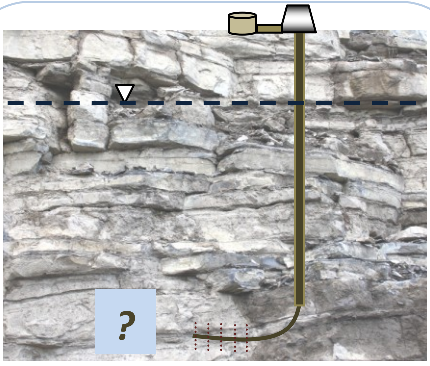
INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS – Irish Group

‘Groundwater: Recent Developments in Discharge & Dewatering’



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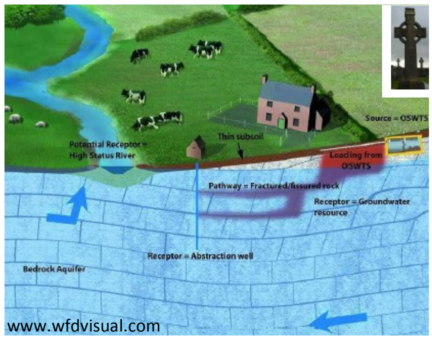
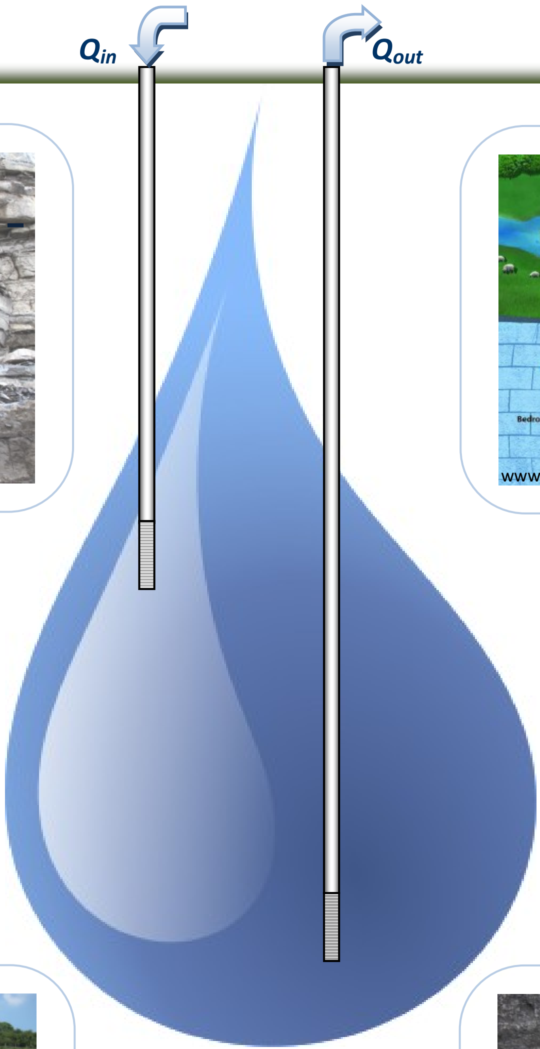


Discharge



Managing

Impacts

Mining

Dewatering

‘Water is the first principle of all things’

Proceedings of the 32nd Annual Groundwater Conference
Tullamore, Co. Offaly, Ireland

24th and 25th April, 2012

www.iah-ireland.org

Binding side

INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS
(IRISH GROUP)

Presents

'Groundwater: Recent Developments in Discharge & Dewatering'

Proceedings of the 32nd Annual Groundwater Conference

Tullamore Court Hotel
Tullamore
Co. Offaly

24th & 25th April, 2012

INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IRISH GROUP)

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

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

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

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

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

2012 Conference Objective

As with previous years, the 2012 IAH (Irish Group) Groundwater Conference can be expected to benefit hydrogeologists, engineers, local authorities, consultants, planners, environmental scientists, public health officials, professionals and practitioners from a variety of sectors involved with groundwater.

2012 is the 32nd Anniversary of the Annual IAH (Irish Group) Groundwater Conference. This year's theme is entitled '*Groundwater: Recent Developments in Discharge & Dewatering'*. The two-day event is being held at the Tullamore Court Hotel and combines an impressive array of national and international speakers with exhibits, poster presentations, fine dining and social evening.

IAH (Irish Group) President Teri Hayes will initiate proceedings with an introduction and welcome address. Taly Hunter-Williams, Senior Hydrogeologist with the Geological Survey of Ireland will chair the opening session on 'Fracking' and will begin by introducing the keynote speaker - Tony Marsland, former Groundwater Policy Manager for the UK Environment Agency. In the context of shale gas and fracking, Tony will review the need for additional regulatory control in respect of potential discharges to groundwater. Mark Cottrell of Golder Associates follows with a technical presentation on managing the environmental risk associated with fracking using a DFN approach. After the coffee break, Gareth Ll Jones and Davide Gallazzi present fracking in the Irish context with an overview of current developments and potential issues. Delegates are then encouraged to engage with the panel through a 20-minute Q&A session.

Before lunch, students who have agreed to present posters at the conference will be invited to briefly summarise their on-going hydrogeologically-related research.

After lunch, Session 2 opens with Pól Ó Seasnáin explaining the EPA's approach to the regulation of mining operations in Ireland. Bringing his experience to bear Kevin Cullen then quantifies the hydrogeological impacts of a mining operation from the perspective of Environmental Impact Assessment. Tiernan Henry of NUIG concludes the session with a case study of east Galway's Tynagh Mine and its associated groundwater issues. A Q&A session precedes a coffee break.

In examining recently-introduced quarry legislation, Duncan Laurence (Consultant), Brendan Slattery (A. Cox & Associates) and Sean Moran (OCM) bring their expertise to the final session on Day 1. In order of appearance respective emphasis is placed on the following: 'EPA Guidance to Local Authorities on the Extractive Waste Regulations'; 'Understanding Section 261A of the Planning Act'; and the 'Environmental Implications of Quarry Legislation'. Session 3 concludes with a Q&A session followed by a meal at The Wolftrap Bar.

Session 4 on Day 2 opens with Discharges to Groundwater Part I. Donal Daly (Head of Hydrometric and Groundwater Section, EPA) and Henning Moe (CDM Smith) jointly present a paper entitled 'Authorising Discharges to Groundwater: Issues & Technical Assessments'. Brendan Cooney (Wexford County Council) follows with the local authority perspective on developments in Groundwater Protection and Management. A Q&A session precedes the coffee break.

Discharges to Groundwater Part II promises to provide an opportunity for delicate reflection in considering the potential for discharges to groundwater under two very different scenarios. Catherine Buckley (Arup) will present a paper entitled 'Graveyards & Groundwater' that touches on a very sensitive topic that lies at the heart of our culture. On agricultural matters, Karl Richards (Teagasc) has agreed to present what promises to be an informative paper on 'Projected Agricultural Changes, Implications for Groundwater Quality and New Mitigation Measures'. Prior to lunch on Day 2 a final Q&A session will be followed by a closing address by the IAH (Irish Group) Conference Secretary, Shane Bennet.

2012 IAH (Irish Group) Committee:

2012 Conference sub-committee:

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

The IAH would like to sincerely thank ARUP for their help with the Conference administration.

Proceedings cover designed by Pat A. Groves. Sources of photographic imagery include WFD Visual (Water Framework Directive Visualisation tool: *www.wfdvisual.com*) courtesy of Scotland & Northern Ireland Forum for Environmental Research (SNIFFER) as displayed in EPA publication *Guidance on the Authorisation of Discharges to Groundwater*, Version 1, 2011; and Pat A. Groves archives.

The proceedings for the 32nd Annual Groundwater Conference 2012 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 32nd Conference:

WYG Ireland part of the WYG group
creative minds safe hands

Shane Bennet

epa
Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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THE UNIVERSITY OF DUBLIN

Pat A. Groves

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Geological Survey of Ireland
Suirbhéireacht Gheolaíochta Éireann

STREAM
BIOENERGY

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

MOR
MALONE O'REGAN

‘Groundwater: Recent Developments in Discharge & Dewatering’
32nd Annual Groundwater Conference

International Association of Hydrogeologists –Irish Group
Tullamore Court Hotel, Tullamore, Co. Offaly: Tues 24th & Wed 25th April, 2012

Programme Day 1, Tuesday 24th April

08:15 - 09:30 *Conference Registration; Tea, Coffee, & Exhibits*

INTRODUCTION

09:30	Welcome and Introduction Teri Hayes – *President IAH Irish Group* (WYG Environmental)
SESSION 1:	**FRACKING**
09:45 - 10:30	Keynote speaker: ‘Shale Gas and Groundwater Protection – The Regulatory Balance’ - Tony Marsland, Independent Consultant (former Groundwater Policy Manager, UK Environment Agency)
10:30 - 11:00	‘Managing the Environmental Risk Associated with Shale Gas Hydraulic Fracturing using a DFN Approach’ – Mark Cottrell (Golder Associates)
11:00 - 11:30	*Tea and coffee*
11:30 – 12:00	‘Shale Gas Fracking in Ireland’ – Gareth Ll Jones (Conodate) & Davide Gallazzi, (Northwest Environmental)
12:00 – 12:20	Discussion, Q&A (20 mins)
12:20	Student Poster Presentations
12:50 – 14:00	*Buffet lunch in Tullamore Court Hotel*
SESSION 2:	**MINING**
14:00 - 14:25	‘EPA Regulation of Mining Operations: The Story so Far’ – Pól Ó Seasnáin (EPA)
14:25 - 14:50	‘Quantifying the Hydrogeological Impacts of a Mining Operation as part of an EIA’ – Kevin Cullen, Consultant
14:50 – 15:15	‘Groundwater Issues in the Tynagh Mine area’ – Tiernan Henry (NUIG)
15:15 – 15:35	Discussion, Q&A (20 mins)
15:35 – 16:05	*Tea and coffee*
SESSION 3:	**QUARRY LEGISLATION**
16:05 – 16:30	‘The Extractive Waste Regulations: EPA Guidance to Local Authorities’ – Duncan Laurence, (Duncan Laurence Environmental Ltd.)
16:30 – 16:55	‘Regulation of Quarries: Understanding Section 261A of the Planning Acts’ – Brendan Slattery (Arthur Cox & Assoc)
16:55 – 17:20	‘Environmental Implications of Quarry Legislation’ – Sean Moran (OCM)
17:20 – 17:40	Discussion, Q&A (20 mins)

17:40 *The final panel discussion on Day 1 will be followed by a meal at The Wolftrap Bar, at the corner of Columcille St. and Harbour St. Tullamore, sponsored by IAH (Irish Group).*

'Groundwater: Recent Developments in Discharge & Dewatering'
32nd Annual Groundwater Conference

International Association of Hydrogeologists –Irish Group
Tullamore Court Hotel, Tullamore, Co. Offaly: Tues 24th & Wed 25th April, 2012

Programme Day 2, Wednesday 25th April

9:00 – 9:30	*Tea, Coffee & Exhibits*
SESSION 4:	**DISCHARGES TO GROUNDWATER (PART I)**
9:30 – 10:15	'Authorising Discharges to Groundwater: Issues & Technical Assessments' – Donal Daly (EPA) & Henning Moe (CDM Smith)
10:15 – 10:40	'Progression in Groundwater Protection and Management: A Local Authority Perspective' – Brendan Cooney (Wexford County Council)
10:40 – 11:00	Discussion, Q&A (20 mins)
11:00 – 11:30	*Tea & Coffee*
SESSION 5:	**DISCHARGES TO GROUNDWATER (PART II)**
11:30 – 11:55	'Graveyards & Groundwater' – Catherine Buckley (Arup)
11:55 – 12:20	'Projected Agricultural Changes, Implications for Groundwater Quality and New Mitigation Measures' – Karl Richards (Teagasc)
12:20 – 12:40	Discussion, Q&A (20 mins)
12:40	Conference closing address: Shane Bennet (*Conference Secretary* – IAH Irish Group)
12:50	*Buffet lunch in Tullamore Court Hotel*

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KEYNOTE SPEAKER

SHALE GAS AND GROUNDWATER PROTECTION – THE REGULATORY BALANCE

P.A. Marsland,
Independent Consultant

ABSTRACT

Public concern over exploration for shale gas in Europe is largely based on reported problems in the United States, with hydraulic fracturing attracting particular attention. Policy makers are under pressure to either ban or place moratoria on development of this "unconventional" energy resource, motivated in part by questions over the role of shale gas in meeting climate change targets as well as the impact of exploitation on the water environment. The potential scale of development and both the ability of operators to maintain good practice and for regulators to enforce this, underpins many concerns.

Shale gas development in Europe is in its infancy and the regulatory environment is significantly different from the US. Divergent views over the sufficiency of existing regulatory mechanisms in Europe have surfaced over the past year. Much will depend on Member States' implementation of EU Directives and the approach of local regulators. Concerns over environmental impacts are likely to remain in the absence of local practical experience.

Policy makers need to give a clear steer on their approach to unconventional gas development and enable regulators to plan and commit appropriate resources. Some lessons can be learnt from the US experience, but its relevance to proposed development in the EU needs to be carefully assessed. More will be gained from close inspection of local developments and working with developers to lower the industry's environmental footprint. Issues such as appropriate monitoring and inspection regimes, disclosure of data, public engagement, and training of regulatory staff need to be addressed.

INTRODUCTION

Shale gas extraction involves the drilling of boreholes, usually to considerable depth with horizontal extension along the target formation and hydraulic fracturing (HF) to enhance its natural permeability. Fluid is pumped into the well bore at pressure to create and propagate fractures in the target formation. Typically, the injected fluid is over 98% water, with sand and other "proppants" used to keep open the fractures to maintain the enhanced permeability, and small amounts of other substances to enhance gas recovery and prevent biofouling. The fluid is then pumped out to release gas. Overall, the process can involve the injection and return of large volumes of fluid, with consequent implications for sourcing of the water in the first instance and then final disposal of the contaminated "flowback" fluid.

In principle the exploration and development techniques are not individually new or unique to shale gas - but the rapid expansion of shale gas exploitation in the United States (made possible by developments in drilling technology) and anecdotal reports of pollution problems and impacts on groundwater supplies in particular has led to increased public concern. There has been intense media interest and increasing opposition, in part fuelled by a documentary movie and several critical reports highlighting the apparent environmental dangers of HF.

In practice it is difficult to verify whether many of the reported pollution incidents are the direct consequence of the drilling/fracking or extraction process or some other issue. However, with over 50,000 shale gas wells in the US constructed by a wide range of operators in varying geological conditions and working under diverse regulatory environments, it seems inevitable that some of reported problems will be due to construction failure and/or poor practice. In response to public concern the US EPA is conducting further studies on HF associated with shale gas, due to report initially at the end of 2012 with a final report in 2014. In addition the US EPA is preparing further guidance associated with shale gas extraction and waste disposal.

In contrast, shale gas development in Europe is in its infancy, with exploration in a number of Member States (such as Poland, Austria, Sweden, Germany, the Netherlands and the UK) but little or no exploitation as such to date. Nevertheless public concern has transferred across the Atlantic, heightened by reports such as that produced by the Tyndall Centre (Ref 5) and the European Parliament (Ref 1) and subsequent (albeit sometimes misleading) reports in the press.

Some of the opposition to the exploitation of shale gas is an in principle objection based on its perceived impact on the development of renewable energy and climate change (a policy issue not dealt with in this paper). This is interwoven with concern over technical issues such as the impact on water supplies (both from a resource availability and pollution impact perspective), the potential to cause minor earthquakes and the management and disposal of wastewater. In each case HF has become the main focus both due to its perceived direct subsurface environmental impacts and the resources needed to support the HF process. With limited practical experience in Europe, concerns seem to be based mainly on the more alarmist reports arising from the US. The potential scale of development and ability of both operators to maintain good practice and for regulators to enforce is being questioned. This paper focuses on these concerns as far as the impact on groundwater is concerned and the role the regulatory environment might play in dealing with these issues.

RECENT PRESSURES AND STUDIES IN EUROPE

As in the US, policy makers and regulators in Europe are coming under increasing pressure to place bans or moratoria on the development of shale gas and in particular the HF procedure. In principle this is a policy decision for governments, informed by technical risk assessments.

Recent EU reports (Refs 1, 4) have highlighted that, in principle, the regulatory environment in Europe is significantly different from the US:

- In many European countries the mineral resource is owned by the State rather than the landowner.
- Most environmental legislation is driven by European Directives which are transposed into domestic legislation. Transposition reflects local administrative arrangements and is a Member State responsibility. This is in effect policed by the European Commission, which can take cases of non or inadequate transposition to the European Court. In some cases Directives are supported by EU level guidance, such as CIS guidance on the implementation of the Water FD and GWDD, and technical working groups (such as CIS Working Group C – Groundwater).
- Notably in the US, HF is exempted at a national level from the Clean Water Act, the Safe Drinking Water Act, the Clean Air Act, and Comprehensive Emergency Response, Compensation, and Liability Act (Superfund). There are no similar exemptions in European legislation.

The European Parliament (Ref 1) has called for extensive new regulation for unconventional gas. In contrast a subsequent report for the European Commission (Ref 4), which looked in particular at how shale gas activities are controlled in Sweden, Poland and Germany, concluded that existing EU regulations are broadly sufficient at present to control shale gas operations. The report did identify that some adjustments may be needed in implementation by Member States to: increase public participation; reduce the thresholds at which Environmental Impact Assessments are needed (at the same time addressing the combined impact of separate schemes or creeping development); and facilitate a more integrated approach by the different regulatory bodies. In January 2012 the European Commission’s (DG ENV) ad-hoc technical working group on environmental aspects of unconventional fossil fuels gave a steer on which European Directives should be used to control shale gas developments, indicating in particular the potential use of the Mining Waste Directive.

