSVE or ex-situ pump and treat) were not considered to offer viable technologies in the context of site specific conditions due to the high operation and maintenance costs associated with treating such large volumes of water and difficult application conditions given the depth of the contamination.

Chemical oxidation ranked strongly as a remedial option however it was also considered to be unviable due primarily to the requirement for oxidants to come into contact with all areas of contamination, the potential for frequent reapplication, in addition to health and safety concerns.

Following s detailed evaluation, enhanced anaerobic bioremediation (and the reductive dechlorination process) was ranked as the preferred option, on the basis that it would enhance mildly reducing conditions already present, that the contaminant levels are within the treatable range and that substrate addition would facilitate the reductive dechlorination of the competing electron acceptors present in the groundwater onsite followed by a reduction in chlorinated solvent contamination. Two organic substrates that are readily available on the market were evaluated as part of the appraisal, HRC-Advanced and ethanol.

HRC-Advanced is a glycerol polylactate/polyoleate produced by Regenesis. It provides effective reductive dechlorination over large plume volumes as naturally occurring microorganisms create hydrogen and, in turn, reducing conditions in the aquifer when they metabolise the lactic and fatty acid supplied by HRC-Advanced. The hydrogen acts as an electron donor within the reducing environment and facilitates reductive dechlorination of the contaminants. This product is used to accelerate the in-situ biodegradation rates of chlorinated hydrocarbons via anaerobic reductive dechlorination processes. The indigenous microorganisms capable of reductive dechlorination use the hydrogen to progressively remove chlorine atoms from chlorinated hydrocarbon contaminants.

Ethanol (CH3CH2OH) is a volatile flammable colourless liquid that is miscible with water. Similar to HRC-Advanced, when ethanol in applied to the subsurface naturally occurring microorganisms utilise the ethanol for energy creating hydrogen. Under anaerobic conditions, ethanol can be biodegraded to acetic acid and hydrogen or to carbon dioxide and hydrogen. The hydrogen acts as an electron donor within the reducing environment and facilitates reductive dechlorination of the contaminants.

Some of the main difficulties of in-situ treatments include achieving contact with all areas of contamination as without direct contact breakdown will not be observed. Ethanol has a short electron donor release profile as it rapidly ferments when compared to the longevity of the HRC-Advanced (4-5 years). Therefore, while ethanol is cheaper upon initial application than HRC-Advanced, its short lifespan within the aquifer would warrant a number of subsequent reapplications at a substantial additional cost. In addition, HRC-Advanced migrates from the application wells via advection, therefore allowing for significant distribution of HRC-Advanced and over its functional longevity. Similarly hydrogen will travel in the subsurface from the migrated HRC-Advanced via diffusion and advection allowing for a greater radius of influence of the treatment which should in turn minimise the number of application wells and reduce the potential for a requirement for repeat application events.

PILOT STUDY IMPLEMENTATION

PILOT STUDY OBJECTIVES

In undertaking the pilot study the primary objectives were to establish whether the technology would provide a viable remedial strategy for the site while at the same time remedially addressing a focused area of high contamination within the source area at the site. Additional objectives for the pilot study included gaining information on:

- The degradation kinetics as a result of the application of the slow release electron donor;
- The longevity of the product and the associated metabolic acids which are released within the pilot area;
- The requirement for electron donor in order to facilitate degradation, and
- Confirmation of the site conceptual model.

PILOT STUDY DESIGN AND IMPLEMENTATION

The location of the pilot study was based on a review of all analytical data available for the site and targeted elevated concentrations of TCE within the source area. Wells 401 and 402 consistently contain the highest concentrations of TCE and are considered representative of the source area. It was considered important from the perspective of carrying out the pilot study, to have a large volume of baseline information on both the control well (Well 402) and the upgradient well (Well 401).

Design Rationale:

- Background/Control well (402): Allowed for the changes in natural attenuation conditions to be compared to background levels.
- Well upgradient of treatment zone (401): Provided a measure of contaminant and competing electron acceptor flux entering the treatment zone.

- Well inside treatment zone (APP1 and APP2): application wells.
- Well downgradient of the treatment zone (DGW): Provided information on the effect HRC-Advanced had on the biodegradation rates of contaminants and on aquifer conditions.

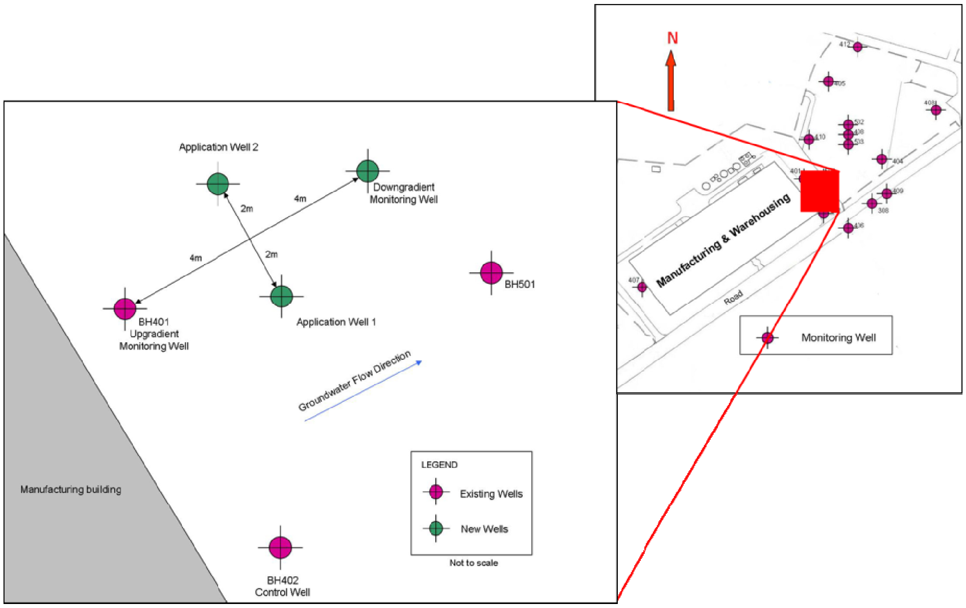

Figure 1: Pilot Study Layout

The volume of HRC-Advanced applied during this pilot test was calculated based on a number of factors including the area to be targeted, representative contaminant concentration, contaminated saturated zone thickness requiring treatment, estimated groundwater velocity, groundwater geochemistry and competing electron acceptor demand for HRC-Advanced supplied electron donor. The remediation pilot study commenced on the 27th July 2007. HRC-Advanced was mixed with water on site to form a micro-emulsion (5:1 dilution). In total 278.8 kg of HRC-Advanced was applied to each of the injection wells (2No.).

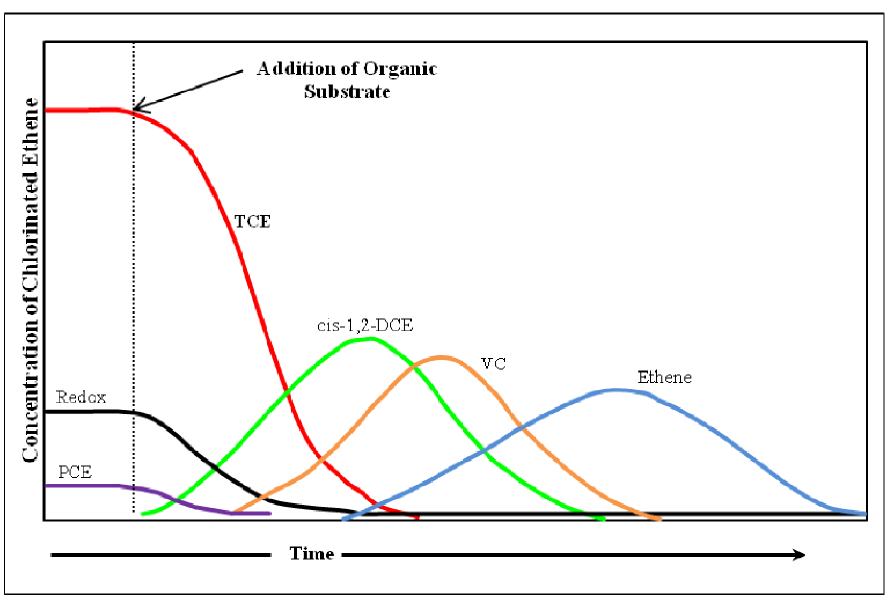

Figure 2: Conceptual model of the predicted change in chlorinated ethene concentration on site over time due to sequential reductive dechlorination.

Following the addition of an organic substrate and in the presence of appropriate microbial communications, reductive dechlorination of the parent compound occurs. For this particular site it was anticipated that TCE would be reduced to the following daughter products, 1,1 dichloroethene (DCE), cis-1,2-dichloroethene (cis-DCE) or trans-1,2-dichloroethene (trans-DCE). These daughter products are reduced to Vinyl Chloride (VC) which is ultimately reduced to ethene.

DISCUSSION OF RESULTS

Following application of the hydrogen releasing compound groundwater monitoring of the pilot study wells was completed on 7 No. occasions over a 14 month period.

Chemical Parameters – Parent and Daughter Compounds

A baseline monitoring event was completed prior to the application of the hydrogen releasing compound. This identified elevated concentrations of TCE in groundwater in DGW (20mg/l). The baseline monitoring event illustrated that minimal degradation of the chlorinated ethene parent compound was taking place with low levels of one daughter product, trans-DCE, evident (0.034mg/l). Low levels of tetrachlorethene (PCE) were also observed (0.004mg/l).

Table 1: Chlorinated Ethene Concentrations - DGW

Compound			Baseline June 2007	Event #1 August 2007	Event #2 September 2007	Event #3 November 2007	Event #4 December 2007	Event #5 January 2008	Event #6 June 2008	Event #7 September 2008
Tetrachloroethene	mg/l	<0.001	0.004	-	-	-	-	-	-	-
Trichloroethene	mg/l	<0.001	20.374	0.008	0.720	0.260	2.353	1.276	1.539	0.010
trans-1,2-Dichloroethene	mg/l	<0.001	0.034	-	-	0.019	0.048	0.104	-	0.018
cis-1,2-Dichloroethene	mg/l	<0.001	-	27.487	12.834	8.069	25.112	32.748	36.070	17.561
1,1-Dichloroethene	mg/l	<0.001	-	0.075	0.043	0.022	0.085	0.180	-	-
Vinyl Chloride	mg/l	<0.001	-	-	0.005	0.015	0.014	0.091	0.492	0.306
Ethene	mg/l	<0.001	-	-	-	-	-	0.003	-	0.033

MDL – Method Detection Limit
- below MDL

Approximately two weeks (19 days) following the application of the hydrogen releasing compound groundwater samples showed clear evidence of reductive dechlorination of the parent compound with a decrease in TCE concentrations to 0.008mg/l and a corresponding increase in daughter products such as cis-DCE (27.487mg/l) and 1,1-DCE (0.075mg/l) (refer Figure 3).

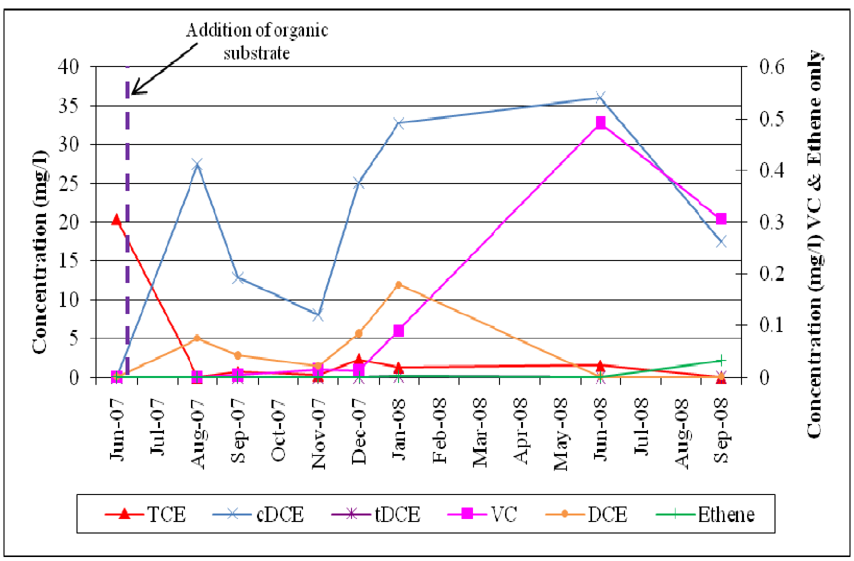

Figure 3: Chlorinated ethene concentrations over time – Downgradient Well (DGW)

Clear evidence of reductive dechlorination was observed in the downgradient well with significant increases in the concentrations of daughter products observed. Similarities were also observed between the conceptual model of the anticipated concentrations over time and the observed concentration distribution. Significantly since the pilot study was completed low levels of vinyl chloride and ethene initially observed following the application of the hydrogen releasing compounds have increased. The presence of ethene in the samples collected from the downgradient well, DGW, is evidence that reductive dechlorination is occurring as a result of the anaerobic conditions and substrate addition from HRC-Advanced. In contrast, the upgradient and control wells displayed minimal and certainly no long term reduction in chlorinated solvent concentration. The upgradient well continued to contain elevated concentrations of TCE in the region of 40mg/l representing the influx of contaminants into the pilot study area on an ongoing basis.

Geochemical Parameters
Geochemical parameters provide supporting evidence that conditions are suitable for reductive dechlorination.

Table 2: Laboratory Analysis - DGW

			Baseline June 2007	Event #1 August 2007	Event #2 September 2007	Event #3 November 2007	Event #4 December 2007	Event #5 January 2008	Event #6 June 2008	Event #7 September 2008
Field Parameters										
pH			7.43	6.57	6.76	7.16	5.39	7.80	7.11	7.08
Temperature	˚C		11.9	11.9	11.8	11.9	11.0	10.0	12.3	11.6
Conductivity	µS/cm		770	1320	1340	1013	479	1264	1114	1026
	%		1.4	2.4	2.5	1.8	1.8	2.4	2	1.8
	ppm		385	659	670	507	956	640	556	513
Dissolved Oxygen	mg/l		3.67	0.26	0.21	NA	0.60	0.26	1.08	0.09
ORP	mV		139	-21	-299	-236	-189	-157	-132	-193
Laboratory Results										
Total Iron Low Level	mg/l	<0.05	-	0.56	31.24	3.679	5.57	1.52	12.97	1.958
Dissolved Iron Low Level	mg/l	<0.002	0.005	0.34	0.051	3.822	0.021	0.396	0.096	0.266
Total Manganese	mg/l	<0.05	-	2.56	11.74	8.845	5.740	8.140	7.57	2.746
Dissolved Manganese Low Level	mg/l	<0.001	-	2.803	8.415	10.930	5.384	7.798	10.810	0.129
Nitrite	mg/l	<0.05	-	-	-	-	-	-	-	-
Nitrate	mg/l	<0.3	7.20	-	-	-	-	-	-	-
Sulphate	mg/l	<3	30	24	16	-	-	-	-	-
Chloride	mg/l	<1	84	71	109	107	92	113	90	97
Methane	mg/l	<0.001	-	-	0.003	0.006	0.004	0.051	0.190	1.300
Ethane	mg/l	<0.001	-	-	-	-	-	-	-	0.001
Ethene	mg/l	<0.001	-	-	-	-	-	0.003	-	0.033
BOD	mg/l	<2	-	467	108	101	52	-	8	35
Ferric Iron	mg/l	<0.05	-	-	-	2.1	-	2.3	-	0.180
Ferrous Iron	mg/l	<0.1	-	-	-	2.1	-	4.7	0.06#	-
Lactate*	mg/l	<0.20	4.07	764	2.80	3.03	2.42	2.72	NA	NA
acetate*	mg/l	<0.20	-	<50	103	89.90	49.30	66.40	NA	NA
i-butyrate*	mg/l	<0.20	-	<2.0	<1.0	<10.0	<1.0	<1.0	NA	NA
n-butyrate*	mg/l	<0.20	-	6.82	<1.0	1.84	0.93	4.34	NA	NA
Propionate*	mg/l	<0.20	-	17.8	152	76.70	21.80	46.10	NA	NA
Pyruvate*	mg/l	<0.20	-	<2.0	<1.0	-	-	-	NA	NA
TOC (Chemex)	mg/l	<0.20	3.39	349	121	59.20	39.10	62.90	NA	NA

MDL – Method Detection Limit
- below MDL
NA not available

- Dissolved Oxygen (DO): DO is the highest energy-yielding electron acceptor for the biodegradation of organic constituents. The results are a clear indication that anaerobic conditions were developed onsite which are required for anaerobic reductive dechlorination to take place.
- ORP is a measure of the oxidation/reduction potential. Measurements continued to remain negative and reflect strongly reducing conditions in the downgradient well.
- Thermodynamically nitrate is the next favourable electron acceptor after oxygen. The decrease in concentrations to below MDL following the application of HRC-Advanced reflect the fact that it is a favourable electron acceptor.

- Sulphate is also used as an electron acceptor in the biodegradation of organic constituents and is reduced to form sulphide (EA, 2000). Sulphate concentrations showed a steady decrease in concentration following the application of HRC-Advanced.
- Methane is an indicator of anaerobic conditions and of the degradation of organics by methanogenic bacteria. It is produced by the microbial reduction of carbon dioxide (EA, 2000). Methane concentrations in the downgradient well have shown a steady increase since the pilot study commenced.
- TOC provides a measure of the total concentration of organic material (natural and anthropogenic) (EA, 2000). TOC was analysed during the first six months of the pilot study and it was clear from the results that HRC-Advanced had a clear impact on the downgradient well immediately after application and for the duration of the sampling and analysis for TOC that took place.
- Metabolic acids provide an indication of the presence of HRC-Advanced in the subsurface. The metabolic acids analysed are short chain molecules which provide carbon and energy for anaerobic bioremediation. In general, the highest concentrations were observed in the downgradient well following the application of HRC-Advanced.
- BOD is a measure of the amount of oxygen used by bacteria in the degradation of organic matter. As expected, BOD concentrations in the downgradient well have significantly increased following the application of HRC-Advanced and thereafter, generally decreased.

CONCLUSIONS

It can be concluded that:

- A significant reduction in the parent contaminant, TCE, was observed with a 99.95% reduction observed when the final samples were collected in September 2008 when compared to the baseline monitoring event.
- An increase in the daughter products of TCE such as cis-DCE, VC and ethene were observed. The presence of these compounds is a clear indication that sequential dechlorination is occurring (i.e. that the TCE is being broken down to its end products). The presence of these compounds, which will undergo degradation in time, either anaerobically or aerobically, is further evidence of reductive dechlorination occurring at the site due to the application of HRC-Advanced.
- Strongly reducing conditions were created and sustained within the bedrock aquifer during the pilot study. These conditions are required to facilitate the degradation of TCE.
- Competing electron acceptors such as dissolved oxygen, nitrate and sulphate all displayed a marked decrease in concentration following the application of HRC-Advanced illustrating that they have been consumed in the process. Conversely, total organic carbon measurements displayed an increase in concentration, illustrating that HRC-Advanced provides an on-going substrate for the reductive dechlorination process.
- The conceptual site model for the site was validated.
- This represents a viable and effective remediation technology for this and other sites.
- Technology improvements are facilitating the remediation of sites where previously remedial options were limited.

REFERENCES

Environment Agency, (2004), Model Procedures for the Management of Land Contamination. Contaminated Land Report 11.

U.S. Army Environmental Center, (2002), Remediation Technologies Screening Matrix and Reference Guide, 4th Edition. SFIM-AEC-ET-CR-97053. Authors: Julie Van Deuren, Teressa Lloyd, Shobha Chhetry, Raycharn Liou, James Peck.

US EPA, (2004), How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers, EPA 510-R-04-002.

US EPA, (2004b) In situ thermal treatment of chlorinated solvents - fundamentals and field applications. EPA, 542-R-04-010 U.S.

Environmental Agency (2000) Guidance on the Assessment and Monitoring of Natural Attenuation of Contaminants in Groundwater. Research and Development Publication 95.

Wright, G. (2000) Lough Public Water Supply: Portarlington Water Supply Scheme & Killenard Group Water Scheme. Laois Groundwater Protection Scheme. GSI Report to Laois County Council.

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ENFORCEMENT OF CONTAMINATED LAND AND GROUNDWATER: THE ROAD AHEAD

Kevin Motherway, Environmental Protection Agency[1]

ASBTRACT

In the absence of a legislative framework several different approaches to dealing with contaminated land and groundwater have emerged over the last few years. This variation in approach has unfortunately also been accompanied by a marked variation in the quality and comprehensiveness of work being submitted to the Environmental Protection Agency (EPA). This has lead to difficulties in decision-making on the part of the regulator in that confidence in the data and proposed options being submitted on behalf of licensees can sometimes be in question. As a result decision-making on some issues has had to be deferred leading to an unacceptable situation for both the EPA and licensees alike. In effort to progress matters the EPA is currently assessing options for the adoption of a contaminated land framework which may be endorsed as best practice and will become the prescribed approach for dealing with contaminated land and groundwater for EPA licensed sites and ELD cases of Land Damage.

THE CURRENT LEGAL FRAMEWORK

There is currently a legislative vacuum in Ireland with regard to soil contamination, with no clear regime or policy in place[2]. Apart from EPA licensed sites, the majority of contaminated land sites fall under the remit of local authorities and are enforced under the Water Pollution Act (1977 as amended). To date the assessment of contaminated land sites in terms of their impact, need for remediation and any cleanup level to be achieved has been done on an *ad hoc* basis using a number of different soil standards from other Member States.

THE CURRENT ENFORCEMENT REGIME

The EPA deals with contaminated land and groundwater issues on a regular basis at its IPPC and Waste Licensed sites; however to date there have been no cases of Land Damage (under the Environmental Liability Directive[3] regime) referred to, or come to the attention of the EPA.

The approach to contaminated land and groundwater taken by licensees and their consultants has to date been variable in terms of the (foreign) regulatory standards applied, the methods of site assessments used, the qualifications and experience of the consultants contracted by licensees and ultimately quality of the work submitted to the EPA. For its part the EPA has also had a varied approach to dealing with contaminated land and groundwater with very developed systems and approaches in place for waste licensed sites (including guidelines and codes of practice on design and undertaking of site investigations and monitoring) but with issues at IPPC sites being dealt with on a case by case basis, with no clear formal guidance on contaminated land and groundwater issued.

In the absence of such documentation for IPPC sites, guidance from the Waste Licensed sector has commonly been applied to IPPC sites with varying degrees of success (sometimes appropriately, but often

[1] The views expressed herein may not necessarily reflect those of my employer.
[2] "Critical Analysis of the Land Damage Provisions of the Environmental Liability Directive", Shields, A.; Irish Planning and Environmental Law Journal - Vol.16, No. 2 Summer 2009.
[3] 2004/35/CE

inappropriately). It must be borne in mind that the imperative for standards to be in place for waste sites such as landfills is far higher than for IPPC sites in that waste sites often contain known long term hazards which represent real risk to soil and groundwater; whereas IPPC facilities (excluding those with waste activities encompassed in their licences) generally present potential hazards which may pose a risk to soil and groundwater. This is borne out in that the majority of contaminated land and groundwater issues the EPA deals with are associated with waste activities (particularly legacy landfills). In many cases the issues dealt with at waste sites are well understood and encompass a very limited suite of scenarios and contaminants whereas the whole gamut of IPPC sites can present a much wider range of scenarios and contaminants.

The below tables (Figures 1 & 2) outline a gap-analysis in the current EPA approach in terms of guidance and policy when compared to a phased Framework Approach typical of contaminated land and groundwater regimes in other jurisdictions. It outlines what is required at present and what may be required in the future to allow the EPA to apply such an approach.

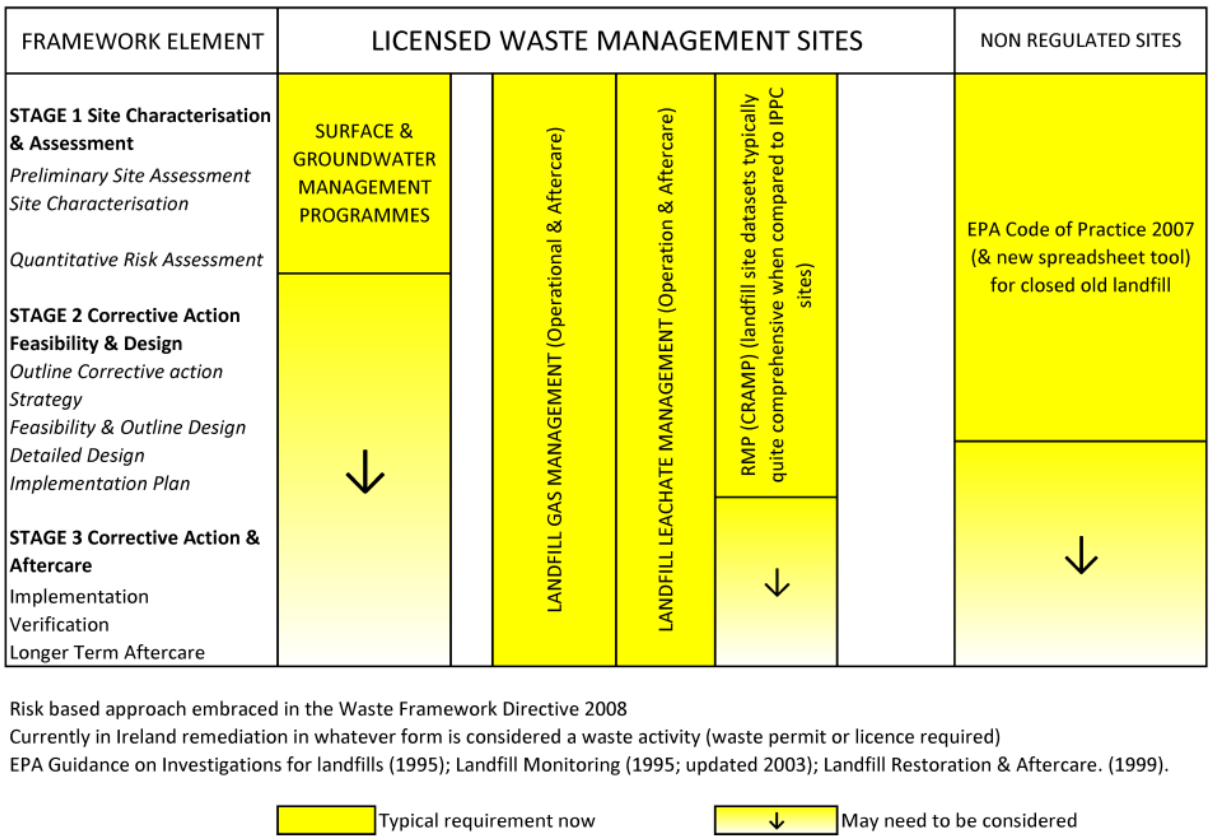

Figure 1: Overview of Existing Contaminated Land & Groundwater Regulatory Requirements at Landfill Sites

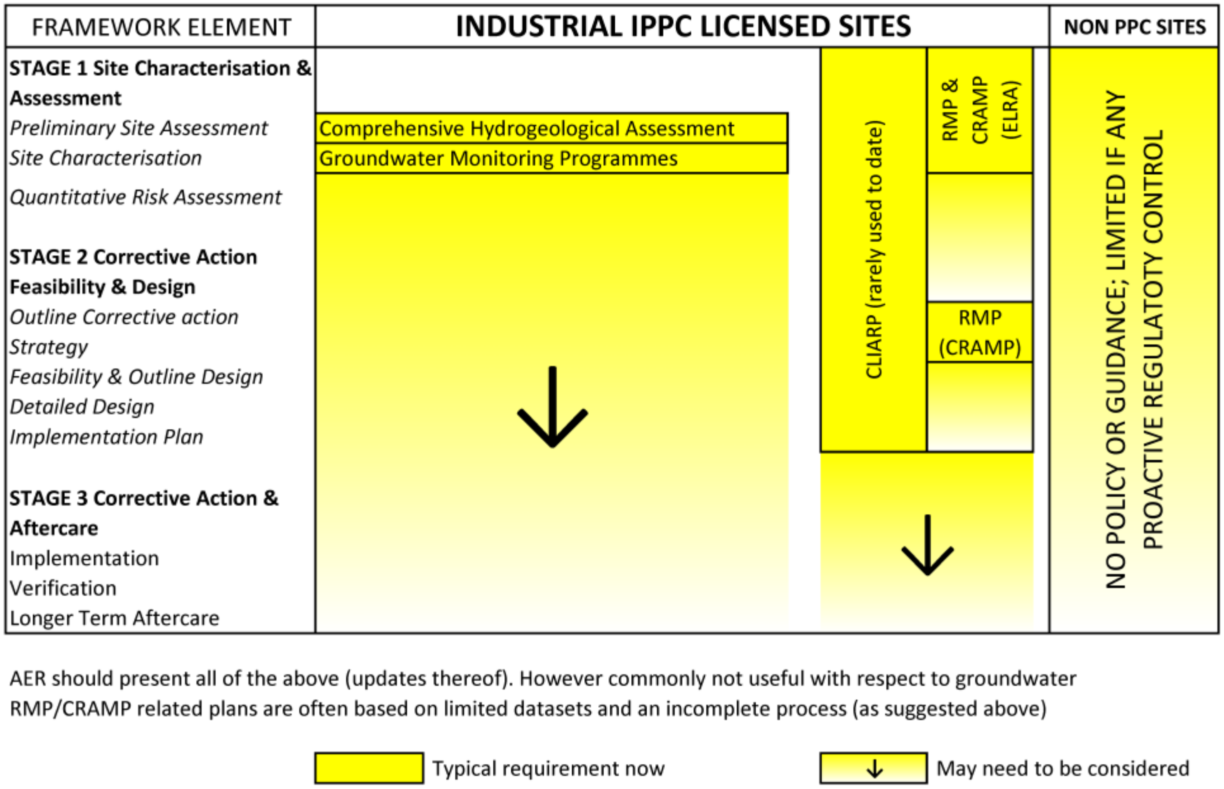

Figure 2: Overview of Existing Contaminated Land & Groundwater Regulatory Requirements at IPPC Sites

TAKING STOCK

The EPA is currently examining the area of the enforcement of contaminated land and groundwater and will in the near future be issuing guidance on what is considered best practice and approaches to be adopted by licensees (and *de* facto their consultants). One of the key drivers for this is the EPA's role in the implementation of the Water Framework Directive and the need not merely to assess issues but progress them and ensure we achieve Good Status by the deadlines prescribed. However one of the other key drivers is also that in the current economic climate the EPA has to ensure that the approaches being adopted by consultants; and that the standard of work being submitted (in both technical and strategic terms) protects the time and budgetary resources of both the EPA and operators paying for such reports. Due to the lack of a statutory framework variations in both technical approach and costs have developed in the consultancy sector, often leaving clients at a loss as to whom they should engage to represent them. In the short-term, lesser experienced or qualified consultancies (often not hydrogeologists at all) may provide an economic advantage, but such in the longer term may not provide a logical framework in which an enforcement issue can be closed out successfully with the EPA. Unfortunately this has led to a situation whereby reputable firms which provide good quality hydrogeological consultancy have been priced out of the market and now no longer even tender for some work, exacerbating the problem of standards of work.

THE WAY FORWARD

It is clear that the current situation, with variable standards and technical approaches and variable quality of work being submitted to the EPA, preventing it from reaching decisions to either close out an issue or to accept a certain course of corrective action, is not sustainable. The EPA is currently undertaking a review with *Ford Consulting Group* in order to develop a Contaminated Land and Groundwater Assessment Framework and Tools. This work involves a wide degree of consultation within the EPA, with key experts in the field, with the consultancy sector and with other regulators. Once this review is completed proposals will go to upper management in the EPA to adopt a proposed approach.

This proposed approach will most likely include the adoption of a set methodology and logical risk-based phased approach (see initial draft below in Figure 3) to the handling of all contaminated land and groundwater issues at EPA licensed sites and ELD cases. It is also probable that the EPA will outline clear technical specification for the standards of work to be done as well as setting out template reports and worked examples for each of the phases. After the outlining of the new enforcement policy and provision of templates, the EPA may adopt minimum acceptance criteria for work submitted and may reject work which does not meet this standard (i.e. work may be screened before being assessed in detail and may be rejected if it does not meet the criteria as outlined to licensee and consultants).

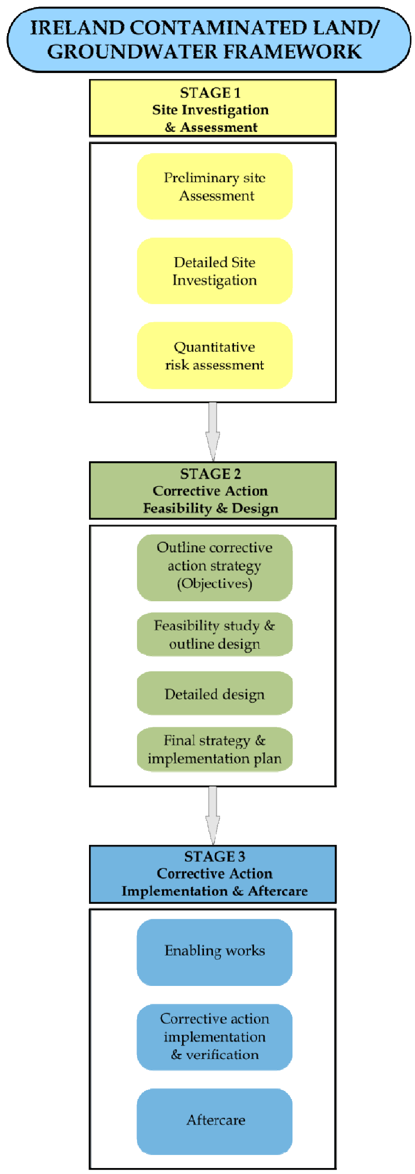

Figure 3: Outline draft of Contaminated Land and Groundwater Framework

INPUT FROM CONSULTANTS

The EPA has already engaged with some of the key practitioners in contaminated land and groundwater in Ireland. It is probable that during the adoption of any new policy or standards by the EPA that there will be a transition phase where the EPA will need feedback from the consultancy sector to ensure that the new framework and associated tools are working effectively. Clear feedback from the consultancy sector during this phase will be essential and the EPA will be seeking to meet with all the key practitioners as well as keeping licensees informed about how their service providers will be adapting their approach to the new framework. There will also be a transition phase where the EPA will seek to issue advisories to consultants regarding any shortcomings or failure to adhere to procedures; after which the EPA will start to formally reject work which does not comply with the minimum acceptance criteria set out. Any such rejections would of course be issued to the licensee (the client). Capable and professional hydrogeological and contaminated land practitioners whom the project team have engaged with to date broadly welcome the outline proposals set out above in that these practitioners have for many years been using the approaches outlined in terms of phasing their work, have been meeting high standards and wish to see any practitioners who do not reach that level discouraged from representing clients. Contaminated land and groundwater issues need to be addressed in a serious, consistent, open and comprehensive way that allows regulators to take decisions confident in the knowledge that a full risk assessment has been undertaken and that what is being proposed is environmentally sustainable. It is hoped that the potential developments proposed in this paper will assist operators, consultants and the EPA to reach that goal together.

SESSION IV

AN INTERNATIONAL PERSPECTIVE ON MINE DEWATERING

Paul Heaney,
RPS Aquaterra

ABSTRACT

Mine dewatering is an important aspect of any mining operation progressing beneath the water table and/or potentiometric surface. The main objective of mine dewatering is to facilitate safe and economic mining. This paper presents a brief summary of why dewatering/depressurisation is required and some of the methodologies adopted to achieve effective dewatering internationally. Mine largely drive mine dewatering plans and hydrogeological/geotechnical conditions. It is important to match dewatering system design with hydrogeological conditions and to understand how different aquifer parameters influence dewatering. Environmental considerations are a critical aspect of mine dewatering and need to be addressed as early in the process as possible. Dewatering is best tackled by adopting a staged approach, with the level of accuracy and confidence increasing in parallel with the mine project itself. Successful mine dewatering is generally achievable with adoption of appropriate planning and flexible management.

INTRODUCTION

Mining below the water table generally requires some form of dewatering and/or depressurisation. Apart from quarries, most of the early mines in our history were underground operations chasing seams or lodes that were initially found at the surface. The limits to a lot of these mines were defined by water inflows in excess of removal/pumping capacity and/or unstable wall conditions as a result of excess hydrostatic pressures.

Mining techniques have improved over the ages such that large scale open pit mining is now both possible and practical. Improvements in dewatering methodologies have kept pace with mining with improved pumping technology and a better understanding of hydrogeological and geotechnical processes. However, it is not uncommon even in this modern age of mining for dewatering issues to cause costly mining delays or last minute changes to mine plans and schedules.

There are also environmental issues relating to mining below the water table which, if left until the last minute, can also result in costly delays to mine approvals or involve costly retro-fit management solutions.

The keys to effective management of dewatering issues are:

- Allowing sufficient time to investigate dewatering requirements and to implement the required dewatering plans.
- A good understanding of the hydrogeological (and geotechnical) issues that determine the need for dewatering, the range of methodologies that can be applied, the lead times required, and the possible regulatory implications of dewatering approaches.
- Broad experience with dewatering systems to allow for timely screening of the available options to focus on workable solutions.

- Application of the above to scope and complete the appropriate level of investigation and analysis to provide the optimum dewatering system design.
- Acceptance that effective dewatering may require some compromise in mining method and mine plan.
- Active monitoring and ongoing performance review.

With forward planning, dewatering issues can be effectively dealt with in the same manner as geological, mining engineering and process engineering issues. That is, the need for and design (even if only preliminary design) of dewatering systems should be confirmed before project go-ahead decisions are made, rather than as an after thought once mining has commenced or the pit has already flooded.

DEWATERING & DEPRESSURISATION - OVERVIEW

It is important to understand what is meant by dewatering. In a mining sense, dewatering means the removal of sufficient water from the rock mass or soil profile such that water levels are lowered to allow for safe and economic mining. It also important to understand the difference between the terms "dewatering" and "depressurisation", which are both commonly referred to as dewatering (and will be for non depressurisation-specific references in the rest of this paper).

Dewatering

This refers to the physical draining of the pore space of the rock mass or soil, and results in the lowering of the water table (or phreatic surface). The volume of water that is removed, per unit decline in the water table, is defined by the unconfined storativity, known as the specific yield (or drainable porosity). This is a dimensionless term usually in the range of 1% (fine sediments, fractured rocks) to 30% (coarse gravels, karst limestone).

Depressurisation

This refers to the lowering of the hydrostatic head (or potentiometric surface) of the rock mass or soil without actually draining the pore space. The volume of water removed per unit decline in the potentiometric surface is defined by the confined storativity, known as the storage co-efficient. This is a much smaller number than the specific yield (and relates to the elastic compression and decompression of water) and is usually in the range 10^{-5} to 10^{-3} (or 0.001% to 0.1%).

OBJECTIVES

The main objective of dewatering is to achieve dry mining conditions. As well as meaning having no free water sitting in the bottom of the pit, dry mining (or the lack of it) can also influence the following:

- Blasting conditions - shallow water levels can require costly wet blasting techniques.
- Trafficability - damp conditions in clayey ores or oxide zones can cause slippery/unstable conditions for trucks and light vehicles.
- Ore quality/handling - ore quality requirements often specify maximum moisture content (e.g. coal). Wet ores can also be hard to load, transfer and feed.
- Pit wall stability- due to overpressure in weak wall rocks and/or lubrication of slip planes.

The main objective of depressurisation is to reduce the potential for "over pressure" related problems, including:

- Pit wall stability- due to overpressure in weak wall rocks and/or lubrication of slip planes.
- Pit wall and floor heave in softer interbedded aquifer/aquiclude sequences (Figure 1).
- Slip failure driven by excess hydrostatic heads and possibly also facilitated by lubrication (Figure 2).

- Burst inflows where confined aquifers burst through a thin/weak aquitard exposed in a footwall or where underground mines intersect saturated and pressurised fractures (Figure 3).