In the UK, the House of Commons Energy and Climate Change Select Committee conducted hearings in Spring 2011 and produced a report on Shale Gas (Ref 2, with government response in Ref 3). It concurred with the view that stronger environmental regulations exist in the UK and Europe generally and concluded that there was no evidence that hydraulic fracturing itself posed a risk to groundwater supplies and that a moratorium was not justified. The Committee did highlight that integrity of well casing was a key risk factor and that the regulatory agencies needed adequate resources to regulate and monitor shale gas exploration and development.

Despite the extensive reports noted above the simple fact is that it will be difficult to assuage public concerns over environmental impact, effectiveness of legislation and sufficiency of regulatory resources with the limited practical experience in a European context to date. US data may not be representative of European conditions (for example, data from recent shale gas exploration drilling in the Fylde area of Lancashire suggests resource usage and general environmental footprint at or below the lower end of typical US figures – Ref 5). Until we have more direct experience and monitoring of shale gas development in Europe, the debate on potential impact on the water environment will not move on.

RISKS AND REGULATORY TOOLS

In general terms most groundwater that requires protection (see Box 1) occurs at relatively shallow depths in comparison with the target formations for shale gas development. There is usually both a significant vertical separation and one or more natural low permeability barriers to gas and fluid flow. Borehole construction provides potential new pathways for fluid and gas migration and therefore good design and construction methods are a key first step to avoiding pollution problems. Monitoring to determine whether well integrity has been maintained and whether new pathways for pollutants have been created, is a particular issue, given the depths of shale gas drilling.

Box 1: What is groundwater in the regulatory sense?

"Groundwater" is often used loosely to describe any subsurface water. However, under European legislation "groundwater" has a specific meaning, associated with certain requirements for protection. The Water Framework Directive (Water FD) defines it as "all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil". All groundwater is subject to the "prevent or limit" requirements of the Groundwater Daughter Directive (GWDD) that provides protection from inputs of pollutants (note that pollutants – "substances liable to cause pollution" - can be both liquid and gas).

The GWDD describes groundwater as "a valuable natural resource and as such should be protected from deterioration and chemical pollution. This is particularly important for groundwater dependent ecosystems and for the use of groundwater in water supply for human consumption." The Water FD also indicates that the ability to make use of a water resource is a driving factor in the requirement to protect that resource, both in terms of quality and quantity. The implication is that groundwater protection should be focused on subsurface water that has a human or environmental use.

Restricting the scope of the term groundwater in regulation focuses protection on aquifers and encourages the siting of higher risk activities on or in low permeability formations. It also enables the setting of compliance points that have some environmental relevance and not arbitrarily in formations that contain environmentally trivial amounts of water. This is reflected in Government guidance in England & Wales where is a technical decision for the Environment Agency to determine what is groundwater, noting that "in very low permeability strata such as clays, evaporates and dense crystalline rocks it may not be possible to define a zone of saturation because the water is bound to the rock or is relatively immobile".

Key factors in determining whether groundwater is present and requires protection include:

- The water lies within a groundwater body as defined under the Water FD;
- There is sufficient resource (in terms of quality and quantity) to maintain a supply of water for human consumption or other human uses with or without treatment (at economic levels);
- There is sufficient subsurface water flow to maintain groundwater dependent ecosystems at the surface or to support a stygofauna underground;

Negative indicators for the presence of groundwater could include:

- As a consequence of the physical properties of the strata it is not possible to define a coherent water table or extract water for human uses;
- There is limited or no connectivity with groundwater dependent ecosystems (terrestrial - ecosystems, dependent surface waters or stygofauna).
- Water quality is insufficient to support human uses or groundwater dependent ecosystems.

The overall sense is that groundwater in the regulatory sense is not present where any subsurface water that exists is in environmentally trivial quantities or is isolated from environmental receptors.

With the diversity of geological environments in which shale gas development can take place it is clear that generic approaches to risk assessment must be supported by a detailed conceptual model of each exploration site to underpin both technical and regulatory risk assessment and decision making. It seems likely that a lack of appreciation of subsurface environmental pathways has contributed to some cases of reported pollution in the US. The absence of sufficient environmental baseline data also seems to have clouded some of these cases.

There are widespread calls for regulatory authorities to undertake independent monitoring of the activities of shale gas operators but for groundwater in particular, realistically there is a limit to what these authorities can achieve independent of the operator. Ground investigations and monitoring boreholes, though technically feasible, are often not financially viable given the depths of the activities in question. Direct intrusive monitoring is in practice probably limited to the shallow subsurface, as well as non-intrusive methods and co-operation with the developer in monitoring their processes on site. Observation of site activities, access to operational data and independent auditing will be the key to providing the reassurance that is being demanded by the public and policy makers. However, this is both technically demanding and resource intensive, leading to questions over whether regulators will be able to cope with any rapid expansion in shale gas development in Europe (set against the perception that regulation in the US has not been effective). With current tight fiscal constraints on public spending it will be difficult to adequately resource regulatory activity unless this is financed in some way by the developing shale gas industry itself. This may be in the form of licence/permit fees but could also include co-operation with the training of regulatory officers, effective transfer of data, financing of research and effective public engagement.

The current pressure to simplify or deregulate many industrial/agricultural activities in order to lower costs to business and stimulate development is in stark contrast to the public concern and calls for strict regulation of unconventional gas developments. From the reports noted above it is clear that policy makers in Europe are relying on regulators to make full use of their powers to provide protection to the public and the environment (Refs 1-4). Choosing an appropriate regulatory regime can therefore be a balancing act, taking into account: environmental/health risk; nature and extent of development (including intended activity and risk of design/construction failure); public concern and the need for public engagement; availability of effective legislative tools and demands on regulatory resources.

None of the existing EU Directives (see Annex) and most domestic legislation relevant to water protection specifically mention shale gas or HF at present, but given the extent of development to date this is perhaps unsurprising. Table 1 lists the types of regulatory controls that may be available, together with some of the underlying European legislation. In principle, the potential range of controls is wide and in some cases more than one form of control may exist. For example, there are technical and financial competence tests in both the Hydrocarbons and Mining Waste Directives and potentially overlapping mechanisms to authorise direct discharges to groundwater under Article 11(3)(j) of the Water FD and the Mining Waste Directive.

In many cases the protection provided by health and safety legislation will also cover a large element of the risk to the environment - the one area where this is possibly less certainty is in the case of subsurface contamination of groundwater, but this is in principle covered by the controls needed to implement the prevent or limit requirements of the GWDD – noted in Box 1 - which apply to both liquids and gas.

Table 1: Risks to water associated with shale gas development and illustrative controls
(Underlying Directives in italics where relevant – see Annex for abbreviations)

Risk area	**Example regulatory and other controls**
1. Operator competence and financial resources	Petroleum exploration or development licence, operating permit *(Hydrocarbons, MWD)*
2. General impact on the environment	Planning controls, Environmental Impact Assessments, Operating permits *(EIA, SEA, Habitats, ELD, COMAH)*
3. Location with respect to sensitive receptors e.g. water supplies	As 2 + Groundwater Protection policies/position statements *(+ Water FD, GWDD)*
4. Disturbance to groundwater supplies from drilling	As 2 + drilling permits, discretionary powers to prevent pollution and baseline monitoring
5. Spills & leaks of stored liquids and gas at the surface	Site operating permit, Health & safety controls, enforcement powers to prevent water pollution *(Water FD, GWDD)*
6. Leakage of drilling muds, fracturing fluids and gas into groundwater; cross connection of aquifers and associated leakage or contamination issues	Prevent or limit controls, drilling consents, Health & safety controls. *(GWDD, Water FD)*
7. Loss of integrity of well casing with release of pollutants to groundwater	Health & safety controls, prevent or limit controls, well construction (ISO/API) standards *(GWDD, H&S)*
8. Damage resulting from induced seismicity	Petroleum exploration and development licences, planning controls, civil legislation
9. Excessive demand on water resources	Abstraction controls (direct or via water undertakings) *(Water FD)*
10. Wastewater management, treatment and disposal	H&S controls, Planning controls, permits for treatment facilities *(Water FD, H&S, MWD, Waste FD)*
11. Use of chemicals in fracking	H&S and product registration controls, indirect control via subsequent risks of groundwater contamination and via disposal routes. *(REACH, Water FD, GWDD, MWD)*

In practice, the most appropriate controls for unconventional gas will depend on the transposition mechanisms in each Member State and how in practice these are applied by regulatory bodies.

Regulation is often equated with the issue of consents/permits/licences (as reflected in the calls for HF to be subject to permits). In practice it can take other forms, such as discretionary powers to serve notices, statutory codes of practice and in the last resort the power to prosecute and/or serve fines. These instruments may be supported by regulatory policies/position statements.

As an illustration, in England & Wales under the Environmental Permitting Regulations (EPR) there is now a single permitting/control framework that implements a wide range of Directives, which potentially makes compliance simpler for both the regulator and the operator and makes it easier to adapt a permit to changing circumstances. Initially the Environment Agency (EA) determined that an EPR permit was not required for the drilling and HF of the initial exploration boreholes in the Fylde area of Lancashire on the basis that the risks to the local environment were low and that there was no groundwater in the regulatory sense in the target formation. However, this approach to permitting was underpinned by the fact that any accidental release of pollutants to a groundwater resource would be an offence, as in principle it required a permit. In addition notices could be served if necessary to require remedial measures. An EPR permit has now been required for the management of NORMS (naturally occurring radioactive materials) arising in the flowback fluid as monitoring of this fluid revealed concentrations in excess of the EPR thresholds. The EA's regulatory approach is supported by its Groundwater Protection policies (now renamed position statements) which seek to restrict shale gas drilling in groundwater source protection zones around potable water supplies.

CONCLUSION

It would be an unnecessary diversion to undertake widespread new legislative changes at an EU level in anticipation of shale gas developments, and in the absence of practical experience of the application of existing legislative instruments. The focus should be on how Member States could or are implementing these existing controls and on monitoring their effectiveness. Further guidance may be needed on the most appropriate suite of controls, informed by experience of early developments. Integration of controls and data obtained under the petroleum licensing, health and safety and environmental protection regimes is needed to make regulation both effective and efficient. Most importantly, policy makers need to ensure that regulators have the necessary technical and physical resources to provide the oversight necessary to ensure environmental protection, meet public concerns and challenge the unconventional gas industry to improve its performance and minimise its environmental footprint.

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2. House of Commons, Energy and Climate Change Committee, May 2011. Shale Gas (2 volumes, Proceedings and Additional Written Evidence). HC 795. The Stationery Office Limited, London.
3. House of Commons, Energy and Climate Change Committee, July 2011. Shale Gas – Government response to the Committee's Report. HC1449. The Stationery Office Limited, London.
4. Philippe & Partners, Nov 2011 (for the European Commission – Energy Directorate-General). Final Report on Unconventional Gas in Europe.
5. Tyndall Centre, May 2011 (for the Co-operative). Shale Gas: an updated assessment of environmental and climate change impacts.

ANNEX

Partial list of European Community Directives relevant to shale gas exploitation and environmental impact on water

- 94/22/EC – Hydrocarbons Directive
- 92/43/EEC – Habitats Directive
- 2006/21/EC – Mining Waste Directive (MWD)
- 2003/4/EC – Public Access to environmental information
- 2000/60/EC – Water Framework (Water FD)
- 2008/98/EC – Waste Framework (Waste FD)
- 2006/118/EC – Groundwater Daughter Directive (GWDD) (preceded by 80/68/EEC - Groundwater Directive)
- 2004/35/EC – Environmental Liability (ELD)
- 85/337/EEC – Environmental Impact Assessment (EIA)
- 2001/42/EC - Strategic Environmental Assessment (SEA)
- 91/271/EEC – Urban Wastewater Treatment (UWWT)
- 96/82/EEC – Control of Major Accidents and hazards (COMAH) as amended by 2003/105/EC (Seveso II Directive)
- 2006/1907/EC – REACH (Registration, evaluation, authorisation and restriction of chemicals)

+ various Noise and Health and Safety (H&S) Directives.

SESSION I

MANAGING THE ENVIRONMENTAL RISK ASSOCIATED WITH SHALE GAS HYDRAULIC FRACTURING USING A DFN APPROACH

Dr Mark Cottrell[1**], Noel Kelly[1], and Dr William Dershowitz[2]
1 – Golder Associates UK & Ireland,
2 – Golder Associates Inc, Seattle, US,
** - Corresponding Author.

ABSTRACT

The recent rapid development of shale gas extraction has been met with significant public and political resistance over the potential effects which the hydraulic fracturing process may have on the subsurface. During the hydraulic stimulation process, hydraulic fracture paths have traditionally been difficult to predict due to their complex interaction with the natural fracturing of surrounding formations. It is this uncertainty which has led to concern that hydraulic fracturing may create preferential pathways for hydraulic fluid migration to conductive faults and aquifers, and in turn generate unforeseen seismic activity.

This paper will describe an approach for mitigating the risks posed to subsurface entities through inadequate understanding of the natural fracture systems of shale reservoirs and hydraulic fracture. Discrete Fracture Network (DFN) analysis of naturally fractured reservoirs provides a state-of-the-art tool for accurately predicting hydraulic fracture patterns and thus potential interaction with these geohazards. The potential for DFN analysis in managing and minimising the risks associated with hydraulic fracture propagation will be discussed. This discussion will identify further benefits that such analysis could provide in managing the environmental risk associated with shale gas extraction.

INTRODUCTION

The emergence of shale gas extraction as a viable energy source in Europe and the Americas has offered the possibility of energy security to areas which have traditionally been heavily reliant on oil and gas imports from the both Russia and the Middle East. Whilst shale gas extraction has been carried out for a number of years in North America, the industry is currently in an early stage of development here in Europe.

Shale gas extraction has been shown to be technically and economically feasible through the application of hydraulic fracturing, to enhance plays which do not have the natural permeability required to allow gas flow commercially to the wellbore. Despite the potential social and economic benefits of shale gas development, its introduction in certain regions, especially mid to Western Europe has been met with significant public and political resistance (see Kulkarni, 2011). This resistance is due in part to concerns over the potential environmental impact of the hydraulic fracturing process, and in particular the perceived threat it poses to groundwater resources and human health (see European Parliament, 2011).

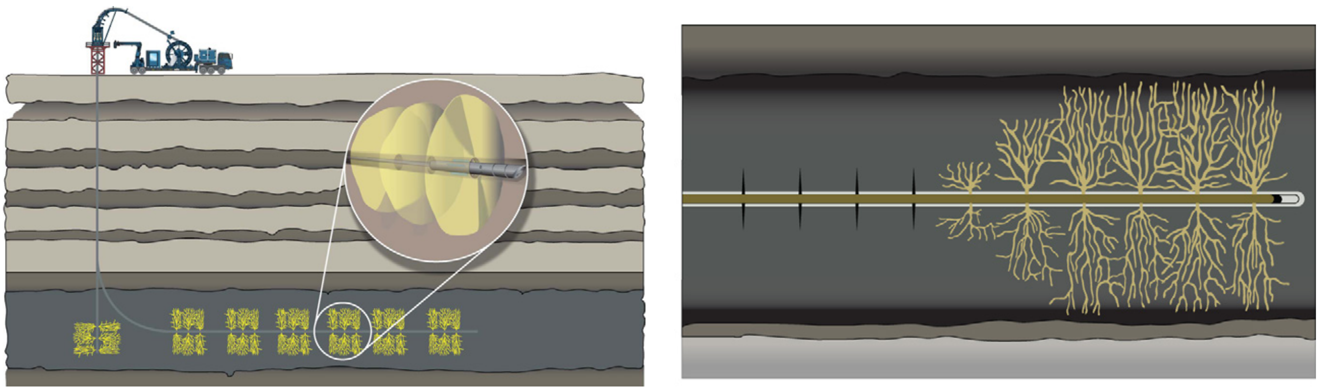
An inherent difficulty encountered with the hydraulic fracturing process is predicting the extent and pattern by which hydraulic induced fracturing will occur and interaction with natural fractures during injection (see Rogers et al, 2010). Therefore, predicting the likelihood and interaction of hydraulically injected liquids connecting to potential geohazards such as aquifers or conductive faults poses a significant challenge in managing the environmental risk associated with shale gas development. State-of-the-art numerical analysis techniques have been developed and proven which can accurately predict hydraulic fracture propagation and interaction with natural fractures and major features (see Dershowitz et al, 2011). Using such techniques can help better understand and manage this risk, thereby helping to alleviate much of the public and political concerns which are currently hindering the expansion of shale gas extraction worldwide.

ENVIRONMENTAL RISKS ASSOCIATED WITH HYDRAULIC STIMULATION

Accompanying the widespread application of hydraulic fracturing technology, the environmental risk posed by shale gas extraction has been a significant topic of debate worldwide. Claims of groundwater pollution and induced seismic activity have been met with suggestions that problems in affected areas have not been directly caused by the hydraulic fracturing process (see Helman, 2012). While this debate remains, every precaution must be made to ensure that any possible environmental risk associated with shale gas extraction is mitigated.

HYDRAULIC STIMULATION IN PRACTICE

Hydraulic fracturing is a practice which involves the pumping of a large quantity of fracture fluid and an inert proppant to a target depth. At this depth, the fluid is pressurised to levels exceeding the minimum in situ stress level to stimulate the previously unproductive natural fracture network existing in the shale focus unit.