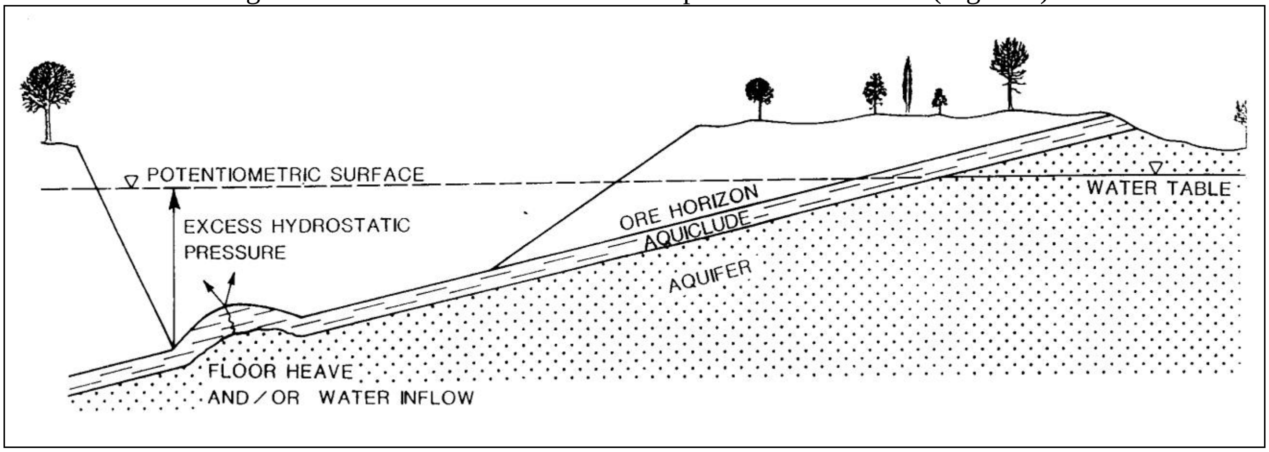

Figure 1: Depressurisation – Shallow Open Pit

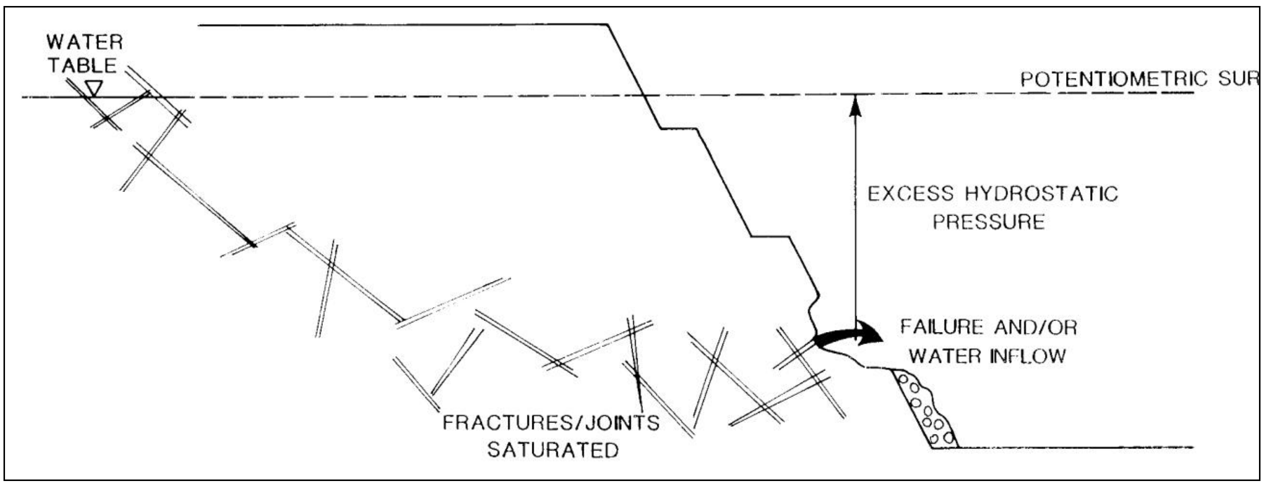

Figure 2: Depressurisation – Deep Open Pit

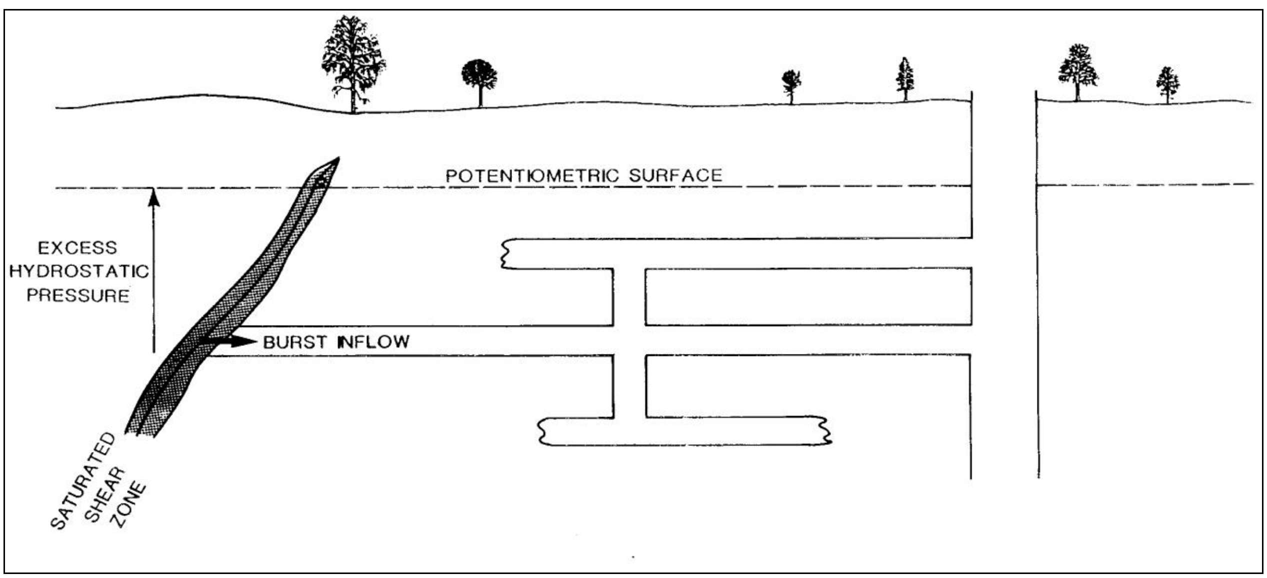

Figure 3: Depressurisation – Underground Mine Workings

METHODOLOGIES
There are numerous dewatering methodologies. However, they can be largely lumped into two broad categories; active (advanced) dewatering and passive (or real-time) dewatering.

Active Dewatering
This refers to lowering the water table or potentiometric surface by pumping ahead of mining. Common methods include:
- Bores, both outside and within the pit area.
- Deep sumps in the pit base (in permeable orebodies).
- Depressurisation holes (horizontal drain holes) in pit walls at the base of the pit as the pit is deepened.
- Drains constructed outside or beneath the pit have also been used.

Passive Dewatering
This refers to collection and pumping out of water that has already flowed into the pit. This still results in a lowering of groundwater levels around the pit, but it is behind rather than ahead of mining. Common methods include:
- Active monitoring and ongoing performance review.
- Shallow in-pit sumps.
- Catch drains on berms.

Active dewatering generally involves drawing groundwater levels down to below the base of the pit and over a larger area than the pit. However, there may also be some residual inflows to the pit (e.g. from sections of pit walls that may not be in good hydraulic connection with dewatering bores). The overall consequence of this is that an active dewatering system usually involves pumping more water than a standalone passive dewatering system.

SELECTION OF DEWATERING APPROACH

KEY FACTORS
The major influencing factors on dewatering and the selection of the most appropriate dewatering systems are the mine plan (schedule and design) and hydrogeological (and geotechnical) characteristics of the mine area. The planned depth, area and development schedule will determine when and by how much the mine will go below the water table or potentiometric surface. The hydrogeological (and geotechnical) conditions within the pit and at the margins of the pit will determine the need for dewatering, while the near pit conditions together with broader aquifer parameters will determine the optimum dewatering method. Specific key factors are discussed in more detail below.

Permeability
This defines the ability of a rock or soil to drain. That is, low permeability materials drain poorly, while high permeability materials drain more easily. Some materials (e.g. clays and some clayey sands/gravels) may never fully drain during the life of mine, and mine plans (batter angles, ramp locations, etc) may need to account for this. Permeability also influences achievable pumping rates from bores or sumps and the distribution and shape of drawdowns around bores, sumps and pits. This is illustrated on Figure 4.

Higher permeability will require higher pumping rates to maintain a specific bore or pit water level although the influence of pumping will be more widespread than for lower permeability. Dewatering can often be achieved with a small number of widely spaced and high yielding bores.

Lower permeability will only require/support low pumping rates and result in steep drawdowns. Active dewatering in low permeability rocks/soils often requires a large number of closely spaced low yielding bores. Also, passive dewatering (i.e. allowing water to run into the pit with sump pumping to remove the water) often only results in the water table remaining just behind the pit face and potentiometric surfaces remaining above the pit base.

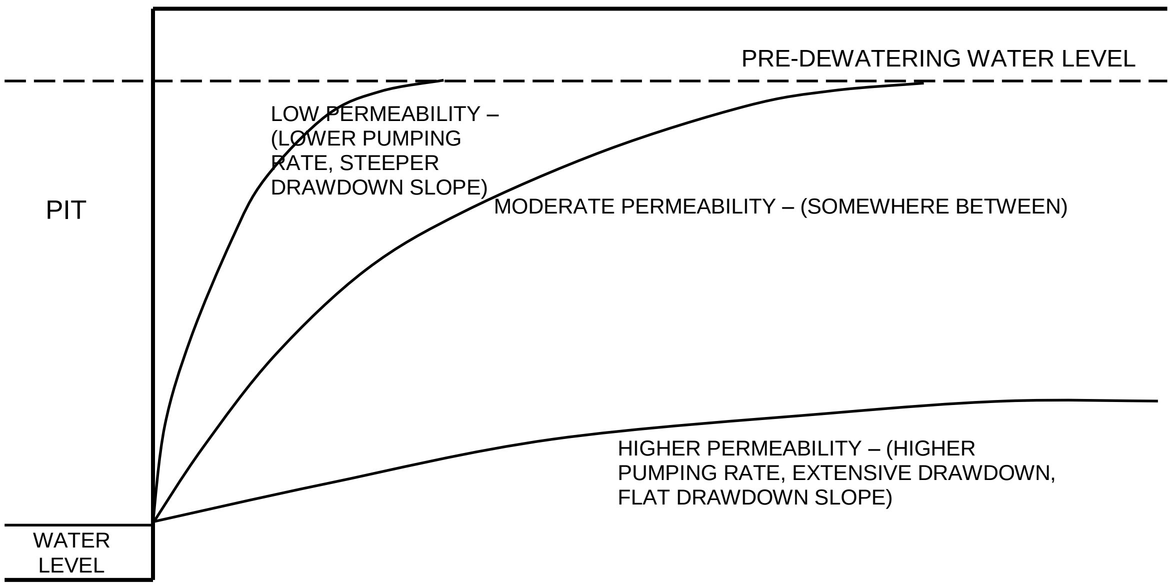

Figure 4: Hydrological Characteristics – Effect of Permeability on Drawdown Slope and Pumping requirement

Storativity

The storativity defines the volume of water released from storage as the water table or potentiometric surface is drawn down, and together with permeability determines the overall volumes of water and rates of removal (e.g. pumping) required to effect dewatering.

The storativity can also make the behaviour of some materials after dewatering difficult for mining. For example, a clay might have a saturated porosity of 60% but a specific yield of only 1%. When “dewatered” (i.e. drained under the influence of gravity) the clay will still have a moisture content of 59%. If the clay is then compacted (e.g. by haul truck wheels or excavator tracks) by only a small amount (ie by 1% volume) it will again become “saturated”. This is a common problem in saprolite pits and often requires modified mining methods (e.g. use of excavators rather than face shovels) and a “flattening” of batter angles.

Recharge/throughflow

Initial dewatering requirements (i.e. reaching target drawdowns) are largely determined by near pit aquifer parameters. However, once target drawdowns have been achieved, the “maintenance” pumping requirements (i.e. that required to keep water levels at target drawdowns) are influenced by groundwater recharge and groundwater throughflow towards the pit. In pits where the main aquifers are limited and there is no significant throughflow, maintenance pumping rates can be very low. That is, once dewatered, the pits remain largely dry. Alternatively, if the pits are in hydraulic connection with major regional aquifers or local aquifers with active recharge, maintenance pumping can be almost as high as initial dewatering requirements.

Timing
The one hydrogeological factor that will affect all dewatering situations; regardless of other conditions is the non-linear relationship between time (i.e. duration of pumping) and drawdown in response to pumping. It can take a lot longer to achieve longer term dewatering targets than short-term results might suggest. Actual time-drawdown relationships are complex and depend on site-specific conditions. However, in general, there are approximate linear relationships between drawdown and log time (and other compressed scales) that can be used to illustrate the problem.

Figure 5 shows typical plots of drawdown versus log time at an observation point in an extensive and roughly homogeneous aquifer system in response to pumping from a bore or borefield. These plots show that, for a constant pumping rate, the first 10m of drawdown is achieved in 10 days, but the next 10m of drawdown takes 3 months (total elapsed time since pumping commenced), and the next 10m takes almost 3 years, and so on. Even if the pumping rate is, say doubled, after 100 days, the next 10m of drawdown will still take almost a further 10 months.

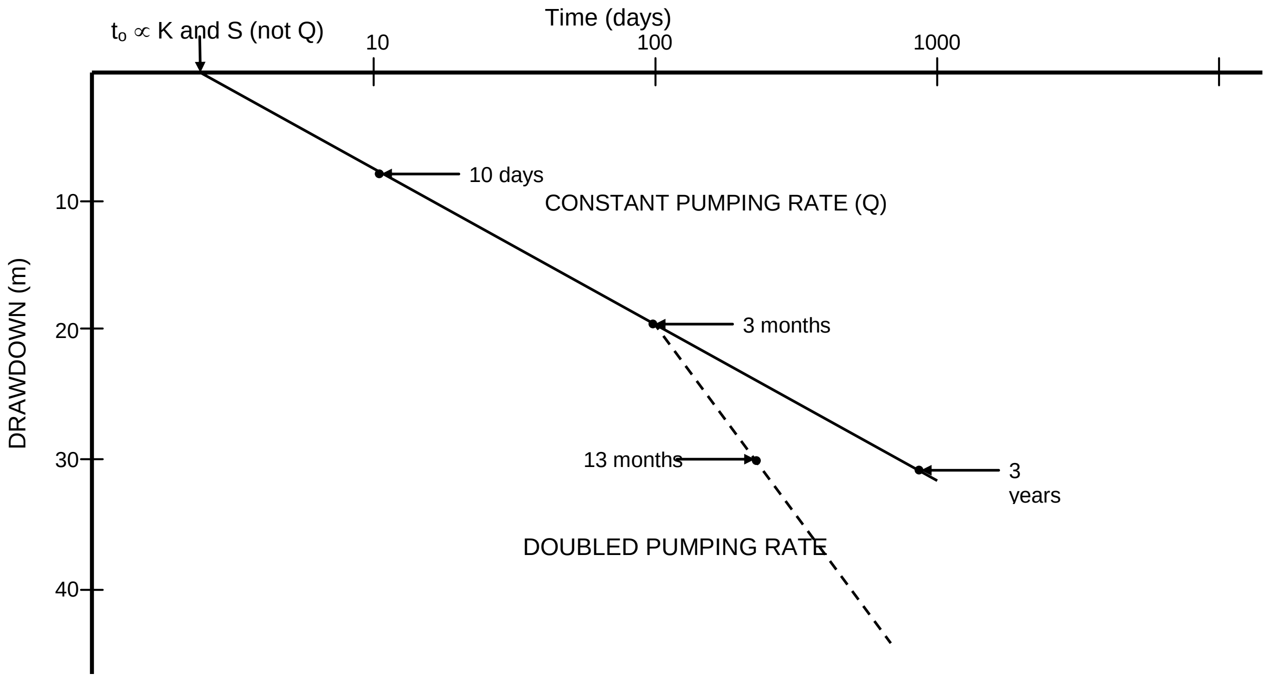

Figure 5: Hydrological Characteristics – Time Drawdown Relationship

The other important timing factor is that the onset of drawdown at any point distant from the pumping bores (e.g. the drawdown in the centre of the pit in response to pumping from perimeter bores) is a function of aquifer permeability and storativity and the duration of pumping (ie time), It is not related to pumping rate. Thus regardless of pumping rate, if there is insufficient pumping lead-time, dewatering targets will not be met.

MATCHING METHODS IN CONDITIONS
The following provides some examples of dewatering strategies for some "typical" situations to illustrate how the different broad dewatering methodologies might be employed. In practice, not all pits will fit the typical examples outlined below and dewatering will require some combination of the methods outlined.

Extensive aquifers
Some mines are within or adjacent to regionally extensive and highly permeable aquifers, e.g. lead/zinc mines in karstic/vuggy carbonates or where the ore is hosted in shallow weathered profiles with sands, gravels, calcretes and/or laterites. These types of mines are best dewatered by advanced dewatering techniques using perimeter bores and/or in-pit bores and sumps (Figure 6). Lead times can be large, up to years in some cases.

For lower permeability aquifers, active dewatering by perimeter bores is often neither practical nor cost effective, and passive sump pumping is the only alternative (Figure 7). This is the case for a large proportion of gold and base metal mines in the older basement complexes across the globe. However, active dewatering/ depressurisation of pit walls by lateral drains may also be required if the pit walls have poor drainability and excessive hydrostatic pressures develop.

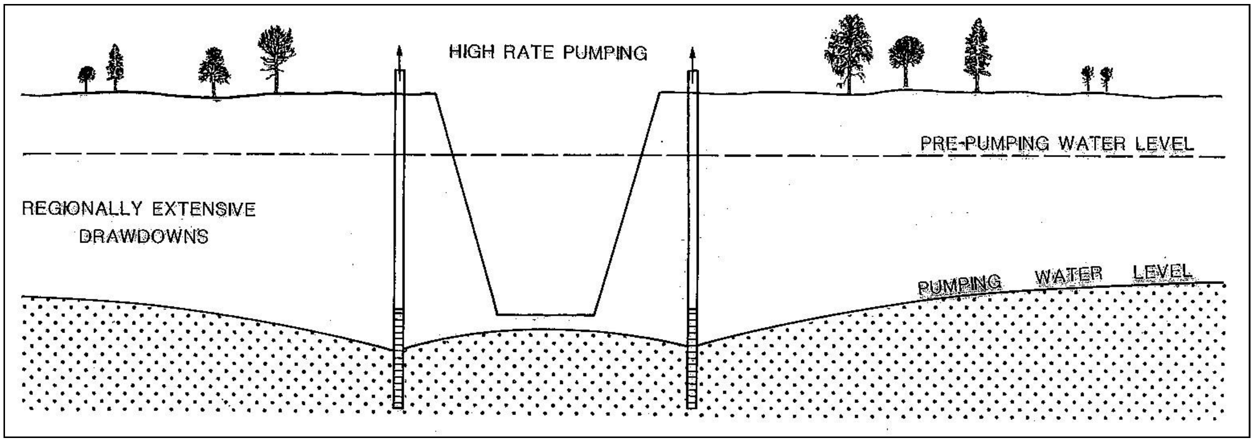

Figure 6: Dewatering Extensive Aquifers – High Permeability

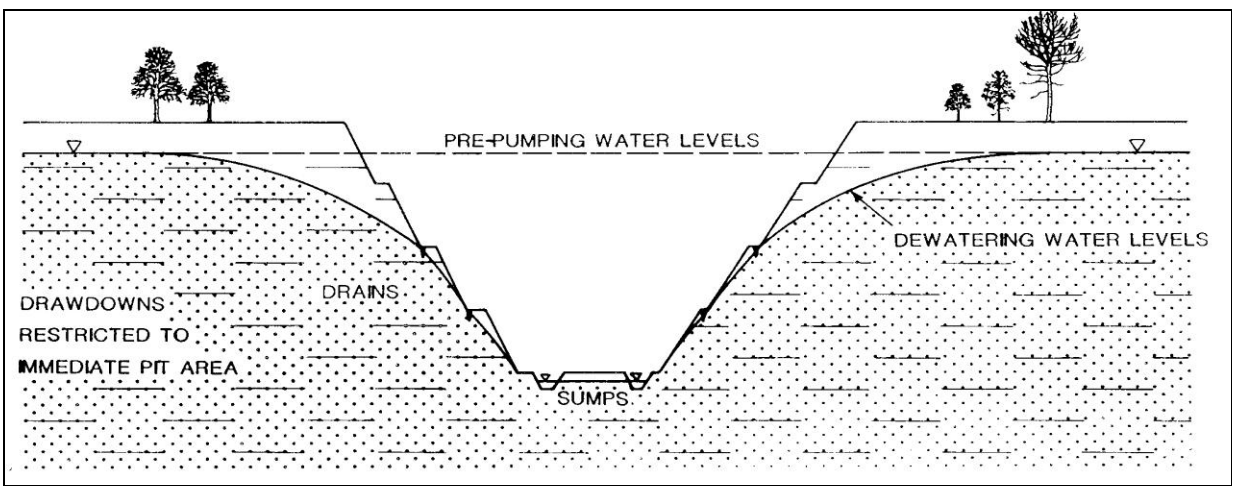

Figure 7: Dewatering Extensive Aquifers – Low Permeability

In some cases where pits are being developed over older underground operations (e.g. the Super Pit in Kalgoorlie, Western Australia), active dewatering of generally low permeability rocks has been achieved by pumping from the old underground workings beneath.