(a) (b)

Figure 1 - Simplified Hydraulic Fracturing Process for a Horizontal Well (Lee et al., 2011) *not to scale

The potential harmful effects of hydraulic fracture fluid and its constituents have been well documented (European Parliament, 2011). While efforts are being made to develop environmentally friendly fracture fluids (Lowry et al., 2011), the use of a traditional fracturing fluid design is vital for the economic extraction of shale gas worldwide.

A successful hydraulic fracture operation is one in which the stimulated fracture volume is confined to the shale pay of interest. Hydraulic fracture propagation beyond this zone during stimulation is detrimental both economically and technically due to the possibility of unwanted fluid production (Zoback et al., 2010) and elevated fracture fluid requirements. From an environmental perspective, hydraulic stimulation beyond the pay of interest could, depending on the extent and direction of the induced fracture, extend to an aquifer or a permeable fault or system of faults.

GEOHAZARDS AND RISK POSED BY HYDRAULIC FRACTURE STIMULATION

Geohazards can be defined as a geological state which has the potential to develop into a situation leading to damage or uncontrolled risk (see International Centre for Geohazards, 2010). Two distinct potential geohazards exist which are unique to hydraulic stimulation treatment. These are:

- Direct hydraulic fracture propagation to aquifer depth, allowing fracture fluid migration and possibly causing groundwater resources to be contaminated with fracture fluid constituents; and
- Hydraulic fracture propagation to faults capable of transmitting fluid, allowing fluid migration to aquifer or surface elevation or possibly inducing seismic activity detectable at surface elevation.

Although fracture propagation characteristics in response to hydraulic stimulation vary significantly depending on geological setting (as will be discussed), it can be construed that risk of fracture propagation to aquifer elevation or to fault location is directly related to proximity (see Zoback, 2010). The data provided in Table 1 give a summary of the variation in thickness and depth of the major shale pays of the USA. This provides an indication of the distance which hydraulic fracture propagation would need to reach to come in contact with groundwater resources at the respective locations.

Table 1 - Depths of Shale and Overlying Aquifers in the US (adapted from Arthur et al. 2009)

Gas Shale Basin	**Barnett**	**Haynesville**	**Marcellus**	**Antrim**	**New Albany**
Depth (ft)	6,500-8,500	10,500-13,500	4,000-8,500	600-2,200	500-2,000
Net Thickness (ft)	100-600	200-300	50-200	70-120	50-100
Depth to Base of Treatable Water (ft)	~1,200	~400	~850	~300	~400
Rock Column between Pay and Base of Treatable Water	5,300-7,300	10,100-13,100	2,125-7,650	300-1,900	100-1,600

It is evident from Table 1, that for the majority of shale plays the depth between aquifer and treatment location is sufficient to imply that hydraulic fracturing to aquifer elevation is extremely unlikely (see Zoback 2010). In contrast, at the Antrim Basin (300 ft) and New Albany Basin (100 ft), depths from shale to aquifer are small thus presenting a much greater environmental risk during hydraulic stimulation. More recently, an investigation by Baisch (2011) into earthquake activity following a recent hydraulic fracture treatment in Blackpool, UK concluded that faulting within 1000 ft of the location of hydraulic stimulation treatment may be at risk of contact by propagating fractures because of the proximity of major faulting, and indirectly a highly variable in situ stress field.

It is at such locations where an understanding of the extent and direction of hydraulic stimulation are extremely important. In such cases numerical analysis can serve as an essential tool in managing environmental risk posed by shale gas extraction.

THE DISCRETE FRACTURE NETWORK (DFN) APPROACH

Introduced in the 1970's, Discrete Fracture Network (DFN) modelling has offered a credible alternate approach to traditional Representative Elementary Volume (REV) method of simulating fluid flow through a geological medium. The DFN approach is a method which explicitly incorporates the properties of a discrete feature in analyzing flow and material transport (see Dershowitz et al., 2011 and Cottrell 2012). This approach is founded on the principles of fluid flow through fractured media. A typical DFN model for a fractured rock formation is given in Figure 2.

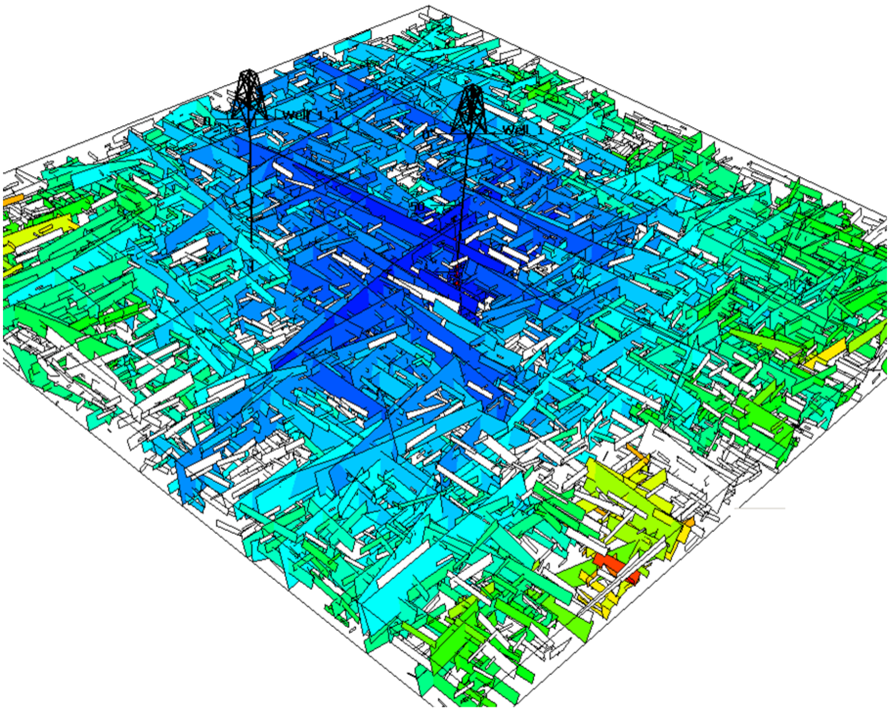


Figure 2 - Discrete Fracture Network Model (Dershowitz and Cottrell, 2011) of a Fractured Shale Formation

It is widely accepted and has been proven that natural fracturing heavily influences hydraulic stimulation characteristics (see Olson 2010). It follows that an understanding of natural fracturing surrounding the treatment zone and in the interval between this zone and a potential geohazard is extremely important to allow assessment of hydraulic fracture characteristics. The Discrete Fracture Network (DFN) approach (see Dershowitz et al, 1996) is a proven method in characterising the three dimensional spatial pattern of the fracturing existing within a naturally fractured reservoir.

The DFN approach simulates the pattern of natural fractures for a given area of interest based on standard geometrical, hydrological and geomechanical properties of natural fractures. The procedure for developing a characterised DFN analysis is summarised in Figure 3.

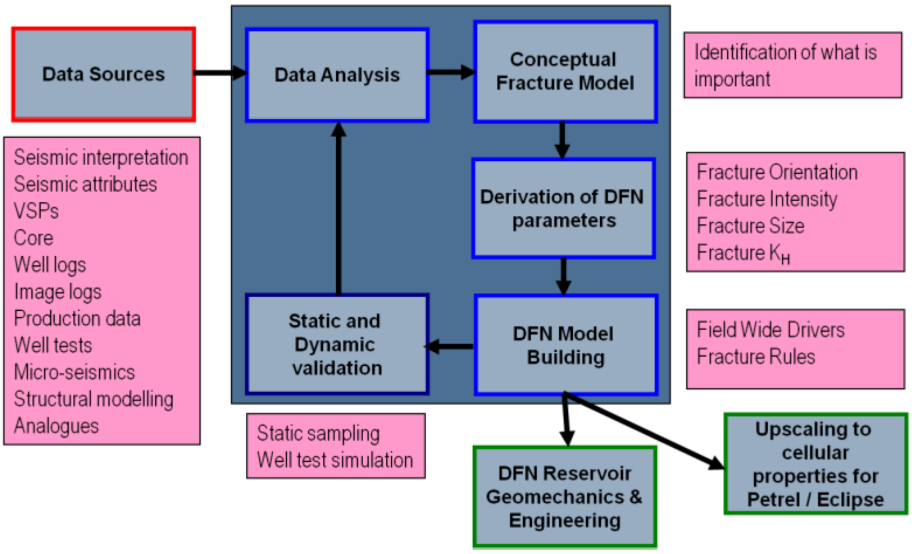


Figure 3 - Standard Iterative DFN Analysis Workflow

The workflow in Figure 3 provides an iterative means to characterisation, analysis and validation of all types of fractured reservoirs. The workflow is populated by data typically gathered during a development cycle, and is processed to enable construction of a conceptual fracture model covering fracture orientation, intensity, and size as well as hydrological properties. The detailed workflow enables both Natural Fracture and Hydraulic Fracture analyses to be accomplished.

NATURAL FRACTURE ANALYSIS

A rigorous DFN analysis capable of accurately incorporating hydraulic fracture analysis is reliant on a basis founded on good quality data which describes the geological conditions in the strata of interest. Natural fractures are generated stochastically from parameters found from derived from the interrogation of available and site specific information. Table 2 details the key parameters required for DFN modelling purposes.

Table 2 - Required Parameters for DFN modelling and Identified Data Sources (Rogers et al, 2010)

DFN Parameter	Calibration Data Source
Fracture Data	
Fracture Orientation	Fracture image log data (FMI / XRMI)
Fracture Size	Power law analysis or based on analogue or outcrop data if available
Fracture Intensity	Fracture image log data (FMI / XRMI)
Fracture Transmissivity	Well test data or can be correlated to fracture size
Fracture Aperture	Fracture image log data or calculated from transmissivity data
Geomechanical Data	
In Situ Stress Data	Integration of density logs, interpretation of downhole geophysical data and borehole breakout data
Stiffness Data	Derivation from downhole geophysical data
Strength Data	Laboratory and in situ testing data

Following stochastic generation of natural fracturing, potential geohazards such as conductive faulting can be incorporated to the model in a deterministic manner. Such features can be inferred from surface outcrop data or more accurately through seismic mapping processes.

In terms of validating the construction process and the finalised Natural Fracture Analysis, this is achieved using a two-step process, a) static validation and b) dynamic validation. In the initial validation step, static parameters including fracture orientation, intensity, and size are matched against observed data (typically Formation Micro Imager FMI data). Following the static validation, a process of validating the dynamic response of the DFN system is performed. Dynamic validation considers the simulation of well production data and aims to reproduce the salient features of the pressure-time and the pressure derivative curves.

HYDRAULIC FRACTURE ANALYSIS

Following the successful calibration and validation of a comprehensive Natural Fracture Analysis and generation of a Discrete Fracture Network model, the developed workflow permits hydraulic fracture analysis to be carried out and helps provide a direct estimate the extent and pattern of hydraulically induced fractures and reactivated natural fractures for a given stimulation design. In addition to the natural fracture system, the hydraulic fracture propagation and fracture stimulation is controlled by the following key properties:

- The well completion design (well orientation, perforation geometry);
- The mechanical properties of the rock matrix;

- The in situ stress conditions (magnitude and orientation); and
- Hydraulic fracture treatment design (injection rate and duration).

In simple terms, hydraulic fracture propagation generally occurs where the minimum effective stress exceeds the tensile strength of the host rock material. This is accompanied by reactivation of the natural fracture network as fluid moves into the existing fracture.

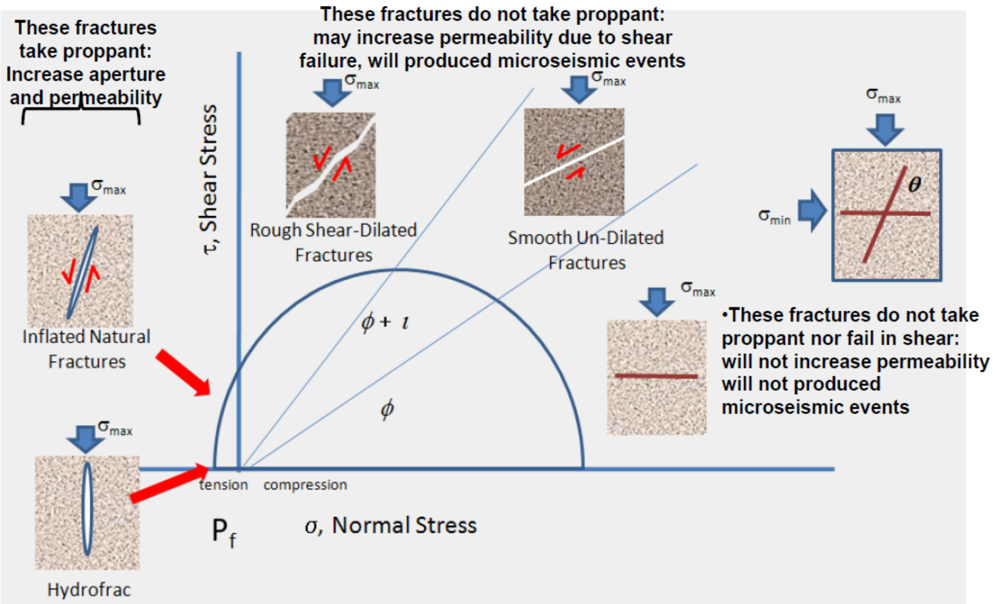


Figure 4 - Failure Modes in Response to Hydraulic Treatment

The DFN hydraulic fracture simulation workflow considers this criterion in predicting fracture propagation. In addition, a fracture shear strength criterion, typically the Mohr-Coulomb or Barton-Bandis frictional criteria is specified to incorporate the role of reactivated natural fractures during hydraulic stimulation. The failure modes occurring during hydraulic stimulation of a naturally fractured reservoir responding to a change in effective stress state is given in Figure 4.

As hydraulic fracturing occurs predominantly in tension and relies on the local fracture normal stress condition, the minimum principal stress orientation and pore pressure state within the target formation heavily influences the direction of fracture propagation (see Dershowitz et al, 2010). The accurate representation of the in situ stress conditions of the focus reservoir is integral to the DFN modelling process.

Once hydraulic fracture orientation is determined, it is important to determine the vertical extent and horizontal extent of fracture propagation. Vertical hydraulic fracture extent is controlled by overlying and underlying stratigraphy in terms of stiffness based quenching. The location of potential quenching material layers are normally identified during the natural fracture analysis stage. Identification of strata which present low enough stiffness to act as a 'quenching' layer is important for providing sufficient vertical control hydraulic fracture stimulation (see Dershowitz et al, 2011). The quenching layer can comprise of a soft material or can be highly fractured, resulting in reduced elasticity parameters which arrest new fracture propagation.

The remaining unknown in simulating hydraulic fracture propagation is predicting horizontal extent. This is based on a mass balance principle where the volume of the induced fracturing must equal the injected volume less fluid leak off to the natural fracture network and to the rock matrix (see Dershowitz et al, 2010). Fluid leak off (or efficiency) is a measure of the proportion of injected fracture fluid which enters the hydraulic fracture as opposed to 'leaking-off' in to the natural fracture system.

VALIDATION AND CALIBRATION OF DFN BASED HYDRAULIC FRACTURE ANALYSIS

Microseismic monitoring is a technique commonly used by hydraulic fracture contractors to monitor the extent of hydraulic stimulation in the field (see Maxwell et al, 2010). It is performed by placing recording geophones in monitoring wells in close proximity to the treatment well and can detect microseismic waves caused by shear reactivation and extension of natural fractures.

By simulating pore-pressure induced shear failure, the method of hydraulic fracture analysis incorporated to the DFN model can output a cloud of points which theoretically should mimic microseismic data. Comparison of microseismic points simulated by the model to field data therefore allows calibration of the model parameters and validation of the hydraulic fracture analysis. An example validation is presented in Figure 5.

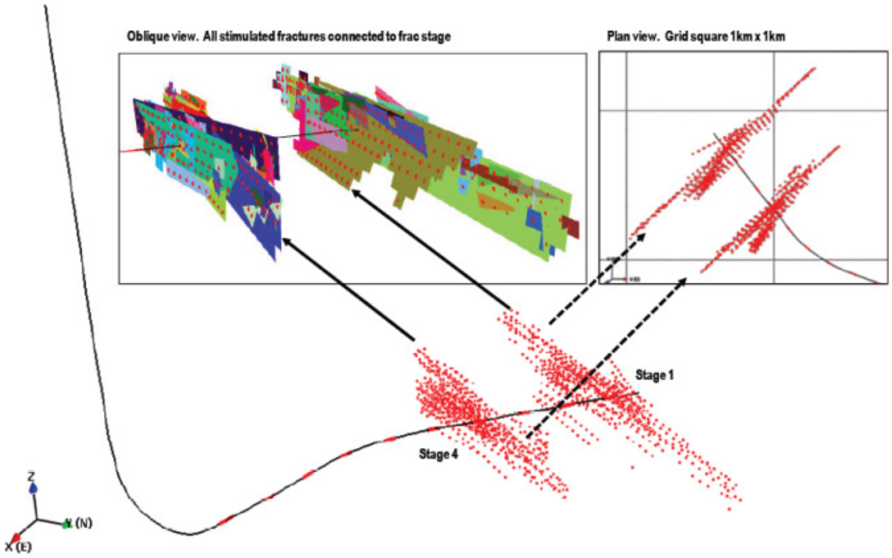
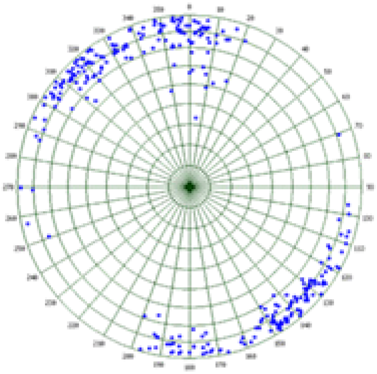


Figure 5 - Validation of Hydraulic Fracture Analysis Through Comparison with Microseismic Data

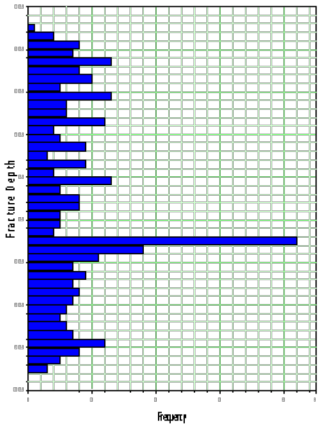
EXAMPLE: HYDRAULIC FRACTURE ANALYSIS IN MANAGING ENVIRONMENTAL RISK

Once it can be established that the DFN model is representative of actual conditions, likely hydraulic fracture propagation characteristics can be investigated through parametric hydraulic fracture analyses. If reservoir properties can be constrained through the validation process, this parametric analysis can be carried out by varying fluid injection properties.

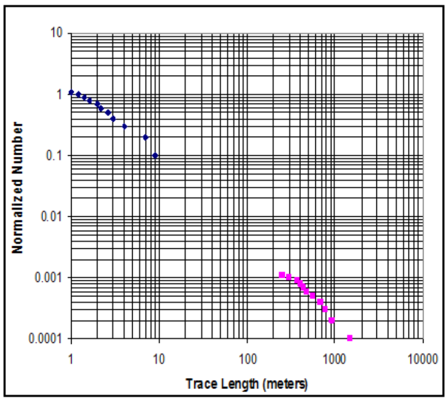
A constructed and validated DFN model is presented in Figure 6. In Figure 6(a) to (c) the geological data required to describe the natural fracture network in terms of fracture orientation, intensity, and size is given. In addition to the identified natural fracture drivers, Figure 6(d) provides inclusion of some deterministic, and seismically observed, major faulting features that provide a potential geohazard. Also in Figure 6(d) is a proposed development well including a horizontal lateral and multiple hydraulic fracture perforation sets. In Figure 6(e) all of the natural fracture analysis data and large scale features, and development well geometry are brought together to form a single sector scale DFN model which can be tested for different hydraulic fracture treatment scenarios.



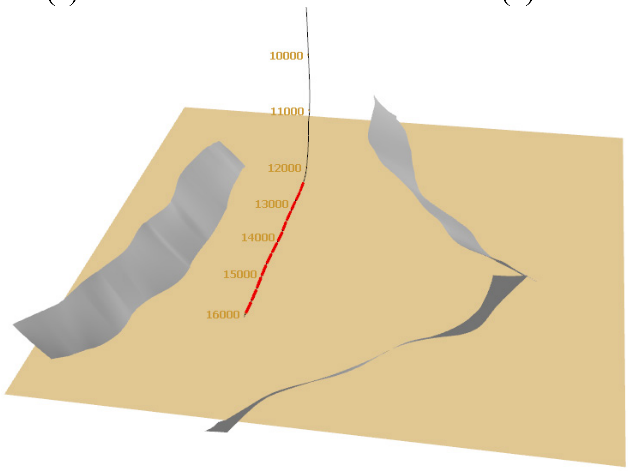
(a) Fracture Orientation Data



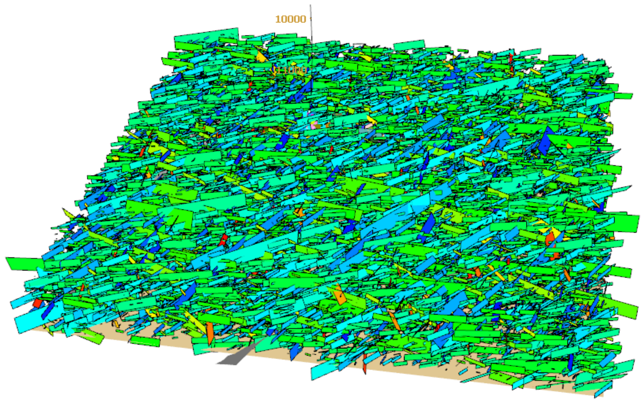
(b) Fracture Intensity Data



(c) Fracture Size Data



(d) Inserted Major Faults



(e) Natural Fracturing of Target Stratum

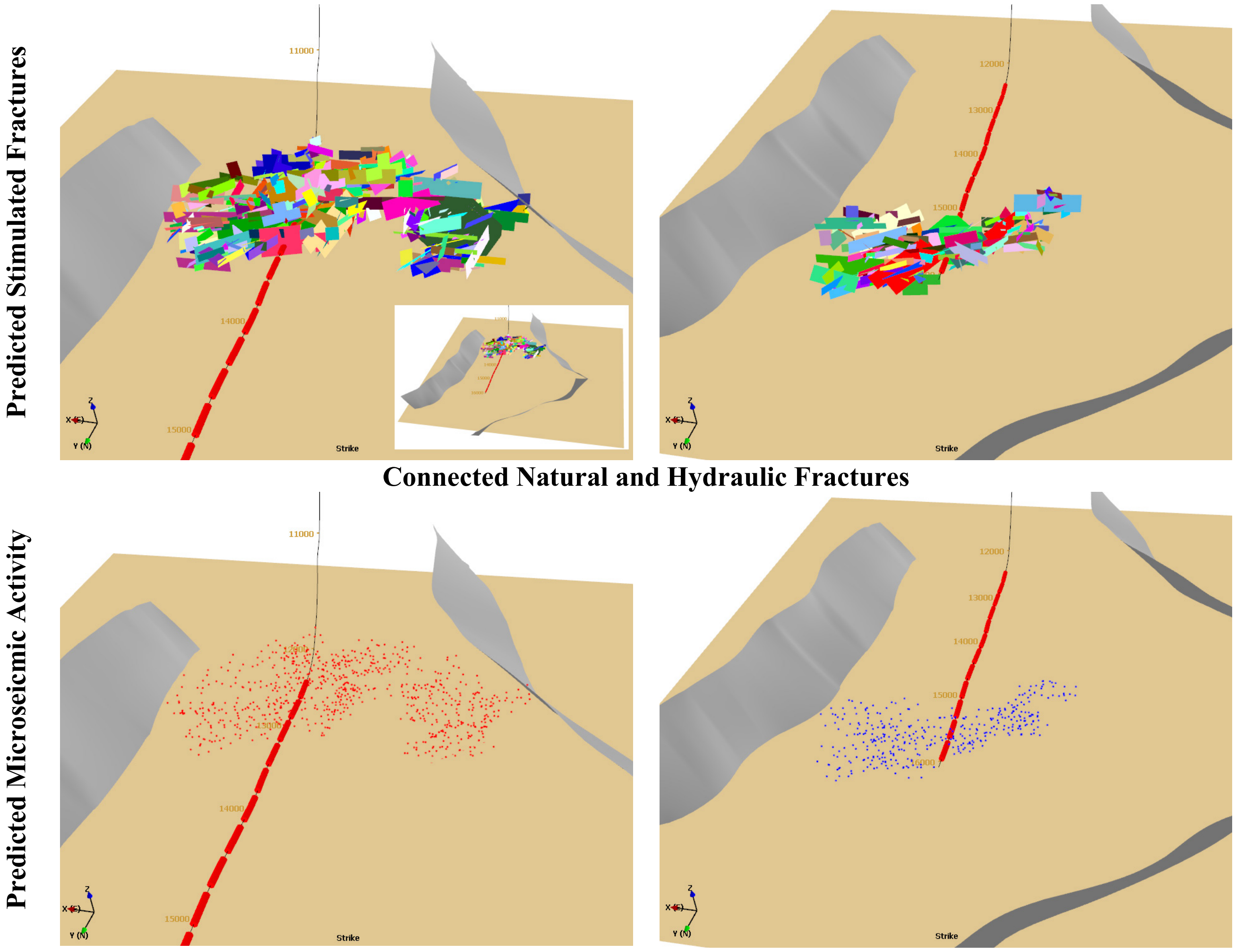
Figure 6 - Natural Fracturing and Inserted Faults for Illustrative DFN Model (all measurement in feet)

Using the constructed DFN model, two hydraulic fracture treatments have been carried out, the results of which are given in Figure 7. These analyses illustrate the subsurface responses which result from (a) a poorly designed (unsafe) hydraulic fracture treatment and (b) a well designed (safe) hydraulic fracture treatment.

In Figure 7(a) plots relating to the simulated hydraulic fracture response for a poorly controlled treatment are given. Poorly controlled hydraulic fracture stimulation can be a result of using too high fluid injection properties, or not having a good understanding of the in situ stress field, or stimulating fractures that are spatially nearby or connected to major faulting. In Figure 7(a), the case where injection has created a significant volume of fractures to be hydraulically stimulated is given. It is evident for this configuration; the combination of the natural fracture system and in situ properties, together with excessive hydraulic fracture injection has resulted in the connected and stimulated natural and hydraulic fractures explicitly linked to the (right hand side) major fault.

In Figure 7(b), an alternative injection location has been adopted and the injection properties have been modified to produce a more controlled stimulated volume of fractures. For this case, the stimulated fractures do not interconnect with the fault system. In addition, it is also seen that the stimulation results in stimulated fractures that are more vertically constrained or quenched.

For both of these configurations is Figure 7(a) and (b), microseismic activity associated with the simulated injection process has been used for verifying the treatment effects. Microseismicity monitoring and comparison provides a reliable means of identifying the fracture paths activated by the treatment process.



Predicted Microseismic Activity

(a) Poorly Controlled Hydraulic Stimulation (b) Well Controlled Hydraulic Stimulation

Figure 7 - Contrasting Hydraulic Stimulation Treatments (all measurements in feet), Showing (a) Poorly Controlled Hydraulic Fracture, and (b) Well Controlled Hydraulic Fracture, Near a Major Faulting System.

It is demonstrated that DFN hydraulic fracture analysis can provide early indications of the level of environmental risk posed by a specific hydraulic stimulation treatment. Such indications can even be assessed prior treatment using typical data gather from vertical exploration wells. Use of this analysis technique can thus help manage the associated environmental risk in two distinct ways:

- A relationship between fluid injection volume and extent of fracture propagation can be established. This allows the hydraulic fracturing contractor to optimise and design a treatment specification which help minimize risk of hydraulic fracture stimulation to a specified geohazard;
- It can help understand the natural compartmentalisation exhibited by fractured reservoirs, and can help identify which structurally controlled compartments are explicitly isolated from the surrounding rock formations; and
- Using predictions provided by numerical analysis, the hydraulic fracturing contractor can establish an optimum volume of fracturing fluid required to maximize stimulated volume within the target pay. This ensures that water is not used unnecessarily and is beneficial both economically and environmentally.

DISCUSSION

Despite the enormous potential benefits of shale gas extraction, if it cannot be shown that environmental risk of the practice can be mitigated, public resistance to the technology may severely hinder, if not halt the future expansion of the industry. As the use of the fracture fluid used in the technique is currently unavoidable, it is imperative that it does not come in contact, either through direct or indirect means, with water intended for human consumption.

Through the implementation of a Discrete Fracture Network (DFN) numerical analysis approach, it has been shown that the environmental risk can be managed by predicting the behaviour of hydraulically propagated fractures in response to fluid injection. The implementation of this technique can help exploration companies provide assurances to all stakeholders that environmental risk has been managed in a comprehensive manner.

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HYDRAULIC FRACTURING FOR SHALE GAS IN IRELAND – THE POTENTIAL

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ABSTRACT

The recovery of tightly bound gas from shale has been practiced around the world for many years, with thousands of wells in production in the U.S.A. Recently option or exploration licences have been issued across the island of Ireland to a number of companies to explore for shale gas. These cover south Clare, the Lough Allen Basin in the north-west and into south-west Fermanagh. A number of conventional onshore exploration licences have also been issued elsewhere in Northern Ireland. The potential for shale gas production is significant, but unproven in Ireland. Advances in drilling methodology, microseismics and especially well completion, now make shale gas plays prospective. There have been reported problems with some shale gas wells in North America, these could have been avoided by good practice and regulation.

INTRODUCTION

Ireland has enormous energy requirements. Well over 90% of our needs are supplied by highly vulnerable imports of coal, oil, gas (and nuclear electricity). Our home produced supplies of gas, peat and renewables would be insufficient if we had to rely on them alone.

We have depended on foreign companies to look for local energy supplies and have been fortunate that they have discovered the Kinsale and Corrib gas fields that have and will keep us staggering along. There is also hope that some further offshore fields will help ease the burden. Most of onshore Ireland is too mature for oil and gas to be found, only to the north is there potential for discovery. Recently the prospect of gas being discovered in the north-west Carboniferous Basin has grown and we have companies hoping to develop indigenous gas supplies.

This will involve the use of hydraulic fracturing, an old technology where water under pressure is forced into the layer of rock holding the gas, to cause it to crack. This allows any contained gas to escape along the cracks and up the borehole. There are constraints and concerns about the methodology that should be addressed by good practice and regulation.

ONSHORE HYDROCARBON POTENTIAL

When organic matter, mostly algal material, falls to the bottom of the sea, it is incorporated into the sediments forming there. As pressure and temperature increase, hydrocarbons are formed from these organic compounds. Depending on the temperature, the maturity of the hydrocarbons produces first oil and wet gas and then finally dry gas. These compounds migrate into reservoirs where they are extracted by conventional methods. The main source of these hydrocarbons is organic rich shales. After the first waves of oil and gas have migrated, there remains a residual shale gas. It is the recovery of this significant resource that now occupies our attentions.

A review of the maturation of onshore rocks published by Jones (1992) showed that over much of the country palæotemperatures had been so high that the rocks were too mature to contain recoverable hydrocarbons (Fig. 1). Conodont Colour Alteration Indices (CAI) of 1.5-3 delineate rocks that are in the Oil & Gas Window, CAIs of 3.5-4.5 show the Dry Gas Window. Only in the northern half of the country is there potential for hydrocarbon discovery. The presence of late stage dry gas was confirmed by wild-cat Ambassador wells of the sixties and seventies, with gas shows in south Clare, Cavan and Fermanagh. Subsequent exploration has confirmed this (Fig. 2).

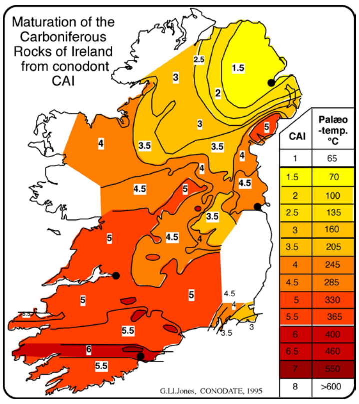

Figure 1 - Irish CAI map (Jones 1992)

Onshore Irish wells that have produced gas

Doonbeg #1	Clare	1962		small gas show	Ambassador/Marathon
Dowra #1	Cavan	1963		gas show	Ambassador/Marathon
McNean # 1	Leitrim	1963		dry	Ambassador/Marathon
Dowra #1 (re-entry)	Cavan	1981	fracked	flared	Aran Energy/Marinex
	Cavan	1981		gas shows	Aran Energy/Marinex
McNean # 2	Leitrim	1981		gas shows	Aran Energy/Marinex
Drumkeeran #1	Fermanagh	1981		gas shows	Aran Energy/Marinex
Slisgarrow #1	Fermanagh	1981		gas shows	Aran Energy/Marinex
Kilcoo Cross #1	Fermanagh	1981		dry	Aran Energy/Marinex
Slisgarrow #2	Fermanagh	2002	fracked	gas shows	Evergreen
Knockbeg #1	Fermanagh	2002	fracked	gas shows	Evergreen
Mullanawinna #1	Fermanagh	2002	fracked	gas shows	Evergreen
Dowra #2	Cavan	2002	fracked	gas flow	Evergreen
Thur Mountain #1	Leitrim	2002	fracked	gas flow	Evergreen

Figure 2 - Positive gas shows from on-shore drilling

ONSHORE OIL & GAS EXPLORATION

Ambassador Oil Corporation began exploration for hydrocarbons onshore Ireland in the sixties with a series of wildcat wells. Those in the south of the country were dry – Meelin #1 Cork, Ballyraggett #1 Kilkenny, Trim #1 Meath. However two wells recorded gas shows - Doonbeg #1 in Clare had a small gas show but was categorized as a dry hole, whilst Dowra #1 in Cavan flowed a significant amount of gas (Collins 1976).

In 1981 Aran Energy/Marinex drilled a number of wells that had further gas shows, they re-entered Dowra #1, fracked the Dowra Sandstone and produced a decent flow of gas, (increased from 30,000 to 250,000 cfgd) though still not commercial.

From 1996 to 2000, Priority O&G / S Morrice Assoc. operated exploration licences in Northern Ireland (Priority & Morrice 2000). In 2001 Evergreen, having acquired the interests of Priority O&G and S.Morrice Associates, drilled a number of wells and fracked them. Four produced gas shows, and Dowra #2 was flared.

In the last year Enegi Oil was awarded Onshore Petroleum Licensing Option ON11/1 covering 495 sq. kilometres in south Clare (Fig. 3).