Limited Aquifers
Sometimes the main aquifer is the orebody itself and it is not possible to target perimeter bores for an active dewatering system, for example some of the major Western Australian iron ore mines (e.g. Whaleback, Tom Price, Paraburdoo and Yarrie). For permeable aquifers, it is possible to actively dewater by means of in-pit bores and sumps, although active pit wall depressurisation may also be required (Figure 8). Low permeability orebodies will behave like extensive low permeability aquitards, and require passive dewatering sumps (Figure 9).

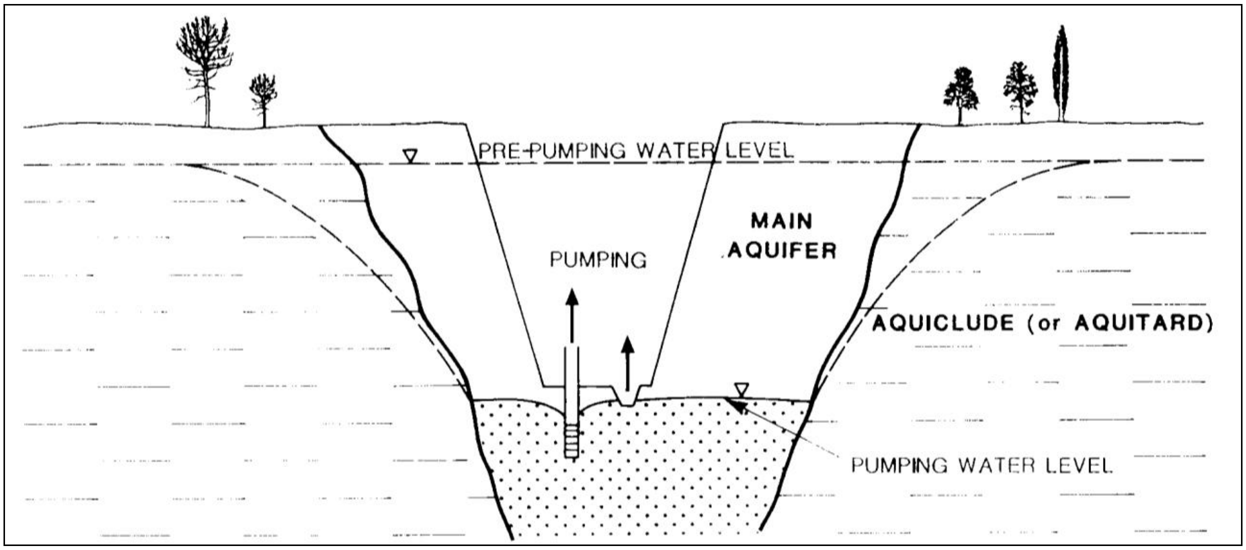

Figure 8: Dewatering Limited Aquifers – High Permeability

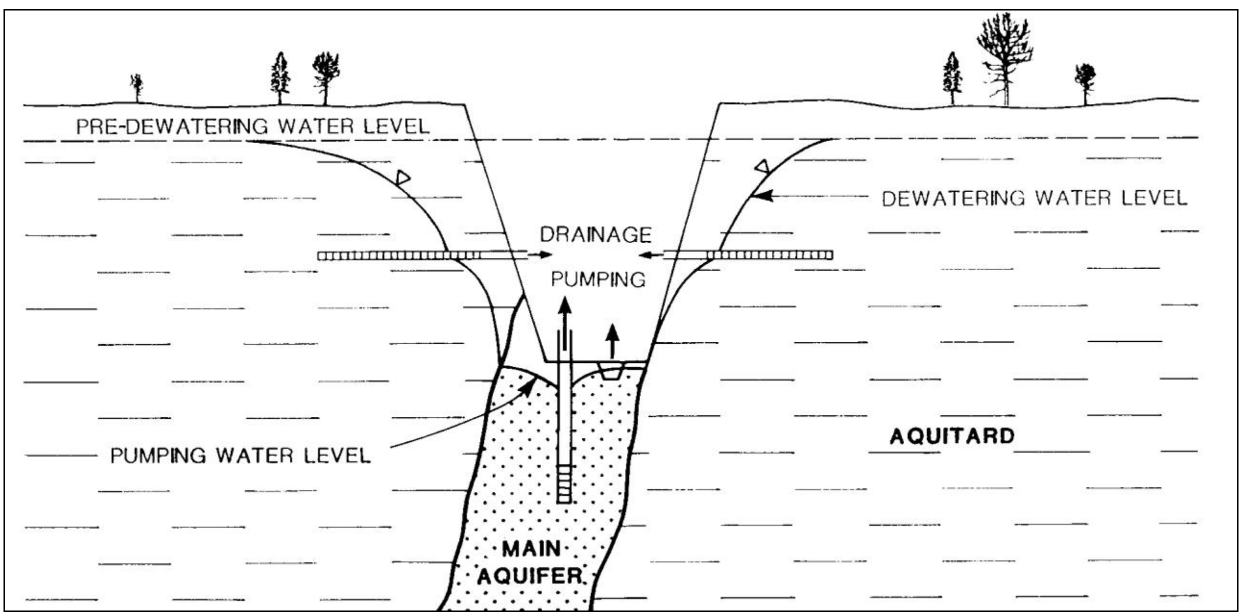

Figure 9: Dewatering Limited Aquifers – Low Permeability

ENVIRONMENTAL CONSIDERATIONS

There are environmental implications and potential impacts of dewatering that must be considered and addressed in dewatering planning, design and implementation. These fall into three broad categories.

Excess Water Discharge
Where total dewatering production exceeds the demand for the water on site (for processing, dust suppression, etc), some form of excess water discharge will be required. The main issues include:

- Salinity and solute loading of discharge – e.g. dewatering in arid regions can produce large volumes of saline to hypersaline water.
- Suspended loads - e.g. active dewatering by perimeter bores will generally result in better quality discharge water than in-pit sump pumping.
- Nature of receiving environments – e.g. abandoned pits, salt lakes, playas, etc.
- Downstream water users - and the impacts of discharge on beneficial use.
- Treatment options - natural (e.g. reed beds or wetland filters) or mechanical/chemical.

Drawdowns
Dewatering will result in some drawdown in the local water table. Depending on local/regional hydrogeological conditions, this will have some impact on local groundwater (and possibly surface water) flows and possible nearby water users.

Final Voids
This is not strictly a dewatering issue, but rather a consequence of mining below the water table that may affect mine closure planning. At the completion of mining (and dewatering) pits will gradually re-fill with groundwater and surface water until a steady state balance is reached between inflows and outflows. There may, as a result, be issues with:

- The presence of the pit lake.
- Water quality within the pit lake (e.g. salinity as a result of evaporative concentration or low pH as a result of acid rock drainage).
- Impact on downstream water quality as a result of outflow from the pit.

TIMING AND SCOPING OF INVESTIGATIONS

As outlined previously, time is a critical issue in mine dewatering. It takes time for pumping or drainage into pit sumps to achieve target dewatering levels. Also, dewatering design investigations take time. Exploratory mineral drilling and resource evaluations usually commence many years ahead of mining and increase in detail as the project becomes more and more certain. Dewatering investigations (which can require drilling, trial pumping and modelling) also take time and benefit from a staged approach. A typical staged approach is detailed below.

Preliminary Characterisation (Screening)
This should be completed in the pre-feasibility stage of the project. The aim should be to identify appropriate dewatering methodologies and typically includes assessment of the following key issues:

- Likely magnitude of dewatering and the appropriate dewatering method(s).
- Likely timing requirements.
- Likely environmental impacts and work required to address these.
- Likely capital and running costs.

This stage of the project is also the best time to plan and scope the work required to cover dewatering related aspects of environmental approvals, as some of the investigation requirements can have long lead times (e.g. baseline water resource conditions).

Dewatering System Design
The next technical step is the dewatering system design and should be done at the project feasibility study stage, including:

- Confirm hydrogeological (and geotechnical) conditions and magnitude of dewatering required.
- Confirm optimum dewatering approach and timing.
- Develop engineering design of pumping and discharge reticulation systems.
- Confirm dewatering cost.
- Environmental impacts, impact management strategies and regulatory approvals.

Installation and Commissioning
The actual work requirements and timing of this will largely depend on the amount of work completed in the feasibility stage and the results of that work, and will probably require some minor revisions to system design to meet conditions encountered during system installation.

DEWATERING SYSTEM OPERATION

The key to maintaining a successful dewatering system is to:

- Operate the system as designed.
- Monitor and review ongoing performance.
- Augment and/or modify the dewatering system where required.
- Undertake regular maintenance.

GEOTHERMAL ENERGY UTILISATION – AN INTERNATIONAL PERSPECTIVE

Riccardo Pasquali
GeoServ, Tonygarrow, Glencree, Enniskerry, Co. Wicklow.

ABSTRACT

The current status of geothermal energy utilisation around the world and in Europe has grown significantly in the last five-year period. Even though geothermal electricity installed capacity has increased by 20% world wide, a more noticeable increase in geothermal energy production for direct uses (79%) world wide and in Europe (114% since 2007) has been observed as a result of high market penetration rates of ground source heat pump systems, the development of new district heating systems as well as the utilisation of geothermal energy resources for a diverse number of commercial and industrial processes. Particular focus has been given to the geothermal heat market in this review as this constitutes a large portion of the current geothermal energy production in Europe. Increasing fossil fuel energy prices and the implementation of incentives for developing renewable green technologies such as geothermal energy have been the main drivers for these developments. Examples of geothermal systems contributing to this growth such as the deep geothermal systems in Pullach Im Isartaal in Germany and the aquifer thermal energy storage system at Arlanda airport in Sweden are discussed in this paper. The geothermal sector in Europe is expected to grow further with the introduction of the EU RES Directive and the definition of the 2020 targets for renewable energy technologies through the National Renewable Energy Action Plans. This paper covers some of the data gathered to date and discusses the expected growth in the European geothermal energy market.

GEOTHERMAL ENERGY UTILISATION WORLD WIDE

Geothermal energy utilisation worldwide has significantly increased between 2005 and 2010. Utilisation is currently divided between direct uses and electricity generation. The former is a lot more widespread across the globe whilst a large proportion of the electricity production is still confined to high enthalpy areas in the world. This section of the paper discusses some of the key figures presented in 2010 for geothermal energy utilisation world wide and provides indications as to the growth rates that have been recorded over the last five years in terms of direct uses of geothermal energy and electricity generation.

ELECTRICITY

Power generation from geothermal sources around the world has reached 67.2 GWh with a total installed capacity of 10.7 GW. This represents an increase of about 1.8GW (20%) over the 2005-2010 period with a rate of increase of about 350MW installed capacity per annum over the same period. Since the early 1980s to 2005 the geothermal electricity installed capacity has grown at a steady rate averaging 1GW installed capacity per annum, with a growth from 2005 to 2010 from 8.9GW to 10.7 GW (Bertani, 2010). More significantly, energy production from available plants has increased significantly in the last 15 years, in 1995 the total installed geothermal electrical capacity was 6.8 GW with a total energy production of 38,035 GWh of electricity. This compares with 67,246 GWh of electricity produced from 10.7 GW installed capacity in 2010 (Figures 1 and 2).

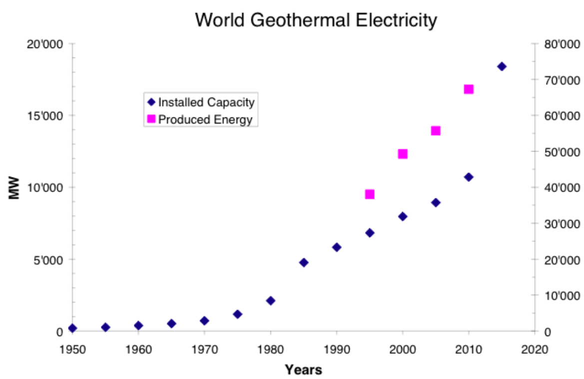

Figure 1: World geothermal installed capacity and produced geothermal energy (Bertani, 2010)

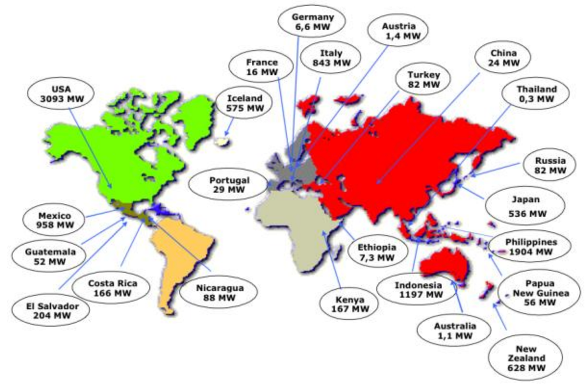

Figure 2: World installed capacity distribution (Bertani, 2010)

This increase in electrical energy production has been primarily driven by improvements in electricity generation plant technology. Whilst the more traditional dry steam plants and single flash plants continue to be utilised in high enthalpy resource areas around the world, the development of double flash steam and binary cycle plant has allowed for the exploitation and development of low to medium enthalpy resources by use of Enhanced Geothermal Systems (EGS).

Forecast electricity production from geothermal resources worldwide is expected to continue to increase with estimates of 18.5 GW installed capacity by 2015. Part of this increase is expected to be met by the development of EGS systems across the world and not limiting geothermal electricity generation to higher enthalpy regions.

HEAT

Direct utilisation of geothermal energy in the world accounted for approximately 50.5 GW_{th} installed capacity at the end of 2009. Estimates from 2005 showed that the total installed capacity has grown from 28.2 GW with an increase of approximately 78.9%. This increase is attributed mostly to the increase in ground source heat pump installations that account for more than nearly 70% of the total world geothermal heat installed capacity. The second largest category is swimming and bathing that has seen up to 24% increase in installed capacity since 2009. This category includes spas, resorts, swimming pools as well as hot springs. Increases in installed capacity in district heating (14%), greenhouse heating (10%), industrial use (10%) and aquaculture (6%) have been recorded since 2005 (Lund *et al.*, 2010). These increases are outlined in Figure 3 and Table 1 below.

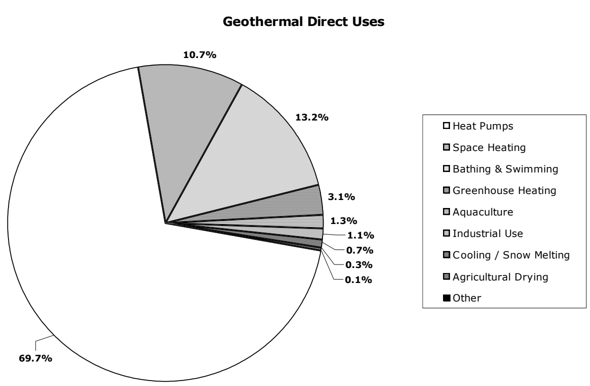

Figure 3: Geothermal Direct Utilisation as a percentage of total installed capacity (Lund *et al.*, 2010)

	2010	2005	2000	1995
Geothermal Heat Pumps	35,236	15,384	5,275	1,854
Space Heating	5,391	4,366	3,263	2,579
Greenhouse Heating	1,544	1,404	1,246	1,085
Aquaculture Pond Heating	653	616	605	1,097
Agricultural Drying	127	157	74	67
Industrial Uses	533	484	474	544
Bathing and Swimming	6,689	5,401	3,957	1,085
Cooling / Snow Melting	368	371	114	115
Others	41	86	137	238
Total	**50,583**	**28,269**	**15,145**	**8,664**

Table 1: Installed Capacity by Category 1995 – 2010 in MW_{th} (Lund *et al.*, 2010)

The countries with the highest geothermal installed capacity for direct use include the USA (12.6 GW), China (8.8 GW), Sweden (4.4 GW), Norway (3.3 GW) and Germany (2.4 GW). However recent comparisons in terms of MW installed and energy utilisation per head of population or land area show that Europe is firmly in the lead in terms of geothermal energy utilisation. Specific growth figures for Europe are further discussed in the next section.

GEOTHERMAL ENERGY IN EUROPE

HEAT

Geothermal energy in Europe has been primarily focussed on the development of resources for heating purposes and direct uses. The installed capacity in 2010 reached 21 GW_{th} (Figure 4) through combined shallow ground source heat pumps, deep geothermal energy systems and Underground Thermal Energy Storage Systems (UTES), this figure has slightly exceeded the projected values estimated by European Geothermal Energy Council in 2009 shown in Table 2 below. The growth of the shallow and deep geothermal energy systems in Europe is expected to reach 39GW_{th} installed capacity by 2020 (EGEC, 2009).

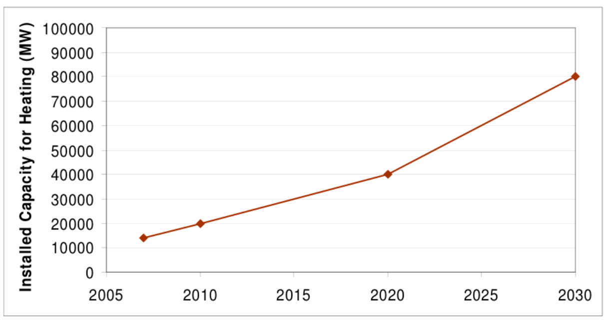

Figure 4: Geothermal Installed Capacity for heating in EU-27 and future targets (EGEC, 2009)

Heating & Cooling - EU-27	**2007**	**2010**	**2020**
Shallow Geothermal (MW_{th})	5 700	11 500	30 000
Deep Geothermal (MW_{th})	4 100	4 500	9 000
Total Installed Capacity (MW_{th})	**9800**	**16 000**	**39 000**
Heat and Cold Production (Mtoe)	**2,6**	**4,3**	**10,5**

Table 2: Heating and Cooling Installed Capacity breakdown, EU-27 (EGEC, 2009)

Ground source heat pump installations have shown the most significant rise in the last five year period and contribute to up to one third of geothermal energy produced for heating purposes in Europe.

Table 3 shows the distribution of geothermal energy sources for heating purposes in the EU-27 region. The three largest categories include ground sources heat pumps (GSHP), district heating and balneology. Other categories such as greenhouse heating, aquaculture, agricultural drying, industrial uses and other have not been included in this table. However, these remain significant contributors to the overall installed capacities in the Eastern European countries and Italy specifically. Even though the number of Underground Thermal Energy Storage (UTES) systems, Aquifer Thermal Energy Storage (ATES) systems across Europe is increasing in countries such as Sweden, Denmark and the Netherlands exact figures on their contribution to the total installed capacity data are not currently available.

Table 3: Geothermal Heating Utilisation in the EU-27 (based on EGEC, 2010 and Lund, 2010, where no figures are quoted these are not available; figures highlighted in grey are not up to date).