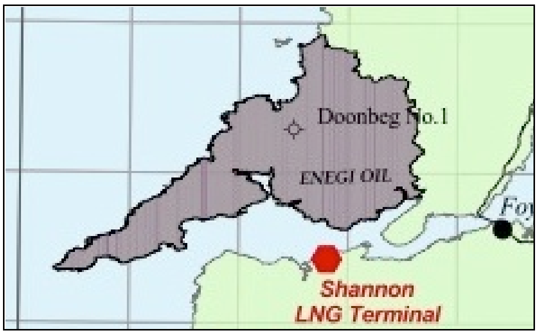

Figure 3 - ON11/1 Enegi Oil Option (PAD 2011)

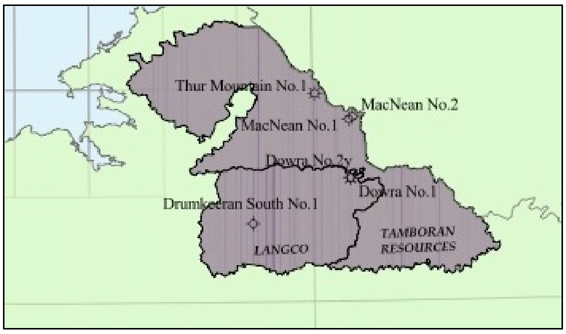

Figure 4 - Langco & Tamboran Options (PAD 2011)

Exploration Option ON11/2 was awarded to Langco over 467 km^2 in Cavan / Roscommon in the Lough Allen Basin in the north-west and Exploration Option ON11/3 to Tamboran over 986 km^2 in Sligo / Leitrim / Cavan / Donegal (Fig. 4), though they have relinquished much of their ground in Sligo. These Options do not allow deep drilling or fracking until they are converted into Exploration licences, at the earliest in 2013. In Northern Ireland Tamboran was awarded an Exploration Licence PL2/10 of ~800 km^2 in south-west Co. Fermanagh (Northern Ireland Assembly 2012), contiguous to its southern option (Fig. 5).

Figure 5 - Tamboran Option (RoI) and Exploration Licence (NI)

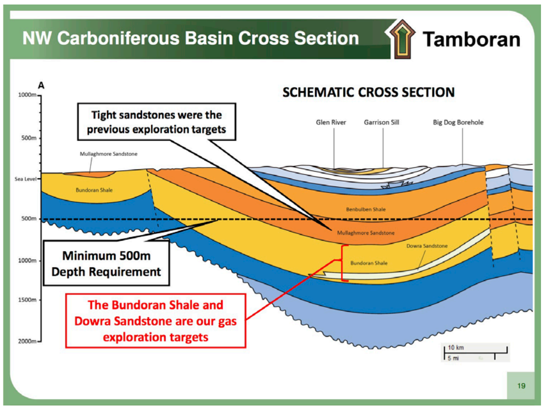

Figure 6 - Exploration targets courtesy Tamboran Resources

In Northern Ireland exploration licences have been issued to three other companies: Infrastrata plc / eCorp O&G UK Ltd., Rathlin Energy Ltd. and P.R. Singleton Ltd. These are concerned with conventional hydrocarbon exploration in the north-east (Northern Ireland Assembly 2012).

Enegi Oil are looking at the Clare Shale Formation in south Clare. Well log analysis indicates the presence of a hot shale area, within the Clare Shale, that appears favourable for shale gas generation. It is an organic-rich potential gas shale interval of approximately 150m in thickness, from a depth of 792m to 1,052m. However Doonbeg #1 was declared a dry well in spite of the gas show recorded. The conodont CAI map (Fig. 1) also places the area beyond the limit of the dry gas window.

In the North-west Carboniferous Basin, Tamboran (on both sides of the border) and Langco are looking at a number of target formations (Fig. 6). These are

- Mullaghmore Sandstones – Aran Energy fracked for a gas yield
- Bundoran Shale – 1,200m – gas in a wet reservoir
- Dowra Sandstone – Aran Energy fracked Methane yield
- Basal Sandstones – a possible deeper play

With a minimum depth of 500m required to produce enough pressure to drive gas to the surface, there is a restriction on the area which may be prospective.

THE PROCESS OF FRACKING

Hydraulic fracturing is of course a routine tool for hydrogeologists to clean out water wells. It is also employed as a different way of breaking rocks, to the usual methods that are used during building foundations, road construction, quarrying and mining. It involves forcing water at high pressure into the rock creating a series of cracks which form a transport route for the gas. It is a standard technique used in the oil & gas industry for decades to improve the permeability of rocks to enhance the flow of hydrocarbons from conventional oil and gas wells world-wide. It was first used at depth in the 1980s by Aran Energy when they re-entered the Dowra Well in Co. Cavan and fracked the tight Mullaghmore Sandstone. It is also used in deep Enhanced Geothermal Systems to create an artificial reservoir at depths of 5-6 km.

A well lined with cement and metal is bored vertically down to the shale rock to a depth of at least 500m and perhaps up to 2 km. The well is then turned to drill horizontally through the target layer for a distance of maybe a kilometer. Water is then pumped under pressure into the rock, which becomes fractured (Fig. 7). The water includes a mixture of chemicals and sand which props the fractures open. While the sand remains in the fractures propping them open, it allows the gas to travel back up the pipe to the surface where it is stored.

The pad from which the wells are drilled may host anywhere between 4 and 12 wells, or even more, as they deviate into different directions (Fig. 8). This minimises the amount of land required for the process, typically 1.3 hectares per pad. The distance to be drilled depends on the cost of the drilling versus the extra area accessed for shale production. Each horizontal well will replace at least 8 vertical wells.

The requirement for repeat fracking has to be assessed by the amount of gas produced and how the volume of production decreases over time. If it is assessed that further hydraulic fracturing will either reopen closed cracks or open further cracks and that this will be economically worthwhile, then a decision may be made to refrack. This could happen between once a year to every 3 years or more.

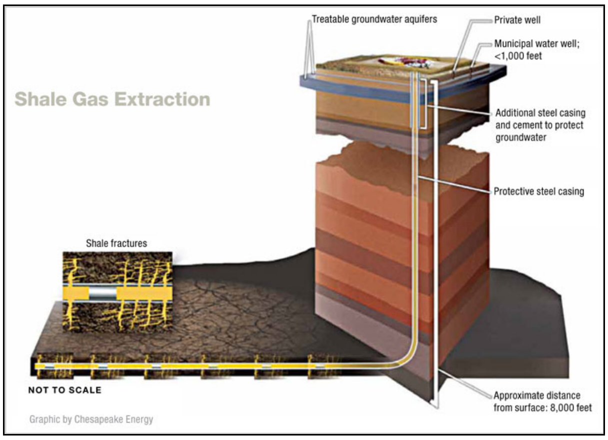

Figure 7 - Fracking set-up (Energy Institute, University Texas 2012)

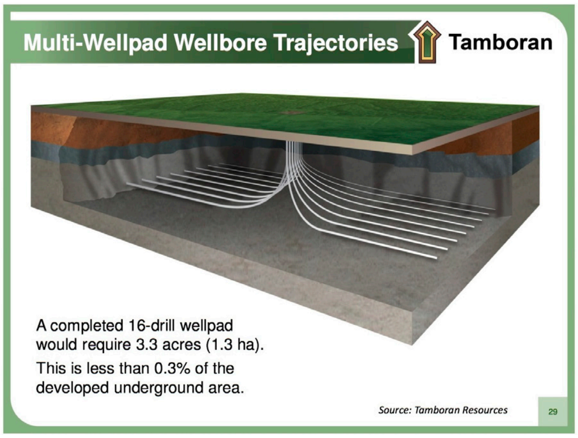

Figure 8 - A 16 well pad array (Moorman & Rollins 2012)

HYDRAULIC FRACTURING IN IRELAND

Hydraulic fracturing has been used for the over ten years in North America to produce gas and sometimes oil from shales where it has been trapped. This would be the first time it would have been used for this purpose in shales in Ireland. In a recent *Dáil* debate, the Minister for Energy outlined the history of fracking in Ireland (Rabbitte 2012):

> *"In the case of conventional gas exploration, such as that carried out in the north west of Ireland over a number of decades, the practice of fracking a very short section or sections of a vertical well has been commonly used internationally by the oil industry for very many decades. In the case of unconventional gas exploration, use of the technology is more recent and generally involves fracking of very long sections of horizontal wells. With unconventional exploration significantly larger volumes of liquids are also used.*

The exploration carried out in the north west of Ireland since the 1960s was "conventional exploration".

In the UK, Imperial College, London has been researching the topic for 25 years and in spite of local indifference finally managed to interest the Government in the potential (Selley 2012). The UK Parliament's Energy and Climate Change Committee (2011a) looked at the impact that fracking could have on water supplies, energy security and greenhouse emissions and gave it a cautious approval (Energy and Climate Change Committee 2011b):

The inquiry found no evidence that the hydraulic fracturing process involved in shale gas extraction – known as 'fracking' - poses a direct risk to underground water aquifers provided the drilling well is constructed properly. The committee concluded that, on balance, a moratorium in the UK is not justified or necessary at present. The MPs, nevertheless, urge the Department of Energy and Climate Change (DECC) to monitor drilling activity extremely closely in its early stages in order to assess its impact on air and water quality.

Also that:

We conclude that the development of the UK shale gas industry will be different from the US — greater population density and stricter environmental legislation in Europe will give a greater incentive to drill fewer, better wells that take advantage of multiwell pad technology and horizontal drilling to minimise the impact on the landscape. (Paragraph 147)

These conclusions have direct effect in Northern Ireland, whilst the reasoning should be very close to that applicable in the Republic of Ireland.

In Poland the initial results from the 4 km+ deep Lebien LE-2H well, with a 1,000 m horizontal section, are promising (Anon 2011).

CHEMICALS

First, although there are nearly 600 chemicals that it is possible to use, there are usually less than a dozen chemicals used in each well. What is generally injected is water and a proppant, usually sand, with only 3 or 4 chemicals. Air and various gases (N_2 and CO_2) can also be used.

No Chemicals? This is an assertion by Moorman & Rollins (2012), who note that it has been used successfully already. However in deep systems, it becomes inefficient to operate at depths of 1-2 km without a friction reducer to make the water flow more easily down the borehole. It is envisaged that gas will be produced at depths between 500 m and 1.5 km in Ireland and that this will reduce the need for viscosity reducing chemicals.

Without antibacterial chemicals, there may be bacterial growth in the system, which produce corrosive and toxic by-products. Without anticorrosion chemicals there may be corrosion of the metal parts of the borehole / production system. Citric acid (lemon juice) is often used to prevent iron precipitation. Companies say that they can carry these penalties and still produce gas economically.

Before fracking is allowed, the department should have firm guidelines in place as to what can and cannot be used. They have until 2013 to put these in place.

ENVIRONMENTAL ISSUES

There have been many issues highlighted by concerned groups and sensationalised in the film “Gaslands”. Scientific investigations are few and far between. Charles Groat, Past Director of the US Geological Survey headed an assessment of Real and Perceived Consequences of Shale Gas Development for the Energy Institute of the University of Texas (Groat & Gimshaw 2012). They found that:

- Researchers found no evidence of aquifer contamination from hydraulic fracturing chemicals in the subsurface by fracturing operations, and observed no leakage from hydraulic fracturing at depth.
- Many reports of groundwater contamination occur in conventional oil and gas operations (e.g., failure of well-bore casing and cementing) and are not unique to hydraulic fracturing.
- Methane found in water wells within some shale gas areas (e.g., Marcellus) can most likely be traced to natural sources, and likely was present before the onset of shale gas operations.
- Surface spills of fracturing fluids appear to pose greater risks to groundwater sources than from hydraulic fracturing itself.
- Blowouts — uncontrolled fluid releases during construction or operation — are a rare occurrence, but subsurface blowouts appear to be under-reported.

They also stressed the need for better regulation in all aspects of the process.

GROUNDWATER POLLUTION

Although the risk of groundwater pollution may be overstated (Walter 2012), nevertheless measures to prevent the pollution of groundwater should be mandatory. Gallazie (this volume) considers these risks in detail. The most important measures include detailed microseismic 3D-mapping, superior well-drilling and completion standards within a tight regulatory framework. Strict control of recovered water containment and treatment on the surface, with maximised recycling of cleaned recovered water within the hydraulic fracturing sequence.

GAS IN WATER SUPPLIES?

This is theoretically possible, but it should be able to avoid this by proper construction of the borehole with casing and cement. This will be required to protect the overlying aquifers anyway. Most of the reported occurrences in USA are in water supplies which have displayed this phenomenon since the 1970s - long before fracking was developed. Microseismic control of hydraulic fracturing will prevent the opening of extensive vertical fractures along faults that could connect to overlying aquifers.

SEISMIC EVENTS

Since hydraulic fracturing involves breaking rock it will produce shock waves. These will need to be monitored by seismic sensors, which will allow the companies to keep these tremors at a level that is barely perceptible to people. The use of microseismics will allow companies to map the underground structures accurately, both for the most efficient development of the field, but also to be able to avoid major fault structures which could slip and cause discernable tremors. This appears to have happened in the UK in 2011 when seismic events of 1.5 and 2.3 on the Richter scale were recorded, followed fracking by Cuadrilla Resources of the Bowland Shale near Blackpool near a major fault line (see de Pater & Baisch 2011).

PLANNING ISSUES

The control of air quality, landscape impact, traffic, noise and other disturbance comes within the scope of the EIS required for planning permission. In Colorado, many working pads are accepted as minor landscape features (Fig. 9).

Figure 9 - A shale gas pad in western Colorado, USA

REGULATION

In order for this process to be carried out properly, several things need to be regulated. This is mostly carried out in the Republic of Ireland by divisions of DCENR - the Department of Communications, Energy and Natural Resources and the Commission for Energy Regulation (CER).

Water quality is looked after by the EPA and by the Groundwater Division of GSI. They ensure no contamination of aquifers. Also the proper treatment of recovered process water in lined ponds, etc.

The Petroleum Affairs Division (PAD) administer the licensing system and ensure the compliance of the companies to their licence conditions. Borehole construction is monitored by PAD. They ensure proper construction of the borehole with cementing and casing. They also ensure that any possible seismic tremors caused by fracking are kept to a minimum, well below Richter scale 3 and probably below Richter 2.

In Northern Ireland, these matters are regulated by Department of Enterprise, Trade and Investment (DETI) and the Department of the Environment (DoE).

CONCLUSIONS

Shale gas may present a significant opportunity for the island of Ireland to have security of energy supply. The development of this resource does not involve new technologies, but the refinement of old ones. However there are constraints and concerns about the methodology these should be addressed by good practice and regulation.

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SHALE GAS HYDRAULIC FRACTURING IN IRELAND

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North West Environmental

ABSTRACT

Approximately 2,250 km^2 in the North West of Ireland are currently studied by two private Companies to assess the potential of natural gas extraction by mean of hydraulic fracturing associated to horizontal drilling from the Bundoran Shale the Dowra Sandstone. These geological formations are classified as Locally Important Aquifer, are directly underlain by a Regional Important Karstified aquifer, and separated from an overlying Regional Import Aquifer by ca. 400-600 m of fractured shales and sandstones. Both the Regional Important Aquifers are used as sources of water by public supplies. Numerous water-dependent protected areas are located within the area under study. The proposed technique has several potential flaws which may lead to significant detrimental impact on the quality of groundwater and/or surface. It is considered that the dubious benefits are outweighed by the high risk and potential losses associated with the project.

INTRODUCTION

There are currently three licensing options issued by the Petroleum Affairs Division of the Department of Communications, Energy and Natural Resources in the Republic of Ireland. Two of these licenses are located within the North West Carboniferous Basin, while the third is located in the Clare Basin:

- Tamboran Resources PTY Limited has been granted a licence option covering approximately 986 km^2 in counties Leitrim, Cavan and Sligo.
- Lough Allen Natural Gas Company Limited has been granted a licence option extending for ca. 467 km^2 in counties Leitrim, Sligo and Cavan.
- Enegi Oil plc has been granted a licence option covering approximately 495 km^2 in county Clare.

These licence options cover a total area of ca. 1948 km^2. A further ca. 4,000 km^2 in the North West Carboniferous Basin and approximately 3,300 km^2 in the Clare Basin have been identified by the Department as “additional acreage” which is on offer.

The licence options allow for initial exploration, primarily as desk study, and drilling to a maximum depth of 200 m to assess the resource commercial viability. If successful, the companies holding the licence options will have a first, but not exclusive, right to an exploration licence.

The Minister for Communications, Energy and Natural Resources has stated that any work beyond the above, including hydraulic fracturing, could be performed only after securing the appropriate permissions and after having being successfully gone through an Environmental Impact Assessment.

In Northern Ireland a total of four licences have been granted in 2011 by the Department of Enterprise, Trade and Investment for '*search and bore for and get petroleum'* onshore [(1)]:

- Tamboran Resources PTY Limited has been granted a licence for an area of ca. 750 km^2 in the western part of County Fermanagh.
- Infrastrata plc, has been granted a licence for an area of approximately 663 km^2 in Central Larne - Lough Neagh Basin, County Antrim.
- Rathlin Energy Ltd. has been granted a licence for an area of ca. 880 km^2 in Rathlin Basin, County Derry.

- PR Singleton has been granted a licence for an area of approximately 15 km^2 Rathlin Basin, in County Antrim.

The licences granted in Northern Ireland are for five years. In most cases, within the third year a decision to drill a well or abandon the project will have to be made. All licencee are required to secure the necessary permissions (planning, landowner, etc.) and an Environmental Impact Assessment before proceeding with well drilling beyond shallow exploration (including for the purposes of hydraulic fracturing).

Of all the licensee in Ireland, Rathlin, Tamboran and Langco are exploring for natural gas, but only Tamboran has declared that hydraulic fracturing is the technique to be applied. Infrastrata has expressed interest only in conventional oil, while Enegi is exploring the oil potential of the Clare Basin [(1)].

HYDRAULIC FRACTURING

In synthesis, as this topic has been extensively illustrated in a previous paper, hydraulic fracturing is a technique applied for increasing or restoring the rate at which a fluid can be extracted from a subterranean natural reservoir. In the case of extraction of natural gas, hydraulic fracturing is used to produce gas from rock formations where the existing porosity is not sufficient to allow this fluid to flow into the well at economic rates. By injecting at high pressure (up to 1,000 bar) a mixture of fluid (usually water), sand and numerous other chemical products, the fractures present in the host bedrock are expanded and extended, thereby creating a conductive path connecting a larger area of the reservoir to the well, hence increasing the area from which natural gas can be recovered.

Per se hydraulic fracturing is not a new technique, as it was used for the first time in 1947, nor is it limited to the extraction of hydrocarbons, as it has been adopted for simulating groundwater wells, for enhancing remediation processes and in heat extraction in geothermal systems, among others. What is relatively new is that thanks to technical developments in horizontal drilling, hydraulic fracturing can now be applied very intensively in an area targeted for natural gas extraction. Typically, the reservoir is reached by drilling a vertical well to the required depth and then drilling continues horizontally for one kilometre within the target rock. More than one horizontal drilling can be performed from the same vertical well, and several wells can be accommodated within each drilling pad. Due to the extent of the horizontal drilling usually applied, the drilling pads are placed at a distance of 2-4 km from each other.

Hydraulic fracturing combined with horizontal drilling for the extraction of natural gas has been used in numerous countries. From Australia, to the USA, Canada, Germany, Poland and China. A ban has been imposed on the procedure in Bulgaria and France, while a moratorium pending detailed and extensive studies is in place in South Africa, New York State and Quebec. In the UK, although not officially banned, hydraulic fracturing for natural gas has been suspended by the exploration company since 2011.

CURRENT LEGISLATION

There are a number of regulations that apply to the extraction of natural gas by hydraulic fracturing in general, and some others because of the specific of the locations where the extraction wells are to be placed:

- Both the DETINI and DCNR have confirmed that an Environmental Impact Assessment will have to be carried out [(1)]. It would however be interesting to know if the EIA would be required for each single pad or otherwise.
- The Water Framework Directive requires a “good” status for surface water and groundwater. It also states that “for groundwater, in addition to the requirements of good status, any significant and sustained upward trend in the concentration of any pollutant

should be identified and reversed". However, it also states "There may be grounds for exemptions from the requirement to prevent further deterioration or to achieve good status under specific conditions, if the failure is [...], for reasons of overriding public interest". This Directive might also apply if the operator requires the abstraction of a large amount of water from a surface or groundwater body [(2)].

- The commercial extraction of shale gas is listed as a Scheduled Activity under the EPA Act ("extraction, other than offshore extraction, of petroleum, natural gas, coal or bituminous shale") and therefore is an activity for which an application for an IPPC licence must be submitted [(3)].
- The Environmental Liability Directive should also apply, as it defines "environmental damage as including damage to protected species and natural habitats, water damage and land damage where the damage is caused by occupational activities" [(2)].
- The Groundwater Directives 80/68/EC and 2006/118/EC also apply, as "Members States shall take the appropriate steps to eliminate discharge by man, directly or indirectly of substances into the aquatic environment the results of which as such as to pose hazard to human health, harm to aquatic ecosystems, damage to amenities" and also "Groundwater in bodies of water used for the abstraction of drinking water or intended for such future use must be protected in such a way that deterioration in the quality of such bodies of water is avoided" [(3)].
- The European Objectives (Surface Water) Regulations 2009, which include measures for the protection of surface water bodies whose status is determined to be high or good and measures requiring the restoration of surface water bodies of less than good status to not less than good status [(3)].
- The Habitats Directive (92/43/EEC) applies if the project could significantly affect a Natura 2000 site and/or the breeding site or resting places of protected species [(2)].
- The Mining Waste Directive (2006/21/EC) applies as the exhaust fracturing fluid is considered "extractive waste" and any storage area a "waste facility" [(2)].
- The Seveso II Directive (96/82/EC) (storage of gas and of hazardous substances the REACH Directive (1907/2006/EC) and the Biocidal Products Directive (98/8/EC) may apply if chemical products are added to the fracturing fluids [(2)]).

GEOLOGY & HYDROGEOLOGY

GEOLOGY

The geological formations present in the area covered by Tamboran and LangCo licence options within the North West Carboniferous Basin and also in the Enegi licence option area within the Clare Basin, are listed in Table 1 below. In extreme synthesis, as more detail is given in Gareth Jones's presentation, these rocks are conglomerates, limestones, sandstones and shales deposited in a generally shallow and warm sea following the marine transgression which started at the beginning of the Carboniferous flooding firstly the south of Ireland and then progressing northward.

Tamboran has identified the Bundoran Shales and the Dowra Sandstones as the target bedrock formations. Langco also includes the Shanmullagh Formation as a potential target [(4)].

AQUIFER CLASSIFICATION

It is defined as an aquifer any geological formation which is capable of storing and transmit water in significant quantities. As the meaning of "significant" is obviously strongly dependant on the point of view, the Geological Survey of Ireland has classified all the bedrock and unconsolidated deposits as aquifer in three major categories and eight sub-categories on the basis of their value as water resource and of their hydrogeological characteristics.

The categories are as follows:

- Regionally Important Aquifers – wells yielding >400 m^3/d

- Karstified Aquifers (Rk)
- Fissured bedrock Aquifers (Rf)
- Extensive gravel/sand aquifers (Rg)

- Locally Important Aquifers – wells yielding 100-400 m^3/d
  - Sand/gravel (Lg)
  - Bedrock which is Moderately Productive (Lm)
  - Bedrock which is Moderately Productive only in Local Zones (Ll)

- Poor Aquifers - wells yielding <100 m^3/d
  - Bedrock which is Generally Unproductive except for Local Zones (Pl)
  - Bedrock which is Generally Unproductive (Pu)

The geological formations present in the area of licence options of both basins have been classified, from the point of view of their importance as aquifers, as listed in Table 1 below (not in appropriate stratigraphic order):

Table 1 - Geological Formations and Aquifers Classification

North West Carboniferous Basin	Aquifers Classification	Clare Basin	Aquifers Classification
Lackagh Sandstone Formation	Pl		
Carraun Shale Formation	Pu		
Dergvone Shale Formation	Pu		
Gowlaun Shale Formation	Pl		
Bellavally Shale Formation	Ll		
Glenade Sandstone	Ll		
Meenymore Formation	Ll		
Dartry Limestones	*Rk*[c]		
Glencar Limestones	Ll	Central Clare Group	Ll
Benbulben Shale	Ll	Tullig Sandstone Formation	Ll
Drumgesh Shale Formation	Ll	Gull Island Formation	Ll
Mullaghmore Sandstone	Lm	Ross Sandstone Formation	Ll
Bundoran Shale Formation	*Ll*	Clare Shale Formation	Pu
Dowra Sandstones	*Ll*	Visean Limestones	Rk[c]
Ballinamore Beds	Rk[c]	Slievanaglasha Formation	Rk[c]
Ballyshannon Limestones	*Rk*[d]	Burren Formation	Rk[c]
Shanmullagh Formation	Pl	Tubber Formation	Rk[c]

It should be noticed that the target formations in the North West Carboniferous Basin are classified as Ll, and that they are directly overlying a Regional Important Karstified (diffuse) aquifer and are 400-600 m below another Regional Important Karstified (conduit) Aquifer.

The Ballyshannon Limestone is the source of water for public water wells in South Donegal and possibly in North Sligo. A number of public water supplies in North Cavan source water from the Dartry Limestone. Numerous lakes in the licensed area are used as source of water for large public water supply schemes, like Lough Gill for Sligo and North Leitrim.

AQUIFER VULNERABILITY

In North Sligo and South Donegal vulnerability ranges from Extreme, generally on the tops and slopes of mountains, to Moderate on the bottom of the valleys and along the sea. In South Sligo and in Leitrim, most of the lowlands fall into the Low category [(5)], with subsoil so rich in clay that water cannot percolate through, so much so that planning applications for single houses in rural parts of the counties are often refused due to failure of the percolation test.

In the Clare Basin, vulnerability ranges from Extreme to Low, with more than half of the area under licence options (between Ennis and Kilrush and along the coast) in the Extreme category [(5)].

The low vulnerability in Country Leitrim and part of County Sligo may help in preventing groundwater pollution from spillages occurring on the surface, but on the other hand may increase the risk to surface water.

HYDRAULIC FRACTURING IN THE NORTH WEST OF IRELAND

In this paper we concentrate only on the plans proposed for the North West by Tamboran, as it is the most active company among those holding a licence option in the Republic, and therefore there are more available information on the plans for extraction of natural gas through hydraulic fracturing, although it appears that these plans are changing quite rapidly and frequently, with particular regards to the number of pads and extraction wells to be installed, the source of water, treatment/disposal of exhaust fracturing fluid.

Within the area covered by the licence and licence option, Tamboran has indicated the following programme of operations:

- a total of ca. 2,500 wells will be drilled (in a more recent presentation a figure of ca. 9,000 wells was mentioned by the Company CEO), placed within 400-600 concrete pads over 20 years. Each pad would accommodate up to 24 wells and would cover an area up to 3.3 hectares (plus access road and possibly rainfall collection pond).
- Typically each well requires up to 1,500 m^3 water during drilling, and up to 11,000 m^3 for each fracturing event, 25% of which is usually recovered, stored at the surface and re-used while the other 75% is lost in the ground. As gas production at each well declines quite sharply after a couple of years, it has been envisaged that each well may require 3-5 fracturing events during its life-span. The water is mixed with sand and typically numerous chemical products (between 0.5% and 2%, equivalent to up to 220m^3 [(2)]) acting as friction reducers, biocide, anti-corrosive etc., some of which are toxic (methanol, 2-butoxyethanol, BTEX). However, Tamboran claims that the procedure will be carried out without the addition of any chemical product to the fracturing fluid, claim which is strongly refuted by independent hydraulic fracturing experts[(6)]. At this stage it is not clear if the water will be sourced from local rainfall or from purpose-built water wells.
- The gas extracted will be flared in-situ or on-site and then transported to a pipeline (at this stage it is not clear where and how).
- At the end of its life, typically 10-20 years, each well will be sealed and the pad dismantled.

Tamboran initially identified an area of ca. 13 km in radius centred on Kiltyclogher, County Leitrim, as “likely to be the only viable drilling area”. However, in a recent presentation the company CEO made no mention of this area. In this “likely viable area” Tamboran indicated that a total of no. 120 multi-well pads would be installed, equally divided across the border. Each pad would have up to 24 vertical wells, and would cover an area up to 3.3 hectares.

ENVIRONMENTAL CONCERNS

Extraction of natural gas by hydraulic fracturing associated with horizontal drilling has occurred in several countries, but with particular intensity in USA and Canada. In both countries a large number of events have occurred where groundwater, surface water and/or soil have been subject to pollution originating from the procedure [7] [8] [9].

The risks of a detrimental effect on the quality of water and soil deriving from hydraulic fracturing can probably be minimised by the strict application of "best practice" procedure, which are in great part shared with activities connected with other kinds of development (road building, quarrying, storage of chemicals in factories, waste water treatment, etc.). However, the two big issues are the density of the operating pads and therefore the sheer bulk of activities required for performing the process, and the cumulative effect which will come into play particularly at the later stage of the process. In the case of the former, experience shows that accidents happen, particularly when a large number of machinery is involved. In the case of the latter, when fracturing is repeated 3-5 times on 2,500 wells (or up to 9,000 wells according to recent a presentation by Tamboran) the progressive shattering of the host bedrock will make increasingly more difficult to prevent unduly migration and escape of fracturing fluid and/or gas, as recognised also by the European Commission[2].

CONSTRUCTION PHASE

Excavation and ground movement for the construction of the pads and of the associated infrastructure can lead to pollution of soil and/or water in several ways:

- accidental spillages, from trucks and machinery;
- "washing-out" of fine sediments, and possibly chemicals, into surface water or groundwater;
- improper storage of excavated soil and subsoil.

During the drilling phase of the project, a negative impact on the quality of soil, surface water and groundwater can derive from a number of sources:

- accidental spillages during storage or transportation;
- leakage through faulty well casings;
- escape of drilling mud and of fine sediments produced by the drilling rig.

OPERATIONAL PHASE

Hydraulic fracturing can have a negative effect on the quality of water and/or soil through the following:

- overflow of hydraulic fracturing exhaust fluid ponds or tanks.
- Accidental spillages from oil or chemical storage tanks or transporting lorries, and considering the very large number of lorries and trucks movements required for the operation of each single pad (over 5,000 return trips by 20-ton lorries during its life-span), an accident is likely to happen. Tamboran claims that there will be no need of such chemicals due to the shallow depth of the reservoir (700-1200 m bgl) and other advances in technology. However, this claim is strongly disputed by independent hydraulic fracturing experts [6].
- Escape of hydraulic fracturing fluid or gas via a failed or faulty casing.
- Propagation of fractures in the reservoir to overlying or underlying aquifers. On this matter there is evidence of induced fractures extending for hundreds of metres, some times over a kilometre, and entering other bedrock formations which are of no direct interest for the extraction process [10].
- Change in the hydrogeology of the reservoir, as the development of a network of new fractures in the bedrock is likely alter the hydrogeological conditions of the area, with potential negative impact on water wells, surface water and wet areas.

- If the water required for each hydraulic fracturing event is sourced locally through a water well to be installed within each pad, it is evident that the removal from the local water cycle of the large amount of water required by the process can have a detrimental effect on availability of water in existing wells and on the surface water, and consequently on water dependent eco-systems (within the "likely to be the only viable drilling area" alone there are ca. 20 protected areas (SAC/SPA/NHA/ASSI).
- Tamboran claims that the fluid recovered from a fracturing event (usually 25% of the injected volume) will be re-used for successive events. However, eventually this fluid will no longer be usable as it becomes more briny with re-use. Hence the fracturing fluid will eventually have to be disposed of. There is no treatment facility on the island capable of dealing with the volumes and poor quality of exhaust fracturing fluid. Therefore this fluid is either exported for treatment or disposed of in some other ways. Tamboran is considering the possibility of re-injecting the exhaust fluid in the bedrock. At this stage it is not clear if this is intended as re-injection on-site or off-site and in what kind of bedrock. However, this procedure may be in breach of Article 11(3)(j) of the Water Framework Directive.

OTHER CONSIDERATIONS

Tamboran claims that through the lifetime of the project (40 years) a total of ca. €5 billion in taxes, equivalent to €125 million/year would be generated. However, this amount appears at a preliminary examination to be easily matched by the revenue generated in the area by agriculture and tourism (€70 million in Sligo and Leitrim in 2010), and outweighed when other enterprises dependent on high quality of water (e.g. Abbott Ireland) are taken into account. The revenue currently generated by Tourism and Agriculture in the area would likely being lost due to the change of landscape deriving from the heavy industrialization associated with the proposed project.

With regards to employment, Tamboran claims that 600 direct and 2,400 indirect jobs would be created through the duration of the project. This level of job creation is matched by the amount of people working in the Tourism and Agriculture sectors (ca. 3,000 people in Agriculture in Sligo and Leitrim in 2006) and outweighed when other enterprises are taken into consideration. Once over, significant job losses would occur in the Tourism and Agriculture sectors due to the radical change of land use associated by the proposed project.

CONCLUSIONS

The extraction of natural gas through hydraulic fracturing entails significant risks of pollution of groundwater, surface water and soil. It would possible to minimise or eliminate some of these risks, but others are inherent to the project and cannot be mitigated.

A significant body of legislation which would apply to the proposed project already exists, although it was not drafted specifically for unconventional natural gas extraction. Self-regulation and "easy-touch" cannot be applied. On the contrary, strict monitoring and enforcement are crucial.

The benefits which could be derived from the proposed project are dubious when not completely outweighed by the probable losses.

The project is more likely to cause further loss of revenue to the Irish State and increase in unemployment outweighing the claimed tax revenue to be generated and the employment to be created.

The precautionary principle should be applied.

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STUDENT POSTER PRESENTATIONS

QUANTITATIVE ANALYSIS OF FAULTS AND FRACTURE SYSTEMS AND THEIR IMPACT ON GROUNDWATER AND CONTAMINANT FLOW PATHWAYS IN IRISH BEDROCK AQUIFERS

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ABSTRACT

Faults and fracture systems are the most important store and pathway for groundwater in Ireland's bedrock aquifers either directly or where they provide conduits that control bedrock dissolving groundwater and therefore form loci for the development of karst. This poster briefly outlines a new project on the quantitative analysis of fault and fracture systems in the broad range of Irish bedrock types, focussing on developing generic conceptual models for fault/fracture systems in different lithologies and at different depths, and linking them to observed groundwater behaviour. The project will define the quantitative characteristics of the different types of fault/fracture systems encountered in Ireland. A variety of attributes/parameters, all of which are critical determinants of the flow behaviour and pathways of such systems, will be defined from high quality natural outcrops, quarries and mines, including fracture orientations, densities, spacing/clustering, sizes (length / aperture / thickness), scaling and connectivity.

Quantitative characteristics of the different fault/fracture systems will be defined in distinctive lithological sequences (e.g. Calp or Waulsortian limestones), in an attempt to provide a mechanical basis for differing fracture system systematics and established differences in the flow and transport conceptualisations across Irish fractured bedrocks, and their variations either in depth or across regional zones. Structural geologic conceptual models and parameterisations will be linked to observed groundwater behaviour (derived from GSI hydrogeological databases and on-going Griffith and EPA-Strive projects) by undertaking flow simulation of simple generic fracture system models and case studies of flow in Irish fractured aquifers.