Country	Total Geothermal Heating Installed Capacity (MW_{th})	Estimated No. of GSHP Installations	Estimated Total GSHP Installed Capacity (MW_{th})	Individual Space Heating (MW_{th})	Balneology (MW_{th})	Estimated District Heating Installed Capacity (MW_{th})	Estimated Total UTES Installed Capacity (Heating Cooling MW_{th})
Austria	662.85	50,000.00	600.00		8.87	50.03	
Belgium (2008)	117.90	9,500.00	114.00	2.10	0.10		
Bulgaria	98.30		20.63	9.28	48.78		
Czeck Republic	151.50	9,168.00	147.00		4.50		
Denmark	>200	20,000.00	200.00			21.00	
Estonia (2009)	63.00	4,874.00	63.00				
Finland (2008)	857.90	46,412.00	857.90				
France	1,345.00	2,000.00	1,000.00		17.00	300.00	
Germany	2,485.40	148,000.00	2,230.00	1.20	44.90	209.30	
Greece	134.60		50.00	1.50	39.00		
Hungary	654.60	4,000.00	40.00	23.70	272.00	94.90	
Ireland	152.88	9,500.00	151.43		1.45		
Italy	867.00	12,000.00	231.00	92.00	187.00	500.00	
Latvia (2005)	1.63	20.00	0.32	0.38	0.53	0.17	
Lithuania	48.10		34.50			13.60	
Netherlands	1,410.26	10,000.00	1,394.30			5.83	
Poland	281.05	>11000	203.00		8.67	68.00	
Portugal	28.10	24.00	0.30		25.30	1.50	
Romania	153.24		5.50	13.28	64.68	58.95	
Slovakia	132.20	16.00	1.60	16.70	73.60	10.80	
Slovenia	104.17	3,440.00	49.70	22.40	25.04	3.29	
Spain	141.04		120.00	3.51	2.60		
Sweden	4,460.00	230,000.00	4,230.00	140.00			90.00
United Kingdom	186.62	5,250.00	181.50		2.11	2.76	

ELECTRICITY

Electricity production from geothermal energy source in Europe has been limited to a handful of countries some of which have plants installed in overseas departments in high enthalpy areas such as Portugal (29 MW_e – 2 plants) and France (16 MW_e – 3 plants). The main electricity production in mainland Europe occurs in Italy (843 MW_e – 32 plants) and Germany (7.14 MW_e – 4 plants) and Austria (1.4 MW_e – 3 plants). The current total installed capacity in Europe is 896.5 MW_e with a total energy production of 6,987.3 MWh.

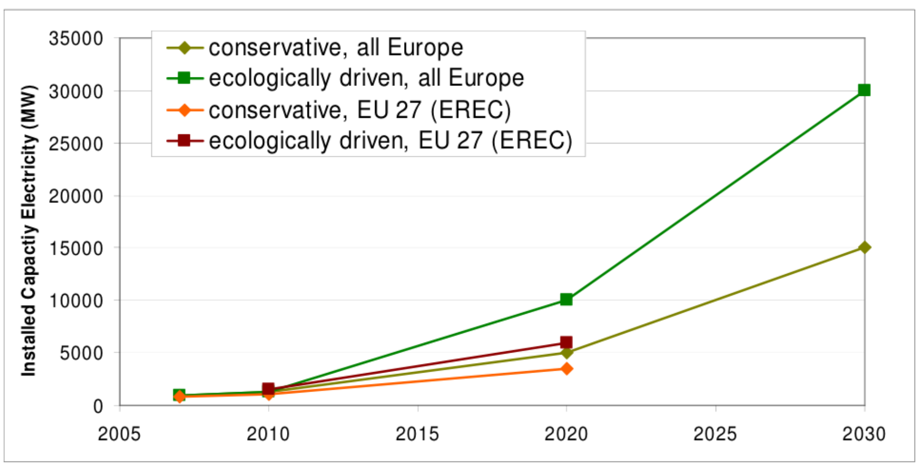

Figure 5: Geothermal Electricity Installed Capacity in the EU-27 and future projections (EGEC, 2009).

The development of geothermal electricity generation in Europe is expected to grow further by 2020. Current targets set by the geothermal energy community in Europe (Figure 5) show the expected installed capacity to rise from between 4 GW and 10GW. This increase will be dependent on a number of key factors which include the implementation of appropriate financial incentive schemes across Europe (GEOFAR, 2009), the introduction of geothermal legislation and regulation to ensure the appropriate development of resources in Europe, the decrease in drilling costs and further research and development on EGS systems that have the potential to increase geothermal electricity installed capacity by exploiting low to medium enthalpy areas.

THE FUTURE OF GEOTHERMAL ENERGY IN EUROPE

The implementation of the EU directive on the Promotion of the Use of Energy from Renewable Sources (EU-RES Directive, 2009/28/EC) in 2009 has resulted in the implementation of legally binding renewable energy targets for renewable technologies by EU member states set in June of 2010 through the National Renewable Energy Action Plans (NREAP). The primary objective of the directive is to increase renewable energy use by 20%, decrease energy usage by 20% and reduce CO_2 emissions by 20% by the year 2020.

National targets set in the NREAP will guide the expected development of the geothermal energy market in Europe. Table 4 below shows a summary of the geothermal energy targets set by member states to be achieved by 2020. The figures shown in the NREAP 2010 estimates were estimated at the time of the publication of the NREAP documents based on 2009 figures. The figures published by EGEC 2010 were compiled in December of last year and more accurately represent the status of the geothermal sector in Europe.

Table 4: Geothermal Energy Targets set in the National Renewable Energy Action Plans in EU member states and estimates by the European Geothermal Energy Council.

	GROUND SOURCE HEAT PUMPS				DIRECT USES				ELECTRICITY							
EU Country	NREAP 2010	EGEC 2010	NREAP 2020	EGEC 2020	NREAP 2010	EGEC 2010	NREAP 2020	EGEC 2020	NREAP 2010		EGEC 2010		TARGET 2020		EGEC 2020	
	(ktoe)	(ktoe)	(ktoe)	(ktoe)	(ktoe)	(ktoe)	(ktoe)	(ktoe)	MWe	GWh	MWe	GWh	MWe	GWh	MWe	GWh
Denmark	119	110	199	166	0	19	0	80	0	0	0	0	0	0	60	468
Finland	*230*	200	*660*	220	0	0	0	5	0	0	0	0	0	0	5	39
Netherlands	90	* (24)	242	250	39	5 (231)	259	*(259)	0	0	0	0	0	0	10	78
Sweden	272	* (1045)	815	832	0	* (2)	-	8	0	0	0	0	0	0	5	39
United Kingdom	120	180	953	1,249	n/a	2	n/a	74	0	0	0	0	0	0	200	1,560
Spain	12	11	41	416	4	5	10	97	0	0	0	0	50	300	500	3,900
Austria	10	70	26	650	19	20	40	178	1	2	1	11	1	2	50	390
Bulgaria	0	7	0	21	1	26	9	116	0	0	0	0	0	0	200	1,560
Cyprus	*0,34*	1	*2,97*	10	0	0	0	6	0	0	0	0	0	0	15	117
Greece	3	5	50	100	24	27 (160)	51	174	0	0	0	0	120	736	450	3,510
Ireland	*18*	18	*84*	52	0	1	0	10	0	0	0	0	5	35	5	39
Lithuania	*0*	7	*14*	21	3	3	5	19	0	0	0	0	0	0	15	117
Malta	0	1	0	10	0	0	0	1	0	0	0	0	0	0	5	39
Slovenia	4	9	38	42	18	19	20	46	0	0	0	0	0	0	30	234
Italy	40	* (42)	522	416	226	214	300	1,161	754	5,632	843	6,575	920	6,750	2,000	15,600
Portugal	0	4	-	62	10	12	25	77	25	163	29	226	75	488	175	1,365
Germany	258	312	521	1,249	34	57	686	686	10	27	7	50	298	1,654	1,000	7,800
Luxembourg	*1,4*	2	*16,9*	10	0	0	0	3	0	0	0	0	0	0	5	39
France	222	280	570	1,600	155	155	500	755	26	153	16	125	80	475	270	2,106
Czech Republic	45	29	118	62	0	2	15	39	0	0	0	0	4	18	50	390
Romania	-	17	-	635	-	30	-	265	0	0	0	0	0	0	200	1,560
Slovakia	0	0	4	52	3	73	90	464	0	0	0	0	4	30	100	780
Latvia	0	0	4	17	-	1	-	5	0	0	0	0	0	0	5	39
Estonia	0	2	0	17	0	0	0	0	0	0	0	0	0	0	0	0
Belgium	*52,2*	10	*350*	170	3	2	6	70	0	0	0	0	4	29	60	500
Poland	*25*	21	*148*	104	23	25	178	330	0	0	0	0	0	0	110	858
Total	**1,522**	**2,407**	**5,378**	**8,433**	**562**	**1,057**	**2,193**	**4,928**	**816**	**5,977**	**897**	**6,987**	**1,561**	**10,518**	**5,525**	**43,127**

The analysis shows that the energy produced by ground source heat pumps is currently 2,407 ktoe (27,993 GWh) and is expected to increase to 5,378 ktoe (62,546 GWh) by 2020. EGEC has estimated this growth could be as high as 8,433 ktoe (98,075 GWh). For other direct uses of geothermal energy that include district heating, greenhouse heating, balneology, aquaculture, agriculture and industrial processes the usage is expected to rise from 1,057 ktoe (12,292 GWh) to 2,193 ktoe (25,504 GWh) whilst EGEC suggest a more significant growth to 4,928 ktoe (57,312 GWh). The growth rate for the geothermal electricity generation is not expected to be as pronounced with a rise from 6,987 GWh in 2010 to 10,518 GWh by 2020 with additional plants installed in only Greece, the Czech Republic and Slovakia and the majority of the increase being limited to installation of new plants by the countries well established in this sector. However, the more optimistic figure of 43,127 GWh installed capacity proposed by EGEC is possible if the deployment of EGS technology can be facilitated across Europe.

CASE STUDIES

Two case studies have been selected as part of this paper that focus on the development of geothermal energy resources in Europe for direct use. The first example from Germany demonstrates the use of deep geothermal systems whilst the second, from Sweden, is an example of an Aquifer Thermal Energy Storage system.

PULLACH DEEP GEOTHERMAL AND DISTRICT HEATING SYSTEMS

The Pullach Im-Isartaal deep geothermal system is located approximately 12km to the south west of the city of Munich in the Molasse Basin. The town has a population of approximately 9,000 inhabitants and following a Local Agenda 21 initiative in 2001, the municipality of Pullach decided to investigate alternative heating solutions for the town to improve security of energy supply, reduce the cost of energy to the municipality buildings and the town residents as well as reduce carbon emissions.

A deep geothermal well doublet system was completed during 2004 and commissioned in mid 2005. The Pullach Th-1 and Pullach Th-2 deviated wells completed to a depth of 3,398m (TVD) and 3,445m (TVD) from a single site in the centre of the town. The formation temperature encountered in the Pullach geothermal well doublet is between 102^{o}C and 107^{o}C. Following pumping and re-injection tests of both boreholes and a formation acidizing programme, the doublet system has a production flow rate of 50 l/s from the Malm aquifer (Schubert *et al.*, 2007).

The current overall installed capacity of the system is about 5.6 MW_{th} even though higher production flow rates were achieved upon completion of the production tests. However, the absence of large-scale fault structures at the completion depths of the Th-1 and Th-2 boreholes has restricted the potential re-injection rates of the system.

The Pullach geothermal boreholes are connected to a 20 km district heating network which provides heating to residential and commercial buildings as well as municipality building throughout the town. The network supplies about 21,000 MWh of heat per year and has resulted in a CO_2 emission saving of approximately 6,000t per annum since the beginning of the operation of the system.

Further seismic reflection surveys were undertaken in early 2010, and identifying the presence of large fractures in the Malm aquifer centred below the northern part of the town. Additional feasibility studies on the completion of a third borehole were undertaken during 2010. The municipality commenced a drilling programme on the 19th of January 2011 to complete a third deviated well (Pullach Th-3) to 3,984m (MD). The drilling operations are ongoing and on the completion of this paper the current depth of the Th-3 borehole is 3,506m.

This third borehole will be completed at a wider diameter of 7 5/8” than the Th-1 and Th-2 boreholes and the new borehole is expected to be used primarily for re-injection purposes. The overall installed capacity of the system is expected to be increased to 15MW_{th} allowing an expansion of the current district heating network to a total length of 40km. Once completed this system will supply over two thirds of the heating needs of the municipality and bringing the total CO_2 emission reduction to 16,000t per annum.

ARLANDA AIRPORT, STOCKHOLM, AQUIFER THERMAL ENERGY STORAGE (ATES)

The Arlanda airport ATES system has been in operation since 2009 and is used in the summer months for cooling throughout the airport terminal. The heat extracted from the buildings is stored in a groundwater aquifer and used to pre-heat the ventilation air for the airport terminal buildings and snow melting at the gates during the winter months. The system's overall maximum thermal capacity is $10MW_{th}$.

The system exploits the groundwater resources of the Långåsen esker with an approximate maximum thickness of 30m and rests of crystalline basement. The overall area of exploitation is about 2.5km in length. The esker has a gross water storage volume of 3.2M m^3 of which 2M m^3 are used by the system. The average aquifer groundwater temperature is 8^oC with an average porosity of 30%. Results from long term pump testing show the aquifer hydraulic conductivities range between $1.7x10^{-2}$ to $2.4x10^{-2}$ m/s (Andersson, 2009).

The system operates through the use of six 'warm' wells used for production in the winter months and re-injection in the summer months as well as five 'cold' wells used for production as part of the cooling cycle and re-injection in the heating cycle. The boreholes are completed to depths ranging between 15m and 30m in depths at a diameter of between 270mm and 400mm. Individual wells are completed with screened areas of between 4m and 8m in depth and individual yields range from 30 l/s to 60 l/s with the overall maximum capacity of the system of 200 l/s. The boreholes are equipped with 12-22kW pumps and connected through a network of 700m of mains pipes to the distribution centre to the airport terminal building (Andersson, 2010). This system has allowed the airport to reduce its energy consumption by 14 - 15GWh per annum as part of the heating cycle as well as reducing its electricity demand in the summer months by 4 – 5 GWh. The total annual CO_2 emission saving is approximately 7,000 tonnes (Wigstrand, 2009).

CONCLUSIONS

The development of the geothermal energy sector has grown significantly over the last year period. Improvement in the power generation cycle and the development of EGS systems has allowed for a higher increase in electricity production around the world over the last five years period than previously recorded.

The implementation of geothermal energy financial support mechanisms and the development of dedicated legislation for the deep geothermal energy systems has been key to the development of the sector for both heat and power generation across Europe such as those available in France, Germany, the Netherlands, Spain and Portugal as well as many other countries around the world.

Globally the geothermal energy sector is focussed on further research and development to decrease the capital investment costs including the decrease in drilling costs and the deployment of EGS technology in deep geothermal applications, as well as the harmonisation of standards and regulatory guidelines to sustain the high growth rate of the shallow ground source heat pump sector particularly in Europe.

The overall projected growth of the geothermal sector is expected to nearly double over the course of the next ten year period. This increase requires that resource management approach mechanisms are implemented to ensure the sustainable growth of the sector, to minimise environmental impacts and the impacts to other subsurface resources such as groundwater.

REFERENCES

Andersson, O. 2009. *The ATES Project at Stockholm Arlanda Airport – Technical Design and Environmental Assessment.* Effstock 2009. 56.

Andersson, O. 2010. *Case Studies – Sweden.* World Geothermal Congress 2010. Short Course 3, Ground Source Heat Pumps. Lecture 4.

Bertani, R. 2010. *Geothermal Power Generation in the World, 2005-2010 Update Report.* Proceedings of the World Geothermal Congress 2010. 0008.

EGEC . 2010. *Statistical Report on Deep Geothermal Installations in Europe.* EGEC.

EGEG. 2009. *Research Agenda for Geothermal Energy - Strategy for 2008 to 2030.* EGEC

GEOFAR. 2009. *Financial Instruments as Support for the Exploitation of Geothermal Energy.*

Lund, J., Freeston, D. H., Boyd, T. L. 2010. *Direct Utilization of Geothermal Energy 2010 Worldwide Review.* Proceedings of the World Geothermal Congress 2010. 0007.

Schubert, A., Höferle, R., Böhm, F. 2007. *Geothermal Doublets Munich Reim and Pullach im Isartaal in comparison: Geological and Drilling Concepts for Minimizing the Geological Risk in the Deep Malm Aquifer.* European Geothermal Congress 2007. 44.

Wigstrand, I. 2009. *The ATES project – A sustainable solution for Stockholm-Arlanda airport.* Effstock 2009. 55.

GEOTHERMAL DEVELOPMENTS IN IRELAND

Gareth Ll. Jones,
Conodate
(Geothermal Association of Ireland)

ABSTRACT

Shallow geothermal resources in Ireland continue to be developed across the country. The emphasis is changing from largely rural single dwelling developments to include urban borehole schemes. Larger office block type schemes using large volume open loop aquifer based developments or multiple borehole closed loop fields are becoming routine.

Deep resource development has followed on from the resource assessment studies and one major scheme is in progress in Co. South Dublin, whilst investigations continue in Northern Ireland and elsewhere.

Significant attention is being paid to regulation resulting in the fast-tracking of a geothermal bill. Also to quality control with an EU wide training scheme attending to the training of designers and drillers.

INTRODUCTION

This talk follows on from the report by Róisín Goodman to the IAH Conference of 2007 (Goodman, 2007). It details some of the recent advances and the intimate relationship with groundwater.

SHALLOW RESOURCES

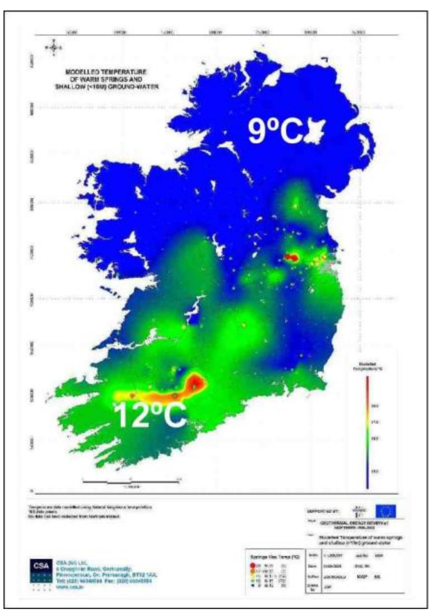

Figure 1: Surface / 10m depth temperatures.

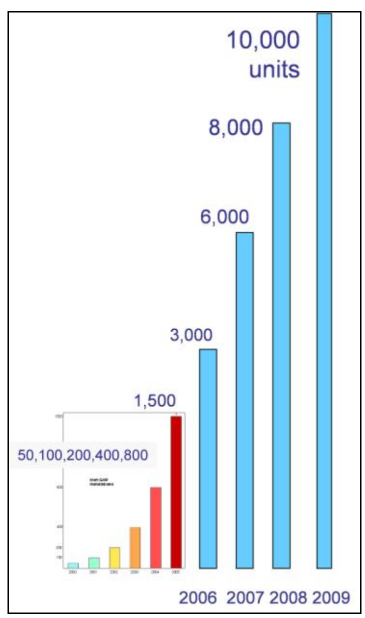

Figure 2: Geothermal units installed. Grants introduced 2006.

Encouraged by government grants, recommended in 2004 by both Goodman *et al.* (2004) of CSA and Boesworth (2004) of Arsenal, Austria, rapid development of ground source heat pump (GSHP) installation has taken place across the island (Allen & Burgess 2010) in the last five years. Warm moist ground conditions (Figure 1) have allowed the development of shallow resources. Horizontal loops are common for buildings with sufficient available ground area, whilst vertical closed loop borehole collectors are now common in urban settings and multiple borehole fields have recently started to appear. Installed capacity has risen very rapidly from an estimated less than 0.5MW in 2000 to nearly 200MW by 2010 (Figure 2).

Whilst the rural house with 0.2 hectares available for a horizontal closed loop collector may remain the commonest system, larger systems are being installed where possible. From the early 2003 Tralee Motor Tax office of 120kW (Figure 3) to the recent 2009 Cliffs of Moher Visitor Centre system with a collector length of 6km and a heating/cooling rating of 120kW (Figure 4).

Figure 3: Tralee Motor Tax office, 120kW.

Figure 4: Cliffs of Moher Visitors Centre, 120kW.

There are a number of moderate sized systems (up to 15kW) with Open and Closed loop heat collectors from water bodies, used for both heating and cooling. Static water bodies can have severe drawbacks unless a circulation system exists.