ASSESSING THE INTRINSIC VULNERABILITY OF GROUNDWATER TO POLLUTION IN IRELAND BASED ON THE COST-620 PAN-EUROPEAN APPROACH

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ABSTRACT

The objective of this work was to assess the intrinsic vulnerability of groundwater to pollution in Ireland. A geographical information systems (GIS) model was developed based on the COST-620 pan-European approach for the protection of aquifer systems. The intrinsic vulnerability of groundwater to pollution was assessed based on three parameters: a) the protectiveness of the overlying layers (topsoil and subsoil), b) the reduction of protection due to concentrated water flow through surface karst features, and c) the influence of precipitation. The output is a composite index that classifies vulnerability into five categories (Very High, High, Moderate, Low, and Very Low). A sensitivity analysis was carried out using Monte-Carlo simulation with the Latin-Hypercube sampling method to investigate the relative importance of the input parameters. Based on the sensitivity analysis the most important parameters were subsoil thickness and permeability (ρ = 0.79) and topsoil thickness and texture (ρ= 0.72). This outcome is in agreement with current knowledge about the parameters that influence groundwater vulnerability in Ireland. The method was verified in karst areas using total organic carbon, which is a natural tracer of groundwater vulnerability. In areas not affected by karstification processes a series of soil and vegetation indicators were used. The analysis showed that the vulnerability as estimated by the proposed method correlated well with field data. Management strategies to reduce nitrate leaching from spring barley to groundwater on a vulnerable soil.

SPATIAL ANALYSIS OF GROUNDWATER NITRATE MONITORING DATA IN THE SOUTH EAST OF IRELAND

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ABSTRACT

Eutrophication is the principal threat to surface water quality in Ireland. In some situations groundwater represents a significant pathway for nutrient transport to surface water. In the Water Framework Directive (2000/60/EC) water quality status assessments, carried out by the Environmental Protection Agency (EPA) in 2008, very few Irish groundwater bodies (less than 1 %) were classified as having poor status due to failing to meet the drinking water objectives for nitrate. However 16 % of groundwater bodies were 'at risk' due to the potential deterioration of associated estuarine and coastal quality by nitrate from groundwaters (unpublished EPA data).

Nitrate data from the EPA's national groundwater quality monitoring network were assessed to evaluate factors affecting groundwater quality and status. Data from 70 monitoring points within the South Eastern River Basin District were investigated with respect to pressure layers (including land cover, fertiliser application rates, livestock and septic tank density) and pathway layers (including soils, subsoils, bedrock geology and climate data). This spatial analysis suggests that pathway parameters are more important than pressure parameters in understanding nitrate concentrations. Linear regression shows that soil type and groundwater vulnerability within the zone of contribution of the monitoring point, as well as the proportion of arable land, are the most significant parameters influencing nitrate concentrations in groundwater.

Further work, utilising additional pathway and pressure data, together with a greater understanding of N transport and attenuation processes, will provide a useful basis for Irish policy makers tailoring mitigation measures.

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ECOHYDROLOGICAL CHARACTERISATION OF WETLANDS IN THE BORDER REGION OF IRELAND

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ABSTRACT

Extensive research has been conducted on the ecology of specific wetland habitats on a regional basis. However, there remains limited understanding of the hydrology of the range of wetland types as found in the border region Ireland. Little is known about how anthropogenic and climactic induced hydrological pressures impact on these wetland systems. There is a paucity of baseline data for Irish wetlands and there is a need to develop our understanding of the relationship between hydrogeological and ecological characteristics of groundwater dependent ecosystems.

The geophysical and geochemical surveys of Tellus and Tellus Border projects will result in seamless maps of key physical properties and of soil and surface water chemistry across the border area. These data will support research into the characterisation and management of border county wetlands. We propose to use the new data, with existing data and newly-collected field data from selected wetland sites, to investigate the water delivery mechanisms and water requirements (notably water levels and hydrochemistry) of different types of regional wetlands across the border counties of Ireland, and to describe and characterise the biological communities within these wetland systems. Emphasis will be placed on developing an understanding of the relationships between hydrogeology, hydrology and ecology, allowing a more holistic understanding of wetland systems. By synthesising hydrological and ecological data and methods, new insights into the functioning of ecosystems and their subsequent management and conservation can be obtained.

SESSION II

EPA REGULATION OF MINING OPERATIONS – THE STORY SO FAR

Pól Ó Seasnáin,
Environmental Protection Agency

ABSTRACT

All new mines in Ireland or extensions of existing mines are subject to a rigorous authorisation and enforcement process. Ireland was one of the first Member States in the EU to institute an integrated environmental permitting system for mines in line with other industrial sectors. Mineral operations were not one of the activities listed as requiring authorisation in the IPPC Directive of 1996, but instead it was decided by the Irish authorities that they should be licensable under EPA legislation. In licensing these unique facilities in the late 1990s and early 2000s, special considerations were given to safety stability, water impact and provision for closure and aftercare. In the licences, the EPA anticipated many of the aspects of the EU Mine Waste Directive (2006) and EU guidance documents. The Agency is currently reviewing licences to address outstanding areas in this regard and to address the Water Framework Directive. In 15 years of enforcement the EPA has proven that, working with stakeholders, the regulation and inspection of mines has been a positive process. Confidence has grown in the competence of the regulatory regime and it is now well placed to address new developments and challenges in this area.

CONTEXT AND MAJOR CONCERNS

Before the establishment of Irish Environmental Protection Agency (EPA) in 1993, the major mineral and extractive operations were controlled by planning law, Mineral Development Acts 1940-1999 and single media discharge licences issued by Local Authorities.

Since 1994 most large industrial activities are required to obtain an authorisation from the EPA in order to commence or continue operations. This authorisation was called an Integrated Pollution Control Licence and anticipated many of the requirements of the 1996 European Union Integrated Pollution Prevention and Control Directive before that Directive was transposed into Irish legislation.

Under the EPA Act as amended, it is a requirement that certain extractive industries are licenseable under Class 1 'Minerals and Other Materials'. This includes:

- 1.2 The extraction of aluminium oxide from an ore, not included in paragraph 5.13.
- 1.3 The extraction and processing (including size reduction, grading and heating) of minerals within the meaning of the Minerals Development Acts 1940 to 1999, where an activity involves—
  - (a) a metalliferous operation, or
  - (b) any other operation where either the level of extracted or processed minerals is greater than 200,000 tonnes per annum or the total operational yield is greater than 1,000,000 tonnes, and storage of related mineral waste.
- 1.4 The extraction of peat in the course of business which involves an area exceeding 50 hectares.

There are 14 facilities in this sector with IPPC licences. The sector covers, among other things, the extraction and processing of minerals mainly lead and zinc, peat and aluminium oxide. The sector includes some of the largest and most complex industrial sites in Ireland. Many of the facilities cover areas of operation of more than 100 hectares. Most of the sites are located in the midlands of the country. The focus of this paper is on the mining sub-sector and in particular the lead and zinc mines.

Metal mining is currently a small sector in relation to the number of facilities licensed but could potentially be in an expansionary phase. Recent discussion with the Department of Communications Energy and Natural Resources (DCENR) has revealed there are approximately 600 Prospecting Licences issued (the highest in 22 years) to some 45 exploration companies. Exploration interest is mainly focused on base metals (primarily zinc and lead). However, there is exploration interest for a range of other commodities including gold, copper, gem minerals, rare earth elements, barytes, coal and molybdenum.

The 3 metal mines currently licensed by the EPA, all of which mine for lead and zinc, that are the subject of this paper are as follows:

1. Vedanta Lisheen Mining Ltd EPA Licence No. P0088-03 Co. Tipperary issued June 27th 1997, revised March 15th 2001 and again September 3rd 2010
2. Boliden Tara Mines EPA Licence No. P0516-01 Co. Meath issued May 29th 2001.
3. Galmoy Mines Ltd (part of Lundin Group) EPA Licence No. P0517-01 Co. Kilkenny issued October 4th 2002.

Even though there are only three facilities, as of 2011, Ireland was the largest producer of zinc concentrates in Europe and the third largest producer of lead concentrates (behind Russia and Sweden). In 2011, 32% of European zinc production and 14% of European lead mine output was produced in Ireland. The mining sector generally extracts their raw material by underground and then processes it onsite. Some figures for ore milled or materials produced in 2010 (in Million tonnes) were: Tara Mine 2.59 Mt, Lisheen Mine 1.53 Mt, Galmoy Mine 0.16 Mt.

The currently licenced mine facilities are unique operations amongst the other industrial facilities licensed by the EPA in that they have:

1. 'Tailings Management Facilities' (TMFs) which vary depending on the size of the ore body but can contain many millions of tonnes of extractive waste.
2. The size of the underground areas. These vary but each has an associated groundwater dewatering impact. The water table impact is greater than 10 km^2 for each of the three mines.
3. 'Design for closure' is a key consideration from pre-application right through the operational life of the mine.

Other important aspects controlled by EPA licences relate to discharge of process waters and mine waters to surrounding water courses (where, at certain points, the dewatering impact has been compensated for), control of air and noise emissions (the latter mainly from blasting), waste management and strict notification and reporting requirements. The EPA licences, EPA inspector reports and licensee Annual Environmental Reports can be viewed in detail on the EPA's website www.epa.ie.

MINE TAILINGS MANAGEMENT FACILITIES

Tailings Storage Facilities, Tailings Management Facilities (TMFs) or Tailings Dams as they are variously called, present a significant challenge in terms of

1. Management of a very large structure to ensure operational and post closure safety and stability.
2. Potential risk from pollution.

The ore consists of lead and zinc sulphide minerals. Processing on site to extract the valuable lead and zinc concentrates produces a waste which is referred to as tailings or tails. This is disposed of on the surface at the facility in the form of the tailings management facility. In addition to producing concentrate the processing plant also produces material called backfill. This material is normally mixed with small amounts of cement and is placed underground as an integral part of the mining process.

The three developers have taken different approaches to the final operation and final end points for their tailings dams though with the same objective of ensuring physical and chemical stability.

Safety and stability considerations were identified as special consideration for TMFs due to their nature and scale. The current approximate tonnages are as follows:

Mine TMF	***Millions of tonnes***
Galmoy	*3.6*
Lisheen	*9.1*
Tara	*34.7*

The authorisation at Galmoy and Lisheen required lining over very large areas of tailings lagoons with a synthetic membrane. The engineered tailings facility at Lisheen at the time was the largest of its type ever-constructed in Europe or North America covering approximately 70 ha. The application assessments required the submittal of a dam failure risk assessments. The TMFs have been built and extended in stages either laterally or vertically. The embankment walls or dam walls are engineered as water retaining structures, constructed with compacted fill. Installation of internal drainage in the form of ‘chimney drains’ and ‘toe drains’ were engineering safety features. Perimeter and embankment monitoring of integrity at the TMFs includes the following:

1. Observation boreholes and piezometers for water levels, pH, conductivity, sulphate and metals
2. Physical assessments including checks for settlement, movement and other indicators

In each of the licences there is a three tiered inspection regime where there is an onus on each tier to carry out inspections but also to review results and trends.

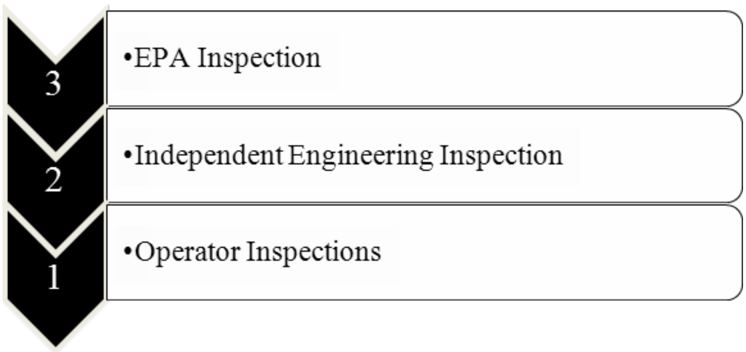

Figure 1 - Three tiered oversight of tailings facilities

The onus in the first instance is on the operator to comply with licence requirements on inspection of the tailings facility (daily, weekly, monthly checks as specified in licence schedules.). Secondly there are annual reporting requirements to the EPA for waste facility safety inspections. This is required to be an independent audit by a qualified dam engineer. The engineer must assess against design, construction and operational parameters of each phase or of the entire structure. The EPA’s role is to ensure compliance with these requirements by carrying out physical checks on the facility, cross checks on monitoring systems, inspection of records kept and interviewing personnel. These standards are to ensure that the risk of dam failure or development of serious leaks should be minimised. Any future tailings facilities will have to meet similar standards for safety.

In support to this regime there is a structured notification protocol in the case of observations or results which indicate inter alia the following:

- Pollution or damage;
- Loss of control of equipment or processes;
- Exceedance of licence limits;
- Exceedance of internally set trigger values.

In the event of the occurrence of any of the above the company must instigate Incident Response Protocols and, depending on the category of the incident, must notify the Agency and/or other first response agencies.

Tailings waste contains varying residual percentages of iron sulphide or pyrite depending on the geology of the ore body or ore bodies. Some tailings represent a pollution risk in the presence of air and water and can generate acid resulting in a polluting leachate, so called Acid Rock Drainage (ARD).

In determining the Best Available Technology for dealing with high pyrite tailings, the results of geochemical and geotechnical testing on tailings at Lisheen Mine and Galmoy Mines indicated that eliminating oxygen under submerged conditions would be an effective ARD control technique.

The TMFs at Lisheen and Galmoy Mines were therefore designed and operated, in such a way as to prevent the exposure of the tailings to air and thereby preventing ARD.

Lisheen proposed to deal with the long term ARD potential by disposing of the tailings waste underwater, both in the mine as backfill and on the surface in the TMF. The basal lining system required at Lisheen Mine minimised basal leakage to an extent that net precipitation would be greater than predicted worst case leakage thereby ensuring permanent saturation.

However, this strategy presents challenges particularly with water level management and maintenance of a safe freeboard between the water surface and the top of the tailings dam. This is particularly so during very wet periods of weather. This has been recognised as being difficult in the long term, when closure and minimum maintenance is aimed for. Lisheen have therefore proposed a strategy change in their Closure Plan, away from a submerged tailings facility (see later).

GROUNDWATER IMPACT

Since all three mines were in agricultural regions with no previous experience of mining, environmental protection was paramount. Particular concerns at Lisheen and Galmoy Mines were regional dewatering and pollution control where host rocks were important limestone aquifers.

Mining below the water table generally requires some form of dewatering and/or depressurisation. 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.

Where mining requires substantial dewatering of an aquifer to a considerable depth, and mining has persisted for 10 – 20 years, the resultant cone of depression can be expected to take several years to reach its new equilibrium after closure. In the case of Lisheen preliminary modelling suggested it would take about five years to equilibrate naturally. In practice, this will depend to some extent on the actual rainfall over the period of rebound, particularly the winter rainfall – a succession of abnormally wet winters would shorten the period, whereas dry winters would extend it.

At the Navan mine, groundwater rebound is not thought to be as significant an issue, in terms of groundwater resources, as at Galmoy and Lisheen Mines. The host rocks have low bulk permeabilities and the dewatering has not necessitated the maintenance of a replacement water scheme as at Lisheen and Galmoy Mines.

The Galmoy cone of depression is not as extensive as was initially predicted. A perimeter dewatering programme proved largely unsuccessful and the mine has depended largely on in-mine dewatering. Pump tests demonstrated that the transmissivity of the rock itself was low. Groundwater is mainly controlled by fracture flow. However, the cone of depression was still sizeable and prior to the first phase of reflooding in 2010, following partial cessation of mining, it extended over an area of approximately 10 km^2, as defined by the one metre drawdown contour.

The cone of depression at Lisheen is larger than that at Galmoy at approximately 70 km^2 (within the 1m drawdown contour). Even with extension of the mine in later years, monitoring to date has demonstrated that the cone of depression is less extensive than predicted. Large fractures influenced the boundary of the cone, resulting in a digitated margin rather than the predicted smooth cone margin. As in the Galmoy case, significant fracture controlled water strikes were made during the mine development which was not predicted. Local in-mine dewatering has been necessary at the intersection of these fractures. Recent numerical modelling indicates that full groundwater rebound after closure should occur within four to eight years under average climatic conditions.

Where river flow augmentation is required because of the dewatering, closure plans include provision for continued augmentation, as necessary, during the rebound period. Where replacement of water supplies is necessary, this will be continued until the natural groundwater regime is re-established in terms of both quality and quantity. Where the consumers so desire the replacement water supply systems will continue indefinitely under local management.

CLOSURE RESTORATION AND AFTERCARE MANAGEMENT PLANS (CRAMP)

In many ways the closure and aftercare plan is the most important requirement of any Environmental Impact Statement for a new mine because while a working mine may affect its environment for a few decades, the impact of a closed mine is unlimited in time. This is particularly true in relation to the consideration of tailings facilities. TMFs are essentially containment facilities, in that, the pollution risk may be isolated, latent or minimised but may not diminish over time. Therefore robust and long term mitigation measures required. And yet, because the final configuration of the mine (new ore bodies may be found) and the hydrogeological conditions at closure are only approximately known when the mine starts out, drawing up an appropriate closure plan is a very difficult exercise.