WARM SPRINGS

Two main belts of warm springs exist (Figure 1), the first running east-west through Mallow and the second, also on a Variscan trend, west of Dublin through Kilcock. In the past both were exploited with Victorian spas at Mallow and at Leixlip. Nowadays only the warm spring at Mallow is used commercially to preheat the water for the Mallow swimming baths.

In the region east of the warm spring at Mallow, Co. Cork an investigation lead by the late Brecan Mooney, (Mooney *et al.,* 2010) defined the newly identified continuation of the warm spring zone to the Glanworth area (Figure 5). It indicated that groundwaters have circulated to depths of 1,100m in Mallow and 1,500m at Glanworth and risen along Caledonian fault conduits (Figure 6).

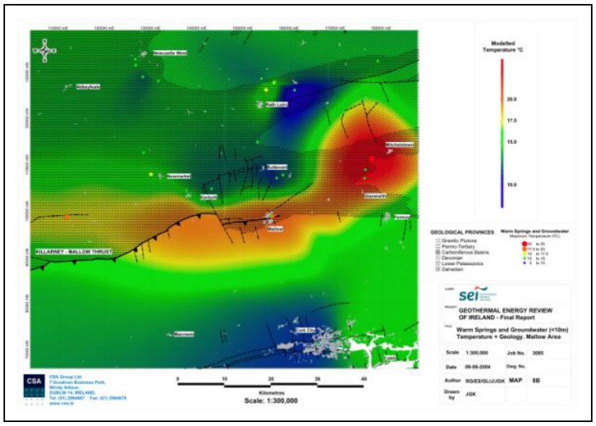

Figure 5: The geothermal anomaly in the Glanworth area (Goodman *et al.* 2004).

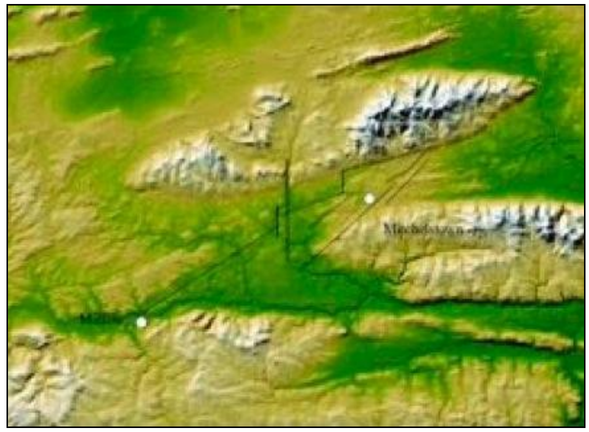

Figure 6: Topographic map showing possible fault conduits (Mooney *et al.* 2010).

SHALLOW DEPTH LARGER SYSTEMS

LARGE OPEN LOOP SHALLOW SYSTEMS

Where shallow aquifers with high yields underlie a development site, then very efficient and highly economic open loop geothermal borehole heating and cooling systems can be developed. Cork City lead the way with the 2003 Share Hostel (120kW) and the classic 2004 UCC Glucksman art gallery (200kW). These were followed by many others as seen in the Offaly County Council offices, Tullamore (Figure 7), the Cork City Council building, the University College Cork schemes (Figures 9 and 10), the 400kW system at the 2008 Vista Medical Centre, Naas, Co. Kildare (Figure 8). Most recently the 2009 Athlone Town Centre Retail (Figure 11) is the largest system in the country at 2.8MW rating, where WJ Groundwater Ltd. used 20 dewatering boreholes and then incorporated a number of them to be the groundsource wells.

Figure 7: Offaly County Council offices, Tullamore.

Figure 8: Vista Medical Centre, Naas, Co. Kildare. 400kW

Figures 9 and 10: UCC Cork IT building and plant room. 1MW heating and cooling.

Figure 11: Athlone Town Centre Retail, 108,390 m2, 2.8 MW Open Loop

LARGE CLOSED LOOP SHALLOW SYSTEMS

Where ground conditions do not provide a shallow aquifer, then the multiple closed loop borehole array comes into its own. We regret the suspension of the Anglo Irish Bank development, with its completed borehole field, but still skeletal superstructure. However we can now turn to the 2009 IKEA store in Ballymun where IKEA invested €1.75m in the field of 158 closed loop boreholes each 90m deep for the heating and cooling of this huge building with a floor area of 30,598m^2.

Figure 12: IKEA store, Ballymun, Dublin.

Ground source was however the only solution that came close to meeting Co. Fingal's requirements, delivering a 65% carbon reduction with 44% on-site renewable. "We targeted the biggest energy user," Darren Penson of building services and environmental engineers GDM explains, "which is the heating and cooling of the space. By using the ground source, that tackled all of the heating and cooling within the store". The heat pump provides space heating of 884,018 kWh/yr (27.6 kWh/m2/yr), and, taking free cooling into account, provides cooling of 207,194 kWh/yr (6.5 kWh/m2/yr).

The geothermal borehole field lies under one of the car parks adjoining the main building, and contains 158 individual boreholes. The water-to-water heat pumps, selected to suit the AHU heating/cooling loads and supplied by Aermec, were installed within the AHU casings on the roof. "The principle," Darren Penson explains, "was that the closed loop bore field pipe-work was distributed within the building to serve a number of water-to-water heat pumps dedicated to AHU's serving various parts of the building – the showroom, market hall, restaurant, kitchen and checkouts. This circuit also serves a number of Mitsubishi WR2 water to refrigerant heat pumps that serve the VRF systems within the office and staff areas of the building."

We expect to see many more of these major closed loop borehole fields being used where other solutions are not available.

MEDIUM – DEEP RESOURCES

DEEP AQUIFER SYSTEMS

Ireland has no recognised deep sedimentary aquifer systems, except in Mesozoic sediments in Northern Ireland (Figures 13 and 14), where there is good potential for district heating from doublet systems (Kelly *et al.*, 2005; Pasquali *et al.*, 2010).

The Geological Survey of Northern Ireland (GSNI) has drilled a 900m borehole at Kilroot in Co. Antrim (Figure 15), targeting the Sherwood Sandstone and Permian aquifers. This strategic stratigraphic hole, together with magnetotelurics and infill gravity, will detail the geothermal potential of the area.

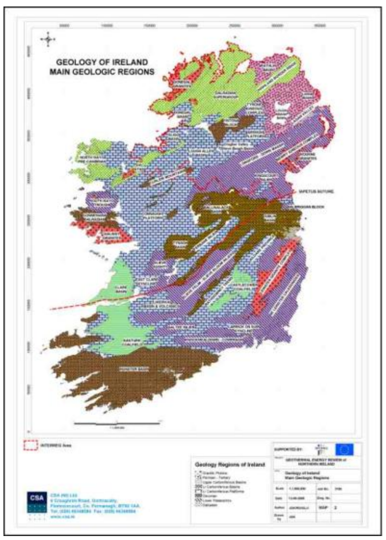

Figure 13: Deep geology of Ireland.

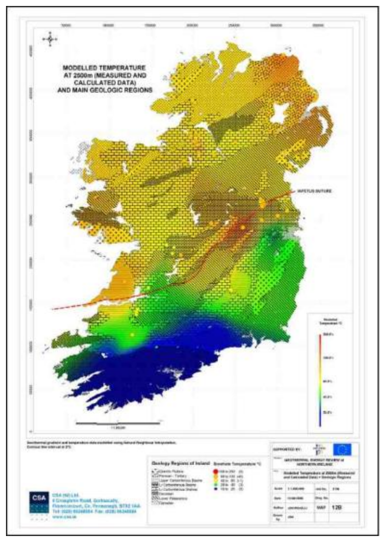

Figure 14: Modelled temperatures 2.5km.

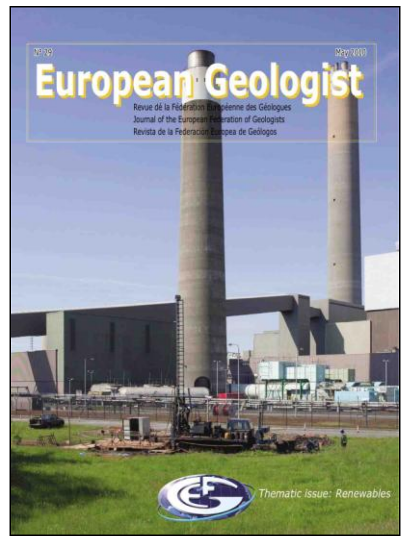

Figure15: Irish Drilling rig at Kilroot

FRACTURE AQUIFERS

Fracture 'aquifers' are common in the Carboniferous sequence which underlies over 50% of the country (Figure 13) and are likely to provide numerous low-medium temperature, high flow, geothermal resource sites as the market develops and their geometry and hydrodynamics are traced at depth.

More detailed investigations (O'Neill & Pasquali, 2005; Jones *et al.*, 2007) recommended specific sites for further study. The combination of deep faults and crystalline rocks has been identified in Germany and other countries as having the biggest geothermal resource. This combination exists south of Dublin where the Palæozoic Blackrock/Rathcoole Fault occurs adjacent to the Leinster granite and Lower Palæozoic Massif (Figure 16).

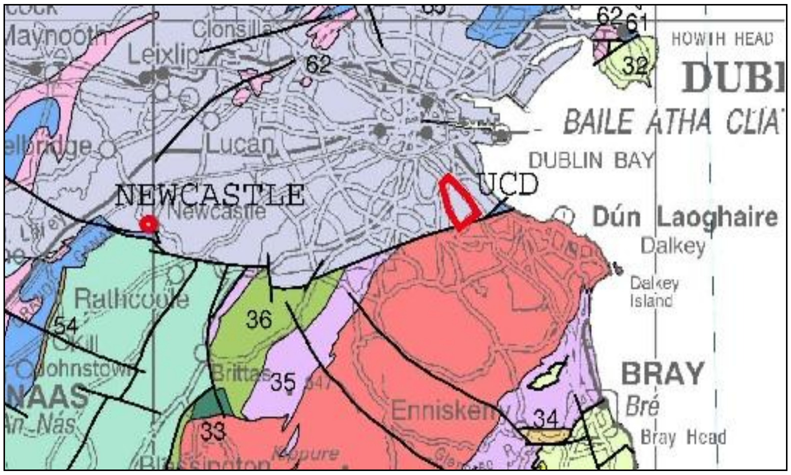

Figure 16: Geology of the Blackrock-Rathcoole Fault separating the Carboniferous Dublin Basin to the north from the older Leinster Massif to the south

Two projects are proceeding to target geothermal resources at 2.5km associated with this major fault in the Dublin area for potential district heating development. In the east University College Dublin are evaluating their location with the potential for a local campus district heating scheme. Whilst GT Energy Ltd. has carried out deep exploratory drilling in the south-west (Figure 17) to 1.4km and a temperature of 42˚C.

Figure 17: GT Energy's Marriott rig drilling a fracture aquifer south-west of Dublin.

DEEP RESOURCES & ELECTRICITY POTENTIAL

The 5km depth resource map (Figure 18) indicates that there is significant potential for electricity generation in some areas, especially in the north-east. Development of this resource depends largely on additional drilling and on new data being collected. At 5,000m depth across Northern Ireland and a number of other locations, modelled temperatures show a number of potential 'hot-spots' with values of 115ºC - 165ºC in the Lough Allen Basin, 115ºC - to 150ºC in the Larne - Lough Neagh Basins and a potential 180ºC in the Rathlin Basin.

The Geological Survey of Northern Ireland (GSNI) has drilled a 600m deep exploration borehole to investigate the geothermal potential in the Tertiary Mourne Granite (Figure 19). The geothermal borehole log and thermal conductivity tests of the samples, with infill gravity will create a 3D model to characterise the batholith.

At temperatures down to 100°C, only binary or Organic Rankin Cycle (ORC) power plants can be considered for electricity generation production from geothermal heat in Ireland. The successful development of Hot Dry Rock (HDR) technology and hydraulic stimulation techniques elsewhere in Europe will increase the perceived geothermal production capacity of Irish sites significantly and thereby accelerate the development in this area of electricity production from higher temperature resources. It should be noted that GT Energy has partnered with ESBI to build Ireland’s first geothermal energy plant.

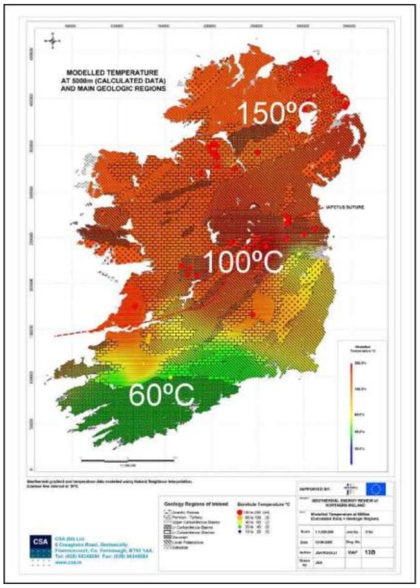

Figure 18: Modelled temperatures 5km depth.

Figure 19: Setting up the GSNI drill rig for the Mourne granite Assessment borehole (Pic T. Rosowski).

SLR have recently completed a Geothermal Play Fairway Analysis for the Sustainable Energy Authority of Ireland (SEAI). This study ranks deep geothermal exploration targets and is designed to attract geothermal exploration drilling in Ireland by international investors.

REGULATION & TRAINING

Ireland recently lead the EU Altener/IEEA funded Geothermal Regulation for Heat (GTR-H) project to look at geothermal regulations throughout the EU. A perceived barrier to the investigation and development of medium-deep resources, is the lack of protective legislation. This drew on the experiences of well-regulated and poorly-regulated countries and was coordinated by Róisín Goodman of SLR. It developed a template (Pasquali & Goodman, 2008) and culminated in the GTR-H conference in Dublin in Autumn 2009.

In parallel to this, the Irish Government moved to establish regulatory controls to guide the development of geothermal energy in Ireland and engaged in a wide-ranging consultation process with geothermal stakeholders. The Irish Government geothermal working group has consequently drafted legislation to cover this area and to provide security of tenure to geothermal companies (King & Dhonau, 2008). This geothermal regulation bill has been fast-tracked through the parliamentary process.

One of the other main barriers to successful development of the geothermal sector is quality control. Most of the hardware, the heat pumps, the collector pipes, etc. are well covered by various country quality standards.

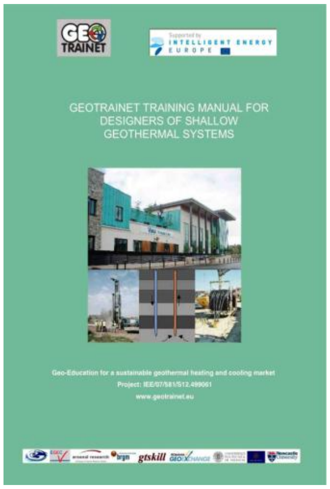

Figure 20: The GEOTRAINET Manual for Designers

The question of training for designers, drillers and installers has been looked at. GT Skills ran basic training programmes from 2007 to 2009, whilst the EU Altener/IEEA funded GEOTRAINET programme concluded this February with the production of a training curriculum, course programme and manual (Figure 20) for geothermal designers and drillers. The GEOTRAINET system will lead to an EU wide certification programme. It is hoped that the attention to quality control will protect the industry and avoid a collapse of the market.

The Institute of Geologists of Ireland has commenced the design of guidelines for drilling geothermal boreholes.

CONCLUSIONS

A combination of resource assessment and government support has promoted the development of shallow resources and stimulated the investigation of specific geothermal locations for deeper projects. Regulation, training and quality assurance are crucial to the future development of the sector.

REFERENCES

Allen, A., Burgess, J. 2010. *Developments in Geothermal Utilisation in the Irish Republic.* Proceedings World Geothermal Congress 2010. 9pp.

Boesworth, R. 2004. *Campaign for take-off for renewable heat pumps in Ireland.* Unpublished Arsenal Research report to Sustainable Energy Ireland, April 2004. 139pp.

Goodman, R. 2007. *Geothermal Resources in Ireland – Applications for Hydrogeology.* Proceedings IAH Conference 2007. 6pp.

Goodman, R., Jones, G.Ll., Kelly, J., Slowey, E., O'Neill, N. 2004. *Geothermal Energy Exploitation In Ireland – Review of the Current Status and Proposals for Optimising Future Utilisation.* Final report to Sustainable Energy Ireland. *CSA rept no. 3085/02.04 September 2005.* 93pp + XII App.

Jones, G.Ll., Pasquali, R., Antin, G., Grummel, T., Goodman, R., Glanville, P., O'Neill, N. 2007. *Feasibility Study & Market Research for the Development of a Deep Geothermal Borehole on the University College Dublin Campus. Final Report to Sustainable Energy Ireland.* Conodate Geology rpt 3533-DG February 2007, 73pp + VI App.

Kelly, J., Goodman, R., Jones, G.Ll., O'Neill, N., Pasquali, R. 2005. *Geothermal Energy Review of Northern Ireland – Final Report to INTERREG.* CSA rept no. 3194/01.05 September 2005. 79pp + XI App.

King, J., Dhonau, B. 2008. Development of Policy for Geothermal Energy in Ireland. Geothermal Resources in Ireland Commercial Opportunities. Geothermal Association of Ireland Conference, Kilkenny 5 November 2008.

Mooney, B., Allen, A., Könige. A. 2010. *Investigation of Source and Conduit for Warm Geothermal Waters, North Cork, Republic of Ireland.* Proceedings World Geothermal Congress 2010. 13pp.

O'Neill, N., Pasquali, R. 2005. *Deep Geothermal Site Characterisation, Final Report to Sustainable Energy Ireland.* CSA rept no. 3366. October 2005, 34pp. (+ Apps in Interim rpt.).

Pasquali, R., Goodman, R. 2008. *Progress & Draft Template Regulatory Framework. Geothermal Resources in Ireland Commercial Opportunities.* Geothermal Association of Ireland Conference, Kilkenny 5 November 2008.

Pasquali, R., O'Neill, N., Reay, D., Kelly, J.K. 2010. *The Geothermal Potential of Northern Ireland.* Proceedings World Geothermal Congress 2010. 5pp.

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SESSION V

GROUNDWATER NUTRIENT PATTERNS IN TWO INTENSIVE AGRICULTURAL CATCHMENTS

Per-Erik Mellander, Alice Melland, Phil Jordan, David Wall and Ger Shortle
Agricultural Catchments Programme, Teagasc, Johnstown Castle Environment Research Centre, Wexford, Co. Wexford, Ireland

ABSTRACT

Within the Teagasc Agricultural Catchments Programme the nutrient transfer continuum concept is being used as a framework for the evaluation of the European Union Nitrates Directive regulations and linkages with the Surface and Groundwater regulations in Ireland. The connections between nutrient sources, groundwater and surface water impact were investigated in two c. 10 km^2 potentially high nitrogen transfer risk catchments, one with predominantly arable land and one with predominantly grassland management, both on permeable soils overlying slate and sandstone geology, respectively. Pathways and impacts were monitored through multilevel monitoring wells on two representative hill slopes per catchment. Groundwater quality was compared with hydrology and farming activity and the spatiotemporal patterns were analysed. Preliminary results indicated that both nitrogen and phosphorus were transferred from diffuse agricultural sources to surface water via groundwater, but that this transfer was buffered, and more so in the grassland/sandstone catchment. Shallow upland groundwater was least buffered. Deep upland and near-stream groundwater was most buffered. There were higher concentrations of nitrogen in upland groundwater and shallow near-stream groundwater, and higher phosphorus in shallow groundwater. In winter, when the groundwater table was higher, the more vulnerable upland is likely to be more efficiently connected to the near-stream pool where a mixing with deeper old water, and flush out to the stream occurs. Despite intensively managed land on permeable soils, the groundwater was, in most cases, compliant with current drinking water standards and with the stream ecological thresholds for phosphorus.

INTRODUCTION

Nutrient loss from terrestrial ecosystems into water bodies can have a negative impact on the quality of drinking water as well as to aquatic ecology. The output of nitrogen (N) to surface water via groundwater pathways is the residual after uptake by vegetation and biogeochemical transformation. Phosphorus (P) on the other hand, tends to fix to soil particles and accumulates on the soil surface and therefore mostly reaches surface water via surface flow paths during rain events. However, P may also reach surface water via the groundwater (*e.g.* Kilroy and Coxon, 2005; Holman *et al.*, 2008) as the residual following attenuation though the soil and subsoil matrix. A large part of the N and P that impacts groundwater and surface waters within the European Union (EU) is excess nutrients from agriculture (OECD, 2001). In particular P from fertilisers has been recognised as a significant contribution to the eutrophication of waters (EPA, 2010).

The EU Nitrates Directive (ND) (EC, 1991) was introduced to limit the use of agricultural fertilizers to agronomic optima, in order to minimize surplus N and P losses to the aquatic environment. The ND is included as part of a suite of Programmes of Measures (PoM) within the Water Framework Directive (WFD; OJEC, 2000) which, together with the Groundwater Directives (GWD; European Commission, 2008) is a holistic integrated approach for national water resources management. N in both surface water and groundwater is monitored within most EU member states; however, the sampling strategy (site typical location, frequency and resolution) varies largely. To improve nutrient management practice for both resource and ecological objectives it is important to understand the spatiotemporal transfers of nutrients to groundwater and its interaction with surface water. Understanding these impacts in agricultural catchments is, however, a challenge. Farm management itself will cause spatial and temporal variation in nutrient sources. In addition there are spatiotemporal variations in groundwater recharge due to weather systems and due to spatial variation in soil permeability. The groundwater flow regime also varies with the type of bedrock and topography. Consequently, there will be spatiotemporal variations in nutrient mobilisation, pathways and residence time, which influence attenuation processes, dilution and interaction with surface water.

In Ireland agriculture comprises 56% of the land use by area (Central Statistics Office 2009) and a substantial part of this land has free draining soils enhancing the diffuse pollution of nutrients to groundwater. The threshold mean and maximum acceptable annual concentrations (MAC) of NO_3-N in Irish groundwater (and other potable water) is 8.5 mg L^{-1} and 11.3 mg L^{-1}, respectively, and these are set to protect drinking water resources. For good ecological status in surface water, the annual mean concentration of P is 0.035 mg L^{-1} unfiltered molybdate reactive P (MRP - EPA, 2009) and this is set as a threshold above which freshwater ecology may be impacted. The Agricultural Catchments Programme (ACP) was established in 2008 to meet the requirements of the ND regulations (Fealy et al., 2010; Wall *et al.*, in review). Its primary objective is to monitor the effectiveness of the Good Agricultural Practice (GAP) regulations in Ireland (SI 378 of 2006; SI 101 of 2009; SI 610 of 2010) and specifically supports the Irish Nitrates Directive National Action Programme (NAP) and associated Derogation. The ACP was established in six catchments to provide a baseline for farm nutrient management and water body quality during the early years of the measures and to provide estimates of trajectories towards water quality targets. A *nutrient transfer continuum* from source, through pathways, to delivery and impact in a water body receptor describes the different phases of diffuse pollution (Haygarth *et al.*, 2005), and is being used as a framework for evaluation. With this concept the Programme is investigating the nutrient source, pathway and delivery in two potentially “high N-risk” catchments in Ireland.

The objectives of this study were:

1. To find out if, and potentially how, groundwater is linking farming activity and surface water
2. To determine if the groundwater was compliant according to national standard thresholds

METHODS

SITE DESCRIPTION

Groundwater and surface water quality is being investigated in two Irish catchments with permeable soils. One catchment is 11.3 km^2 with predominantly arable crop production (spring barley) and the other 9.7 km^2 is mainly intensive grassland management (dairy and beef production). The catchments were chosen by GIS multi-criteria analysis (Fealy et al., 2010) to suit the purpose of the NAP evaluation by defining high nutrient source (farming intensity) and transport (soil and geological permeability) risk of transfer.

The arable catchment, located in Co. Wexford, is overlying Ordovician volcanic slate rock which is classified as a poorly productive aquifer with an expected fissure-flow. The study sites in this catchment have a topsoil layer of gravely clay (0.6 – 2.5 m thick) overlaying a dense layer of sand and gravel (0 – 2.5 m thick). The uplands have thinner and freer draining soils than the near-stream land where the topsoil is richer in clay content. Below the sub-soil are layers with different grades of weathered rock. First a weak, highly weathered slate (1.5 – 9 m b.g.l.), followed by a stronger moderately weathered slate (3.5 - 11 m b.g.l.). Depth to bedrock is 7 – 20 m and locally there is siltstone below 22 m. The area normally receives 877 mm rain per year (1961-1990 mean at Rosslare Meteorological Station, Met Éireann).

The intensively managed grassland catchment, located in Co. Cork, is overlying Devonian old red sandstone and mudstone and is classified as a productive aquifer with an intergranular flow. In this catchment the study sites have a loose topsoil layer (0.5 – 2 m thick) overlaying a firm layer of gravely clay (0.5 – 7.5 m thick) and a dense layer of clayey sand and gravel (0.5 – 2 m thick). The uplands have thinner soils. There are patches of highly weathered sandstone (1 – 8 m b.g.l.). Depth to bedrock is 2 – 8.5 m. In some local sites there is mudstone at depths greater than 8 m, and strong siltstone (3.6 – 20 m b.g.l.). The 30 year mean annual rainfall is 1207 mm (1961-1990 mean at Cork Airport, Met Éireann).

EXPERIMENTAL DESIGN

Each catchment had two focused study sites (hill slopes) chosen to represent the catchment in terms of land use, soil type, geology and topography following conceptual modeling of existing data layers and geophysical surveying. These latter surveys included ground conductivity (EM 31, EM 38), ground penetrating radar, 2D-resistivity and seismic refraction. At these sites groundwater is investigated through high resolution monitoring of water levels, monthly low-flow water quality sampling and campaign sampling during storm events - all in 6 multilevel monitoring wells per catchment (Figure 1). Each monitoring well contains three piezometers screening 3 m of highly weathered bedrock, moderately weathered bedrock and deep bedrock in the arable/slate catchment, as defined via geophysical surveys, and shallow bedrock, mid bedrock and deep bedrock in the grassland/sandstone catchment. Water quality sampling continues to be made on a monthly basis (occasionally every second week) and filtered samples are transported in cooling boxes for analysis in the laboratory within two days. Stream water discharge and high resolution measurements of water quality are being monitored at the catchment outlets. Rainfall and weather parameters for estimating potential evapotranspiration are being measured within each catchment.

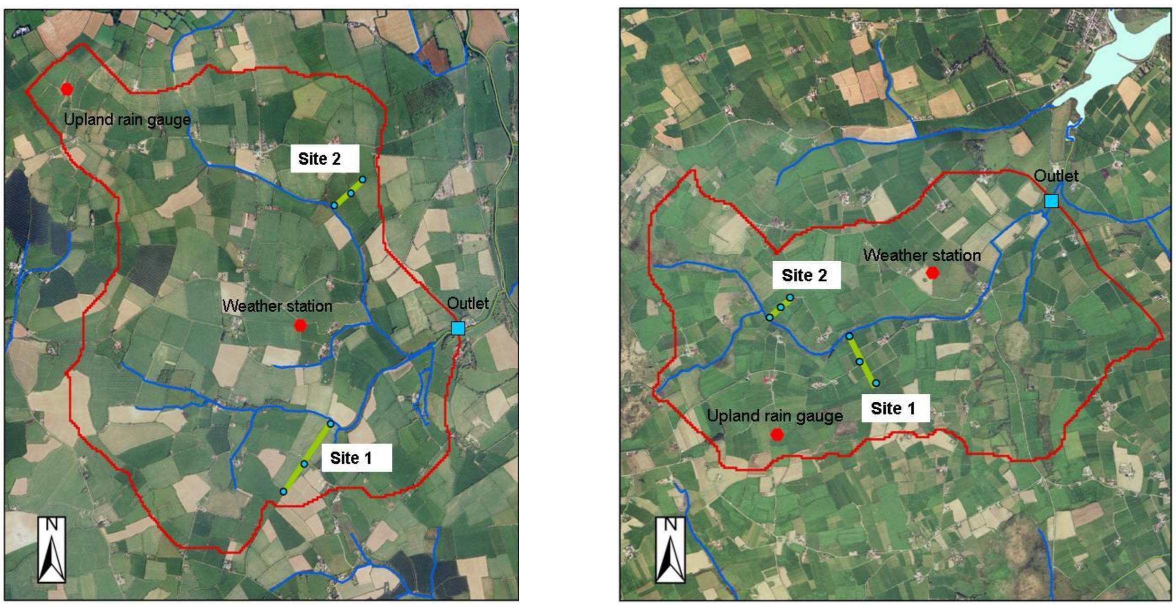

Figure 1: (i) Left: arable/slate catchment in Co. Wexford, and (ii) Right: grassland/sandstone catchment in Co. Cork, Ireland. Catchment boundary, focused study sites 1 and 2, multilevel monitoring wells, weather station, upland rain gauge and outlet are marked.

RESULTS

LAND MANAGEMENT

The arable fields are generally ploughed in mid February, fertilised with an NPK compound fertiliser applied in conjunction with seeding with spring barley in early April, and additional N fertiliser is applied during the growing season. Spring barley harvest takes place in mid August followed by a closed season for ploughing until 30th November (unless a green cover is established). Constraints on the timing and magnitude of nutrient use and timing of ploughing are among the main measures to mitigate diffuse nutrient loss to water bodies in such catchments.

General practice for the grassland was application of urea (46% N) between February and April. Thereafter Calcium Ammonium Nitrate (CAN, 27% N) is applied until July and less frequently between July and September, followed by a closed period after September 30th. Pasture improvement took place in 2010 at site 2, which was ploughed, fertilised and reseeded with grass in early September. Organic nitrogen loading (kg ON ha^{-1}), as a surrogate for livestock intensity, and constraints on the timing and magnitude of inorganic and organic fertiliser applications are among the main measures to mitigate diffuse nutrient loss to water in grassland catchments.

GROUNDWATER RECHARGE & FLOW REGIMES

This experiment is on-going and so some preliminary results from Phase 1 of the ACP are presented for January 2010 – March 2011 for two of the sites (arable/slate catchment site 1 and grassland/sandstone catchment site 2). The yearly rainfall (2010) in the arable/slate catchment was 920 mm and the potential evapotranspiration (PET) was 591 mm. In the grassland/sandstone catchment the rainfall was 1016 mm and PET 579 mm. Compared to 30 year average the annual rainfall of the study period (2010) was approximately average; however, July 2010 was exceptionally wet (138 mm in the arable/slate catchment and 220 mm in the grassland/sandstone catchment) resulting in higher water recharge. August 2010, however, was exceptionally dry (35 mm and 27 mm, respectively).

The piezometric water levels in the arable/slate catchments showed a more peaky character with a quick response to rain events typical for fissured flow (Figure 2). The effect of the homogenous and distinct stratification was seen in the stepwise recession of the piezometric water levels which revealed temporal changes in flowpaths. In the grassland catchment on sandstone, the piezometric water levels were less peaky as the groundwater recharge is more buffered due to its intergranular flow characteristics. The response times were longer, and less stratification in the bedrock gave a smoother recession in the piezometric water levels, which in general were lower in the grass/sandstone catchment.

Typically there were higher water levels and discharge potentials in the near-stream zone than in the uplands. The further away from the stream (higher upslope), the deeper the water levels were and the recharge potentials were higher. The topographical effect on flowpaths was seen when comparing the longer and slightly steeper slopes (site 1) with the shorter, less steep slopes (site 2) of both catchments (data not shown). In both of the longer slopes the water head was higher, giving higher discharge potentials in the near-stream zone. In the shorter slopes, the discharge potentials in the near-stream zone were lower and changed direction with season, thus only acting as a discharge zone during high water levels, *i.e.* mostly in winter.

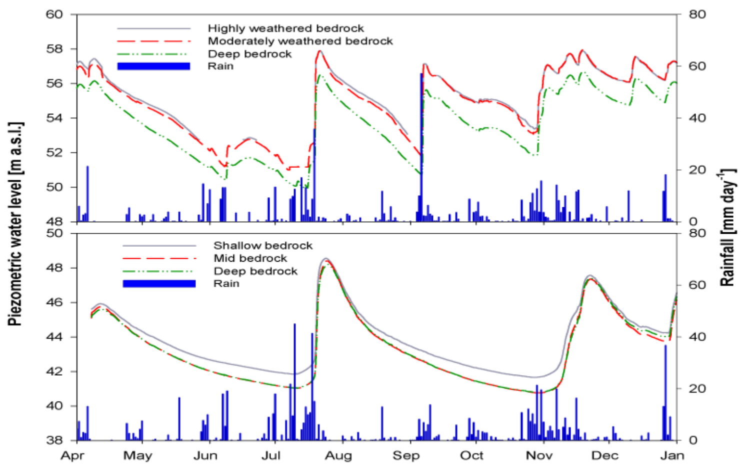

Figure 2: Example of hourly averaged piezometric groundwater levels and daily rainfall in:

Above - slate bedrock (Site 1), and

Below - sandstone bedrock (Site 2). The examples are from the midslope wells where the ground level is 61.2 m a.s.l. in the slate catchment and 51.8 m a.s.l. in the sandstone catchment.

NUTRIENTS IN GROUNDWATER

There was little spatial and temporal variation in the groundwater concentration of NO_3-N in site 1 of the arable/slate catchment (Figure 3a). The values ranged between 2.5 mg L^{-1} (upslope shallow water in early January 2011) and 7.8 mg L^{-1} (near-stream shallow water in mid August 2010). In the near-stream zone and in the midslope the average NO_3-N concentrations were higher compared to the upslope (6.0 mg L^{-1} and 4.5 mg L^{-1}, respectively). In the upslope and midslope, the deeper water had higher NO_3-N concentration than the shallow groundwater, whereas in the near-stream zone this relation was reversed with slightly higher concentrations in the shallow groundwater, with a few exceptions in the summer when it was occasionally higher than in the shallower layers. The stream water was in the same range as the near-stream groundwater but was typically diluted during rain events. During baseflow the stream water was reflected by groundwater in the highly and moderately weathered zone and also by deeper water in winter.

In the shorter slope of the grassland/sandstone catchment (site 2) there were temporal trends in all wells. On average the NO_3-N concentration was 6.1 mg L^{-1} in the near-stream groundwater, 9.6 mg L^{-1} in the midslope and 7.6 mg L^{-1} in the upslope (Figure 3b). The levels were generally higher in the shallow groundwater in all wells. The shallow groundwater in the upslope was high and varied less over time, whereas in the deeper water there were changes with concentrations varying from 1.1 to 10.4 mg L^{-1}. In the midslope there was little difference between the layers. Not until a peak occurred in January 2011, did the concentration between the layers differ, with higher values in the shallow water. In the near-stream groundwater, at the start of the measuring period (March 2010), the shallow water was 0.1 mg L^{-1} and a year later it had increased to 15.9 mg L^{-1}. The concentration trends in the deep water were reversed with 8.6 mg L^{-1}in March 2010 and 0 mg L^{-1} in March 2011. The stream water concentration of NO_3-N was, on average, 3.8 mg L^{-1} and didn't change much until a slight increase in December 2010 – January 2011, when the groundwater concentrations were high. The stream water NO_3-N was similar to that in the mid bedrock. The NO_3-N concentration in the water of the shallow bedrock, interface and subsoil were higher throughout the period.

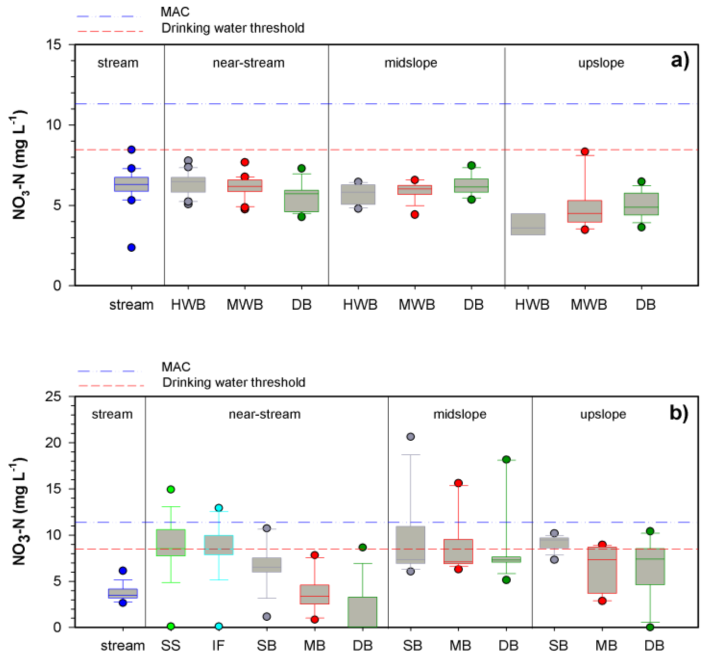

Figure 3: Yearly median, 25th and 75th percentile, and minimum and maximum of Nitrate-N in groundwater of:
a) Arable/slate Site 1
b) Grassland/sandstone Site 2.

Irish drinking water standards (NO_3-N = 8.5 mg l^{-1}) and MAC (NO_3-N = 11.3 mg l^{-1}) are marked with dashed lines (red and blue, respectively). Str = stream, HWB = highly weathered bedrock, MWB = moderately weathered bedrock, DB = deep bedrock, SS = sub soil, IF = interface, SB = shallow bedrock, and MB = mid bedrock.

In terms of NO_3-N concentrations, there was no clear response to land management seen in groundwater of the arable/slate catchment. In site 2 of the grassland/sandstone catchment the shallow groundwater in the uplands showed a possible response in NO_3-N concentration to a reseeding event in September after two months. It took four months to reach a peak of 20.6 mg L^{-1}in the subsoil/bedrock interface. The response to the same management event in the deep groundwater in the uplands and in the near-stream groundwater was three months. The peak concentration of 15.9 mg L^{-1} was reached in the near-stream groundwater after five months. There was also a response observed in dissolved reactive phosphorus (DRP) for the same management.

COMPLIANCY

The most potable groundwater strata (with regard to potential production) are likely to be in the weathered bedrock in the arable/slate sites and the shallow bedrock stratum in the grassland/sandstone catchment. Site 1 of the arable/slate catchment was compliant according to Irish drinking water standards and MAC (Figure 3a). In all wells of site 2 in the grassland/sandstone catchment the deeper, potable, groundwater was compliant to drinking water standards (but not in the shallow groundwater) (Figure 3b). In winter 2010/2011 the NO_3-N concentrations in the water of all levels of the midslope well, and in the subsoil of the near-stream zone, reached well above the MAC but the yearly average was below this concentration.

In site 1 of the arable/slate catchment the threshold of P, above which freshwater ecology can be impacted if groundwater is a significant contributor to surface water, was exceeded in the shallow groundwater of the near-stream zone and in the shallow groundwater of the upslope well (Figure 4a). The same pattern was seen in site 2 of the grassland/sandstone catchment where the shallow groundwater of the near-stream and upslope exceeded the threshold of P (Figure 4b).

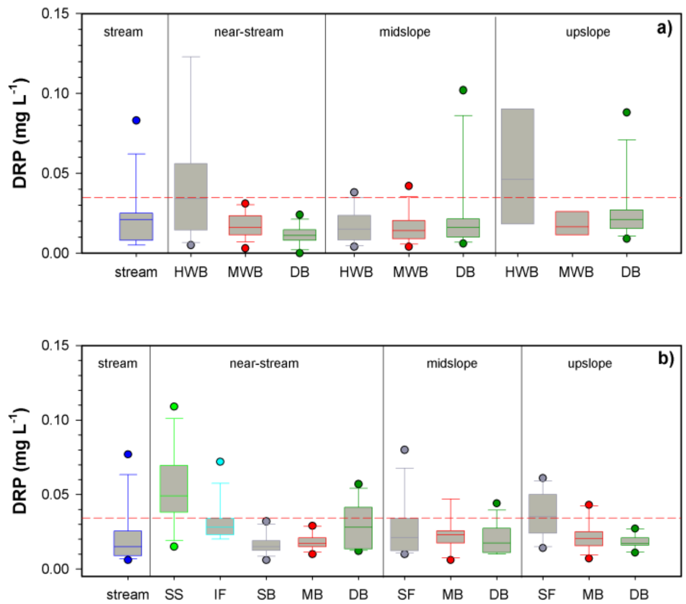

Figure 4: Yearly median, 25th and 75th percentile, and minimum and maximum of dissolved reactive phosphorus (DRP) in groundwater of:
a) arable land site 1, and
b) grassland site 2.

Str = stream,
HWB = highly weathered bedrock,
MWB = moderately weathered bedrock,
DB = deep bedrock,
SS = sub soil,
IF = interface,
SB = shallow bedrock,
MB = mid bedrock.

DISCUSSION

The sites in both catchments are relatively homogenous in the strata and are assumed to represent catchment soils, geology and topography. With detailed demonstrative studies on representative hill slopes the method can, therefore, provide knowledge and conceptual understanding of below ground pathways and processes at a catchment scale.

From data gathered during 2010-2011, the connection between farming activity and groundwater chemistry was seen to be buffered due to lag times; while the groundwater in the near-stream zone was more chemically mixed than upslope sites it was directly linked to the stream water chemistry with a relatively quick chemical and hydrological response to events. This was clearer in the arable/slate catchment where the effects of recharge processes likely dominated the effect of land management due to flow regime. Most of the interflow occurs in the permeable highly to moderately weathered layers on top of the bedrock. The different flow regimes of these strata were reflected in the recession limbs of the piezometric water levels in this catchment. The groundwater water table was higher in winter which gave quicker recharge as there was less vertical distance to the groundwater. This likely induced a quicker interflow in the shallower layers (having higher transmissivity) to the near-stream zone where it mixed with the deeper (older) water. In that catchment the baseflow stream water chemistry was mostly reflected by water in the highly and moderately weathered bedrock on top of the strong bedrock. In the grassland/sandstone, where groundwater in general was deeper and more buffered to recharge, the stream water chemistry was mostly reflected by near-stream groundwater in the shallow bedrock.

Both N and P were transferred from diffuse agricultural sources to surface water via groundwater. The groundwater in the upland, with shallower soils, was least buffered (two month response to a reseeding event of the grassland). The deep upland and near-stream groundwater was more buffered with a three months response demonstrating lag processes, at least in terms of delivery (Fenton et al., in press.). Subsequently, there was a small increase in the nutrient concentration of the stream water. There was also a response to the reseeding event in P in the groundwater and this will require further process investigation.

As the grassland/sandstone catchment was more buffered to water recharge it was also likely to be more buffered in nutrient transfer than the arable/slate catchment. In this catchment there was a gradient with higher NO_3-N concentration in the shallow groundwater and lower in the deeper water. There were also lower NO_3-N concentrations in the near-stream zone. This coincided with concentrations of dissolved oxygen (DO) being lower with depth and near-stream (data not shown) indicating more biogeochemical loss of NO_3-N in the intergranular flow of sandstone compared to that in fissured flow of weathered slate.

For this first study year the data suggest a general groundwater compliancy to drinking water standards, MAC and ecological thresholds within the investigated catchments. Despite vulnerable soils and intensive agriculture the groundwater was mostly compliant to the standards. However, there were non-compliant periods and sites. The most vulnerable places were shallow groundwater in the uplands, where the soils are thin with little attenuation of N and with possible preferential flows of P, and in the more stream connected shallow groundwater of the near-stream zone, where N could be attenuated by denitrification but where P on the other hand is likely accumulated. In terms of drinking water standards, these areas are less likely to be used as potable water supplies and may be signals from the flux process from shallow to deep water strata.

CONCLUSIONS

1. Both N and P were transferred from diffuse agricultural sources to surface water via groundwater, but these transfers were buffered, and more so in the grassland/sandstone catchment. Shallow upland groundwater was least buffered. Deep upland and near-stream groundwater was more buffered.
2. Near-stream groundwater interacted directly with surface water and responded quickly to events.
3. In winter, when the groundwater table was higher, the distance from source to groundwater was shorter. The more vulnerable upland will then likely be more efficiently connected to the near-stream pool where a mixing with deeper and older water, and flush out to the stream occurs.
4. There were higher concentrations of N in upland groundwater and shallow near-stream groundwater, and higher P in shallow groundwater.
5. In terms of compliancy: intensively managed land on permeable soils was compliant according to current Irish drinking water standards, with the exception of light upland soils. The shallow groundwater of the uplands and near-stream zone was potentially not compliant compared with the ecological threshold for P but the streams remained mostly below this threshold anyway.
6. During baseflow, surface water was reflected by near-stream groundwater in the weathered bedrock of the arable/slate catchment and in the mid bedrock of the grassland/sandstone catchment.

ACKNOWLEDGEMENTS

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www.teagasc.ie/agcatchments
www.teagasc.ie/catchmentscience

REFERENCES

European Commission. 2008. *Groundwater protection in Europe*. Brussels. European Commission.

European Parliament and Council. 2000. *Water Framework Directive establishing a framework for community action in the field of water policy*. Official Journal of the European Communities, 2000/60/EC, L327, 1-73.

EPA. 2009. *Water Quality in Ireland 2007-2008. (In): J. Lucey (Ed.), Key indicators of the aquatic environment.* Environmental Protection Agency, Ireland, Johnstown Castle, Wexford.

EPA. 2010. *Water quality in Ireland 2007 – 2009.* Ed.: McGarrigle M., Lucey J., Ó Cinnéide M. Environmental Protection Agency, Ireland, Johnstown Castle, Wexford.

Fealy R.M., Buckley C., Mechan S., Melland A., Mellander P.-E., Shortle G., Wall, D., Jordan P. 2010. *The Irish Agricultural Catchments Programme: catchment selection using spatial multi-criteria decision analysis.* Soil Use and Management, 26, 225-236.

Fenton O., Schulte R.P.O., Jordan P., Lalor S.T.J., Richards K.G. *Lag time: a methodology for the estimation of vertical and horizontal flushing timescales to nitrate threshold concentrations in Irish aquifers.* Environmental Science and Policy – in press.

Groundwater Regulations S.I. No. 9/2010 – European Communities Environmental Objectives (Groundwater) Regulations 2010.

Haygarth P.M., Condron L.M., Heathwaite A.L., Turner B.L., Harris, G.P. 2005. *The phosphorus transfer continuum: linking source to impact with an interdisciplinary and multi-scaled approach.* Science of the Total Environment, 344, 5-14.

Holman I.P. Whelan M.J., Howden N.J.K., Bellamy P.H., Willby N.J., Rivas-Casado M. McConway P. 2008. *Phosphorus in groundwater – an overlooked contributor to eutrophication?* Hydrological Processes, 22, 5121-5127.

Kilroy G., Coxon C. 2005. *Temporal variability of phosphorus fractions in Irish karst springs.* Environmental Geology, 47, 421-430.

Nitrates Directive S.I. NO. 101/2009 – European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2009.

Wall D., Jordan P., Melland A.R., Mellander P-E., Reaney S., Shortle G. *Using the nutrient transfer continuum concept to evaluate the European Union Nitrates Directive National Action Programme.* Environmental Science and Policy – in review.

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REDUCING PRESSURE ON GROUNDWATER SOURCES: THE LESSONS OF UNIVERSAL METERING IN THE GWS SECTOR

Barry Deane
National Federation of Group Water Schemes

ABSTRACT

Group Water Schemes (GWS) are community owned & community controlled water supplies which were established in the 1960s, through the 70s and into the early 80s. One of the major challenges for a modern group water scheme is the extent of water wastage in distribution networks. Virtually all group schemes invested heavily in treatment facilities and as a consequence the costs associated with producing drinking water increased dramatically. Until recent years, water abstraction rates were high on group schemes (as on public schemes). In the absence of metering and a meter-based charging system, the overwhelming majority of schemes levied only a small flat rate charge on their members for an unlimited supply of water. Funding was introduced under the rural Water Programme to replace leaking mains and to install bulk meters on distribution networks. This highlighted areas of the distribution network that were leaking and needed to be repaired and also identified that the bulk of water loss was not on the distribution mains however, but on the consumer side of the connection. Many consumers were unaware that the leaks existed. Despite initial reluctance amongst some schemes to embrace metering, there is now universal recognition that it is a key management tool. By introducing a charging system, schemes have moved away from flat rate charging, which has resulted in many members aiming to conserve as much water as possible, and has encouraged them to identify potential leaks in the distribution network. The benefits of conservation and reduced loss have resulted in lower abstraction volumes and overall savings in the cost of running the schemes.

BACKGROUND TO GROUP WATER SCHEMES (GWS)

Group Water Schemes (GWS) are community owned & community controlled water supplies, involved in the sourcing, treating, storing and distribution of water to their members. They were mostly formed in rural areas where there was no public supply of water. The concept of the group water scheme was pioneered in West Wicklow in the late 1950s through the efforts of a local Catholic curate, but it was a joint initiative between the Department and the Irish Countrywomen's Association in 1961 that saw the development and promotion of the GWS idea in other parts of the country.

Most group water schemes were established in the 1960s, through the 70s and into the early 80s, encouraged by the introduction of a Department of the Environment grant towards the installation costs. While the Irish Farmers Association (IFA) was largely opposed to the development of schemes in the 1960s, by the 1970s farming and rural organisations generally were significant promoters of schemes at local level, forming the backbone of local committees, motivating communities, collecting contributions and installing much of the pipe work through direct labour.

Nationally the vast majority of schemes sourced their water supply from boreholes & springs, but in much of the west and border counties schemes largely came to depend on surface water supplies. In the 2007 EPA Drinking Water Report, 69% of privately-sourced GWS were supplied by groundwater sources.

Once established, group water schemes received no funding towards their operations, or towards capital replacement works. The voluntary committees were required to make do with whatever infrastructure they had and to raise money from their members. As raw water quality deteriorated from the early 1970s onwards and as the early enthusiasm waned, group schemes found it increasingly difficult to function. Many had no treatment or only minimal treatment in place and their members were increasingly unwilling to pay for water that was sub standard.

A BRIEF HISTORY TO THE GWS DEVELOPMENTS

In the late 1990s there was an obvious need for investment in GWS sector. The main driver was the EPA's Drinking Water Quality Reports, particularly those published at the turn of the millennium which showed that a substantial proportion of schemes were failing to meet drinking water standards, while almost half of all schemes were failing to comply with the crucial microbiological parameter, E.coli. In November 2002, the European Court of Justice issued a damning indictment of the sector, listing hundreds of schemes that were non-compliant.

By then, the turn-around was already underway under the auspices of a National Rural Water Monitoring Committee (NRWMC) established as part of a new Rural Water Programme (RWP) in 1998. Through a strategy developed by the NRWMC, most drinking water quality issues have now been resolved on group schemes and the success of the strategy was confirmed in the latest EPA report for the years 2008 and 2009.

The provision of fully treated water has highlighted other issues, not least the extent of water wastage in distribution networks. This issue presents one of the major challenges for a modern group water scheme and in addressing this issue; schemes are finding that there are clear advantages to reducing water demand.

WHY IS THE QUANTITY OF WATER BEING USED/ABSTRACTED AN ISSUE?

One of the main reasons why the quantity of water being abstracted from the source became such an issue for GWS was down to affordability and GWS viability. Virtually all group schemes invested heavily in treatment facilities and as a consequence the costs associated with producing drinking water increased dramatically. The viability of a large number of schemes came into question as their water demand was so high. Indeed, for many it was higher than the design capacity of their new treatment plants (even though this was based on projected water demand 20-years from the date of construction). This put serious pressure on the plants as they had to operate up to 24 hours per day. This in turn was affecting the quality of the water being supplied which was ironic considering that the water quality issue was the main reason the plants were installed in the first instance.

The sustainability of the sources was also becoming an issue. Despite our typically mild and wet climate, in 1995 and again last year (in early summer 2010), some public schemes and group schemes reported a considerable drop in their source levels, as there had not been enough rain to recharge aquifers. The implications for some schemes was that water had to be rationed to reduce the pressure on wells.

Changes in legislation were also a major factor influencing schemes to look seriously at their abstraction rates. In 2007 the Water Services Bill was enacted. This highlights the area of water conservation and the importance of all water suppliers minimising water wastage as part of their management. The legislation proposed licensing of group schemes. Although this has yet to commence, the conditions for getting such a licence are interesting. In addition to providing water that meets the quality standards, GWS management will be considered and this will include the management of water demand.

The Water Framework Directive is also a factor, prioritising drinking water sources for remedial and protective actions, not least in terms of minimising abstractions.

Beyond this, a major driving force influencing how schemes look at the cost of water demand is the receipt of an annual subsidy of up to €140 per household towards their operational costs. One of the conditions for drawing down this subsidy is that that schemes have to demonstrate to their Water Services Authority that they are implementing water conservation measures and taking active steps to reduce daily water demand.

WATER DEMAND

Until recent years, water abstraction rates were high on group schemes (as on public schemes). In the absence of metering and a meter-based charging system, the overwhelming majority of schemes levied only a small flat rate charge on their members for an unlimited supply of water. With only a couple of exceptions, it wasn't until the 1990s that group schemes began to seriously consider introducing universal metering. That they did so at all was because of the substantial increase in water demand across schemes during the late 1970s, 80s and 90s as rural homes were transformed with the addition of bathrooms, flush toilets, and washing machines. The demand of the older generation was minimal compared to the voracious appetite for water of the bungalow generation and their children. This rapidly increasing demand had a direct bearing on the day-to-day running costs of schemes, even if only in terms of increased pumping charges. Those costs would rise significantly with the addition of full treatment facilities.

Prior to designing such facilities many GWS had water audits completed to establish how much water they ***should*** be using based on the population served. The results confirmed a considerable difference between theoretical water demand and actual demand. For its part, the Department of the Environment could only sanction funding for treatment plants to meet the theoretical demand of a scheme (allowing for population growth over 20-years), plus a 25% allowance for Unaccounted For Water (UFW).

Following representations from the NFGWS, the Department acknowledged that high usage figures on schemes would have serious implications in terms of the capacity of the new plants to cope and for the schemes themselves in paying for the excessive water demand. As a result further funding was introduced under the rural Water Programme to replace critical (i.e. leaking) mains and to install bulk meters on distribution networks. On more than 200 schemes that were participating in design, build operate projects as part of their upgrade strategy, universal metering was now a requirement. All of these supports proved to be the major incentive for schemes to invest in their infrastructure, some of which had not been touched since the schemes were originally constructed. To be truthful, the reduction in abstraction from sources wasn't considered in all of this … rather it proved to be a happy consequence of the strategy to reduce demand for treated water.

Once schemes had invested in bulk and consumer metering they were in a position to monitor the amount of water that was being pumped into supply on a regular basis and compare these figures to the amount of water that was being consumed by the members. This highlighted areas of the distribution network that were leaking and needed to be repaired as well as further sections of critical mains that needed to be replaced. The bulk of water loss was not on the distribution mains however, but on the consumer side of the connection. Universal metering highlighted those consumers that had unacceptably high usage or leakage on their own service pipes or within their own distribution systems. Many consumers were unaware that the leaks existed as they were under tarmacadam driveways and would never have been found without metering.

As part of the transformation of the sector over the past decade, group schemes generally have greatly improved their management structures. The majority are now registered co-operatives with a board of directors that oversees strategic management of their scheme. Many larger schemes have employed full and part-time staff to manage and maintain their schemes. The NFGWS and the Water Services Training Group (WSTG) have also developed a number of training courses to help schemes manage their water usage, including the Federation's training course 'Reducing Daily Water Demand' and the WSTG's course 'Leakage Control in Rural Water Supply Networks'. By providing schemes with this information, they now understand that monitoring water usage including leakage location & repair is a continuous process in effectively managing any communal drinking water supply.

Despite initial reluctance amongst some schemes to embrace metering, there is now universal recognition that it is a key management tool. Committees understand the importance of controlling water demand in the network and now embrace any technological advances that will facilitate this. In recent years, telemetric bulk metering has become the norm, providing instantaneous alarms should there be a sudden surge in flow through the network. Similarly, Scada systems are used to check flow from reservoirs and increasingly schemes are moving towards full telemetry on consumer meters also. It isn't that all schemes are so technologically advanced, but the trend is clear to see.

Apart from metering, the most significant factor influencing the reduction of daily water being abstracted from GWS sources has been the introduction of a charging system based on metered usage. By introducing such a system schemes have moved away from flat rate charging system for which GWS members pay a fixed amount of money per year for an unlimited supply of water to a system where people pay for what they use or, more correctly for their excess usage, because most schemes provide an allocation of 'free' water for essential use. Apart from being a very fair and equitable way of charging for water used introducing such a system many GWS are reporting that their members are now much more conscious of the value of water. This has resulted in many members conserving as much water as possible, allowing them to identify when they have a leak much more quickly which results in repairing leaks much more quickly.

Table 1: Examples of Groundwater source schemes that have managed to reduce the amount of water being abstracted from their sources.

GWS	Location	Approx. No. of members	Source	Former Abstraction Rate (m^3/day)	Current Abstraction Rate (m^3/day)	Difference	% Reduction in Abstraction
1	Sligo	70	Spring	300	30	270	90%
2	Wexford	30	Spring	40	5	35	88%
3	Cork	70	Borehole	70	30	40	57%
4	Laois	750	Borehole	1,400	800	600	43%
5	Carlow	300	Spring	620	380	240	39%
6	Limerick	120	Borehole	220	120	100	46%
7	Louth	210	Borehole	140	110	30	22%

The table above represents a sample of GWS that were involved in all or some of the process outlined above and shows that the abstraction rate of these schemes has reduced from between 22 and 90% when compared to their previous usage.

LESSONS LEARNED BY THE GROUP WATER SCHEME SECTOR

One of the key lessons learned by schemes that have gone through this process is the importance of involving the community and membership at all stages. Some schemes unfortunately learned this lesson the hard way, coming into conflict with members who had major leaks of which they were unaware until a major bill arrived from the GWS. In order to avoid these situations, many schemes held meetings with their members, sent out information letters, compiled leaflets, sent text messages etc. to make sure that members were fully aware that the GWS would soon be moving to a charging system based on metered usage and that they should check their internal distribution systems for leaks. In many cases it came down to approaching some of the larger users and discussing their usage, sometimes on more than one occasion.

A pattern emerged in relation to where the lost water was going. A study carried out on six schemes in the west of Ireland challenged the perception that most water loss occurred in the distribution mains by showing that the majority of leakage and wastage of water (between 55% and 80%) was on the consumer side of the connections. The experience of group schemes would generally confirm the findings of this study, as the ratio of water loss on each side of the connection is 50:50 at a minimum. Such results support the NFGWS's view that a complete mains rehabilitation allied to a flat-rate charging system would have relatively little impact on reducing water demand, as opposed to a strategy of replacing mains and introducing a metre based charging system.

One point that has been clearly proved by the experience of the GWS sector is that leakage control is a continuous and ongoing process. At its simplest, when I fix a leak on one part of the network, the increased pressure in the distribution main may lead to other leaks. Using the infrastructure that was installed on a consistent basis is critical for any scheme to maintain low levels of water usage, as is a sensible charging policy that discourages wastage.

It is clear now that where schemes in the past had high abstraction rates in excess of the treatment plants design demand, the treatment process was under severe pressure and at times could compromise drinking water quality supplied by the GWS. By reducing the abstraction rates to lower levels many of the schemes are achieving longer life out of items of plant and have noticed a significant reduction in their power requirement and in their running costs.

But there are other advantages also. By reducing the level of water being abstracted from borehole sources, schemes are potentially improving the quality of their raw water supply because the zone of contribution for recharging the source is reduced, as are the zones of vulnerability. The pilot project being conducted by the GSI in conjunction with the Federation in delineating GWS zones of contribution and points of vulnerability will hopefully lead to similar studies on all GWS groundwater sources over the next 5 years. This will inevitably increase the understanding of GWS activists that reducing abstraction pressure on their sources has major benefits, both for themselves and for the wider aquatic environment.

In conclusion, many lessons have been learned by the GWS in terms of reducing water demand. The key to reducing abstraction rates on groundwater sources used for drinking water is to invest in the appropriate infrastructure (bulk and consumer meters) and to use this infrastructure to identify sections of critical mains to be replaced, introduce a charging system based on usage and ensure effective communication with all consumers. These measures will result in significant reductions in water usage and abstraction from groundwater sources, promote water conservation, reduce pressures on treatment facilities, help improve source protection and maintain drinking water quality.

REFERENCES

EPA. 2002. *Drinking Water Quality Report 2002.* Environmental Protection Agency, Ireland, Johnstown Castle, Wexford.

EPA. 2007. *Drinking Water Quality Report 2007.* Environmental Protection Agency, Ireland, Johnstown Castle, Wexford.

NFGWS. 2010. *Annual Report*. National Federation of Group Water Schemes

WSTG. *Leakage Control in Rural Supply Networks.* Water Services Training Group.

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