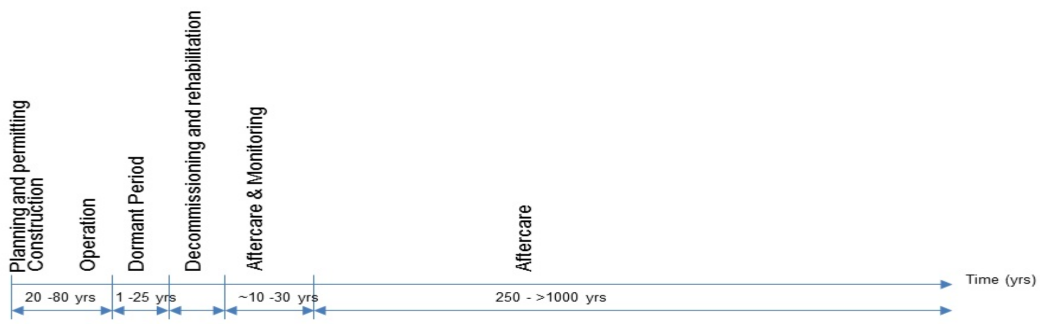

Figure 2 - Possible Mine Life Cycle Time Line (Courtesy: SLR Consulting Ltd)

The regulatory authorities in Ireland and their advisors have made considerable efforts to ensure that proper closure planning is integral to all mining development in the country. The regulatory authorities have taken the view that a closure and aftercare plan is more than a document – it is a ***process*** which is pursued throughout the life of the mine and beyond. The process can be viewed as comprising:

- Initial Closure Restoration and Aftercare Management Plan (CRAMP)
- Investigations and monitoring to derive parameters and criteria needed for final CRAMP
- Modelling, validation, trials for CRAMP
- Periodic review - Interim CRAMP(s) or amended CRAMPs
- Final CRAMP
- Implementation of Closure and Restoration element of CRAMP
- Periodic Review
- Validation of Closure and Restoration (after 5 to 10 years)
- Implementation of Aftercare Plan
- Periodic review

A Mine Closure Restoration and Aftercare Management Plan must be:

- Clear and logical
- Comprehensive
- Realistic
- Flexible
- Robust
- Financially achievable
- In accordance with Best Available Techniques

In Irish mines the main water issues involved in mine closure are:
- Groundwater rebound
- Water contamination from mine workings or waste after groundwater rebound
- TMF

The regulatory experience with implementation of the first stage of the closure and aftercare process (the closure plan), has thus far been largely positive, though it should be noted that no closure plan has been fully completed yet.

The companies have characterised and have kept under review the nature of the tailings at their TMF sites and have presented evidence in supporting documentation to the Closure Plans that the risk of ARD generating potential is generally low and that even if some arises that the buffering ability of the calcium carbonate dominated matrix of the tailings will inhibit or eliminate the risk of any emergent pollution in the Aftercare Period.

This is one of the factors which has supported justification for a change in strategy for Lisheen Mine away from the requirement for a permanent submerged tailings surface to a strategy of a capped and vegetated final surface. The capping approach has been put forward as less vulnerable to the vagaries of climate, will require less monitoring and provides more options for viable final land use including the possibility of an annual economic return. The approach is referenced in the European Commission 'Reference Document on Best Available Techniques for Management of Tailings and Waste-Rock in Mining Activities (BREF)' which was published in 2004 and formally adopted in 2009.

Trial rehabilitation with a view to proving such a strategy using imported soil forming materials has been carried out over several hectares of the tailings surface at each site, more recently at Galmoy Mines and Lisheen Mine. Vegetation has been established over a few seasons, with successful cattle grazing and silage cutting. These trial areas have now become the basis of what is known as 'progressive closure' or 'phased closure' and provided the basis for key decisions concerning the closure plans.

Conditions imposed by the regulatory authorities aim to ensure that mine operation monitoring and model review will produce an acceptable post-closure outcome. Critical to this process is ensuring that sufficient funds will be available either for planned or premature closure and to deal with post-closure problems requiring remediation. Solutions to this problem have been established to a large degree in co-operation with the developers who recognised that this is now an essential part of mine development. Each has provided a substantial surety (€12.9m for Galmoy Mines, €24m for Lisheen Mine, €12.5m for Tara Mine). All are indexed for inflation. In addition these sureties were set up with an independent guarantee underwritten by a Bank. Withdrawals for spending on closure works require the consent of the permitting authorities. Galmoy Mine was the first of the mines to begin implementation of their closure plan in 2009. The authorities agreed with the mine company to form a Mine Closure Committee (MCC) as a forum to review implementation and spending on closure works and to agree procedures for withdrawals from the closure fund. An MCC has also been formed for the same purposes at Lisheen mine. The EPA has assumed a co-ordinating role for the authorities in these situations, particularly in relation to financial determinations.

In addition to these provisions the operator is required to maintain sufficient indemnity to underwrite the clean-up or reinstatement costs resulting from an accident or unscheduled emission. The operator is required to quantify this risk or liability and demonstrate to the satisfaction of the regulators provision of same.

REGULATORY APPROACH

IPPC DIRECTIVE

In the current regulatory environment a developer submits three applications: (i) to the planning authority for planning permission, (ii) to the EPA for an integrated pollution prevention and control (IPPC) Licence and (iii) to the Department of Communications Energy and Natural Resources for a State Mining Lease or Licence (depending on whether the minerals are in State or private ownership). These permits cover different aspects of the developments, but the three authorities co-ordinate closely at pre-consultation, operational and closure stages. The IPPC licence, however, is the principal regulatory tool for the control of day-to-day operations of a mine. IPPC is a single permit approach to all emissions to all media. Therefore the individual impact on groundwater and surface water as well as any transfer of impact from one to the other is considered. It is a highly transparent and pragmatic approach to regulation. The Best Available Technique principle is a core element of this authorisation and control philosophy.

In Ireland the protection of groundwater and surface water from mine activities is principally driven by the implementation of the Water Framework Directive 2006. The transposed Environmental Objectives (Surface Waters) Regulations 2009 and Environmental Objectives (Groundwater) Regulations 2010 require the Agency to examine every authorisation granted for compliance with the requirements of the regulations by 22nd December 2012. This in support of the environmental goal for 'Protected Water Resources' by ensuring authorisations granted by the Agency aim to achieve the objectives and the milestones of the Water Framework Directive.

Ireland was one of the first Member States in the EU to institute this integrated environmental permitting system for mines in line with other industrial sectors. In Ireland the IPC legislation was stricter than Council Directive 96/61/EC 1996 concerning ("IPPC Directive") and brought mining as well as the processing of minerals into the IPC licensing net. The EU IPPC Directive excludes mineral mining per se, but it could be embraced as an associated operation of mineral processing, which is a listed operation in Annex 1 of the Directive.

MINE WASTE DIRECTIVE

This was largely driven by major failure incidents at tailings facilities associated with mineral operations in Europe and recognition by the Commission of their significant environmental and safety implications. They are now subject to review under Directive 2006/21/EC on the 'management of waste from extractive Industries' (known commonly as the 'Mine Waste Directive' 2006). This was transposed under S.I. No. 566 of 2009 – the Waste Management (Management of Waste from the Extractive Industries) Regulations 2009 which came into force on the 31st December 2009.

The Extractive Waste Regulations set out a range of requirements in relation to the management of 'extractive wastes' which include materials such as overburden, rock, sediments and process tailings. Under these regulations the higher risk waste facilities are known as Category A facilities. The Regulations set out a wide range of specific and detailed requirements in relation to the operation, maintenance and monitoring of Category A facilities. The three lead and zinc mines will be classified as a Category A facilities.

It is a requirement of the Regulations that all EPA licensed sites that are producing and managing extractive waste are in compliance with the requirements of the regulations by 1st May 2012. The Agency is currently undertaking reviews of current licence conditions in order to comply with the regulations as a result. The EPA largely anticipated many of the aspects of these regulations in their licences and as a consequence there is a relatively small gap to bridge from IPPC compliance to Mine Waste Directive Compliance.

ENFORCEMENT POLICY

The EPA has, over the years, refined its approach to the enforcement of licensed IPPC and Waste sites with a view to ensuring that a risk based approach to enforcement is applied in a consistent manner across all sectors. The EPA developed the risk-based approach having regard to enforcement practices in a number of countries and in particular by the Environment Agency. The risk categorisation of licensed sites falls into 3 main categories (A, B, C) which are further broken down into 8 sub-categories (A1, A2, A3, B1, B2, B3, C1 and C2). This enables the EPA to apply resources to IPPC/Waste sites where its need is greatest. However, within the risk-based approach there is a need to focus on problems that are persistent and need a more holistic approach in order to deliver an outcome for the environment. On an annual basis the categories are reviewed and if necessary revised due to changes in compliance record, enforcement effort etc. The companies in the first instance undertake a 'self-review' followed by a review and final determination by the EPA. This is reflected in the annual licence fee charged to the company.

Mines are currently classified in the 'A' category under this methodology which approximates with the Category A under the Mine Waste Directive.

The EPA system of inspections is in line with EU 2001 Recommendation on Minimum Criteria for Environmental Inspections (RMCEI). Under this system the EPA:

- Produces an annual plan for inspections and audits
- Plans include focus or target subject areas
- Undertakes inspections in implementation of the plan
- Produces written reports of those site inspections and audits
- Issues report to mine company with corrective actions and deadlines
- Places reports and correspondence on public files
- Follows up inspections or actions (up to including legal action)

In general the guiding principles of the EPA's operation as set out in our enforcement policy are:

- Proportionality in application of environmental law
- Consistency in approach to all companies in different sectors
- Transparency on how the EPA operates
- Targeting of enforcement actions
- Implementation of the Polluter Pays Principle

In general the EPA's expectations of the operator and/or their external experts are:

- Transparency and communication with the regulator
- Operators should follow up on adverse observations or trends

- Close out of issues
- Be proactive in achieving Best Available Techniques

CONCLUSIONS

In 15 years of enforcement of this sector the EPA has proven to stakeholders that regulation and inspection of mines has been a positive process. It has ensured Best Available Techniques were adhered to in design, construction and operation. The process has grown public confidence both in the ability of modern mining practises and the response of the Agency to develop its expertise and procedures in order to police the sector. The EPA has worked closely and indeed co-ordinated with other main regulators in this area (Planning Authorities, Government agencies). As a result, potential new developers, normally coming from outside the country, will also have greater confidence in the competence of the regulatory regime here.

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QUANTIFYING THE HYDROGEOLOGICAL IMPACTS OF A MINING OPERATION AS PART OF AN EIA

EurGeol Kevin T. Cullen PGeo

ABSTRACT

Mining in Ireland could potentially be in an expansionary phase, with Ireland being the largest producer of zinc concentrates in Europe and the third largest producer of lead concentrates in 2011. There is an expectation that any proposed mining operation must comply with the provisions of the various licences and be carried out without causing damage to the environment. The Irish planning system has many players, each with its own rights, responsibilities, needs and goals. Depending on the nature and sensitivity of the issues involved, it is possible that each player could have its own technical advisor. In such a scenario, the numerical model and the geological and hydrogeological assumptions on which it is based might be reviewed possibly by 5 separate hydrogeologists. Therefore, recognising the uncertainty associated with hydrogeological systems and the degree of interrogation that any conceptual model and related numerical modelling are likely to undergo within the planning process is critically important, and as such it is advisable that significant time and resources are committed to collecting base line information, developing a robust hydrogeological model and then modelling a range of potential scenarios. Provision of good quality geological and hydrogeological information in the planning phase of the mine operation provides critical information that may be used in the operational and closure phases of the mine and ensures that the regulatory process is fulfilled without causing damage to the environment.

APPROPRIATE ASSESSMENT

When a company receives an exploration licence, undertakes an exploration programme and finds a mineable deposit there is an understandable expectation that mining, planning and operating licences will be granted by the various authorities. This expectation of course accepts that the proposed mining operation must comply with the provisions of the various licences and be carried out without causing damage to the environment.

Up to quite recently the Irish regulatory process was quite straightforward, if a bit lengthy, overlapping and extremely costly. However, there is recognition by Government that the protection of Natura 2000 sites under Articles 6(3) and 6(4) of the Habitats Directive takes precedence over the established planning procedures has complicated the permitting process.

Planning Authorities are now required to determine prior to any evaluation of a planning application whether the proposed project on its own or in combination with other plans or projects will or will not adversely impact upon any Natura 2000 site. As mining operations can impact on the environment many kilometres away from the mine site through the dewatering operation and discharges to surface waters it is likely that a planning authority will, through its screening process, determine that an Appropriate Assessment (AA) is required. In such circumstances the Planning Authority will most likely request that the developer prepare a Natura Impact Statement (NIS) prior to the Authority undertaking the AA. Where there are no Natura 2000 sites in close proximity to the mine site the AA would focus on possible *ex situ* effects on Natura 2000 sites located downstream or possibly in adjoining catchments. The level of detail that will be required to be submitted with a NIS remains to be seen.

Where the AA carried out by the planning Authority deems that no adverse effects will follow then the project can proceed to the usual planning system. Where the AA concludes that adverse effects are likely or cannot be ruled out then a derogation is possible, but only in cases of overriding public interest. It is not envisaged by Government that such derogations would apply to private projects other than those relating to infrastructural projects of vital public importance.

Hopefully, future mine proposals will not fall foul (no pun intended) of the Habitats Directive and that following a positive outcome from the AA process the projects can proceed with some confidence to the normal planning process.

ENVIRONMENTAL IMPACT ASSESSMENT

The completion of an environmental impact assessment (EIA) for a proposed underground mining operation in Ireland is not dissimilar to completing one for an industrial complex in a rural environment. Both will have a series of above ground buildings and structures which will be potential sources of impact to the human and natural environments. For example, both will have emissions to air and water and be a potential source of noise. Both will have traffic implications for the local road network and both will have potential impacts on the landscape, flora and fauna.

Regulating for emissions to air and noise sources is relatively straightforward in that emissions limits can be set at the stacks and noise levels can be prescribed for particular noise sensitive receptors. The nature and scale of the air emissions and noise sources can be managed through a range of engineering measures. Importantly, the modelling of stack and noise sources is accepted by the Regulator as a reliable method of predicting likely impacts both at the property boundary and at sensitive receptors.

The same situation exists for emissions to water from industrial processes where limits on flow and quality can be set depending on the sensitivity of the receiving waters. The discharge quantity will be a function of the scale and nature of the water usage involved within the industrial process and the level of treatment required will depend on the range of raw materials used within the plant. Again, the Regulator is provided with a high degree of certainty with accurate flow and process diagrams indicating the water inputs, the range of processes involved and finally the quantity and quality of the licensable discharge. Critically, the regulator has the option of requiring a reduction in the discharge quantity through the use of more efficient processes, should the receiving environment demand it.

It at this point that an EIA for an underground mining operation diverges somewhat from the normal industrial development in that there will be a high degree of uncertainty as to the quantity of water required to be discharged due to dewatering operation. Of course, an estimate is required for the regulatory process but as that estimate is founded upon a series of geological and hydrogeological assumptions, there is scope for the estimate to lack credibility among stakeholders and the regulatory agencies.

Dewatering rates vary from c.20,000 to 60,000 m^3/day (20 Ml/day to 60 Ml/day) for a mine in Ireland. To put these rates into perspective, the much talked about Bog of the Ring groundwater abstraction in north County Dublin abstracts a mere 4,000 m^3/day while 60,000 m^3/day is enough water for a population of 300,000……the population of Cork City and suburbs in 2011 was c.200,000!

Assuming that the quality of the discharge can be managed, i.e. using technology to achieve the required standard, then it is the quantity of the discharge that will determine the scale and range of potential impacts away from the mine area and within the receiving environments. The degree to which the discharge estimate, and by inference, the required dewatering rate, will be interrogated, scrutinised and argued over within the regulatory process will be, to a large degree, a function of the sensitivity of the surrounding natural environment and also the controversial nature of the proposed mining operation.

For example, some nearby landowners might argue that the actual dewatering rate will be much larger than predicted, with the result that the impacts will be greater away from the mine than those predicted and so the mitigation measures will be inadequate. Those Bodies with responsibility for groundwater and surface water dependant habitats (not Natura 2000 sites, such as Natural Heritage Area (NHA's) and proposed NHA's) might argue that the planned dewatering rate will damage protected habitats or alternatively that the discharge rate is an underestimate and so masks the full potential impact of the dewatering on the dependant habitats. The Developer will base the water usage of water within the milling and tailings operations on the projected available water quantities from the dewatering and will use the cost of the projected pumping rates within the project feasibility study.

Critically, it is not open to any of the stakeholders to control the required dewatering rate. The dewatering rate will be a function of the hydrogeology of the mineral deposit, the mining depth and to a lesser degree the mining method. If the actual dewatering rate is much lower than that predicted this may have implications for the milling and tailings processes as the systems will have been designed on the availability of a certain supply of onsite water. While if the actual rate is much greater than that predicted this may result in health and safety issues in the underground mine, and a greater degree of environmental and third party impact than allowed for within the regulatory process.

It is clear, therefore, that the determination of the projected dewatering rate for an underground mine must be founded on a realistic hydrogeological model for the mine and its environs. The model should be based on a sufficient number of data points, together with information on how the groundwater regime responds to recharge and pumping. An understanding of the hydraulic interconnectivity within the geological units will be important, as will the interconnectivity between the groundwater and surface water systems.

A reasonable estimate of the dewatering rate can be derived from the numerical modelling of the hydrogeological regime and this exercise can also provide information on impacts to nearby properties and dependant habitats. However, the level of confidence that can be placed on any modelled dewatering rate depends on the quality and representative nature of the data inputted into the model.

The Irish planning system has many players, each with its own rights, responsibilities, needs and goals. Depending on the nature and sensitivity of the issues involved, it is possible that each player could have its own technical advisor. In such a scenario, the numerical model and the geological and hydrogeological assumptions on which it is based might be reviewed possibly by 5 separate hydrogeologists. Also, each element of the regulatory process has an open ended time frame, i.e. there is no requirement for An Bord Pleanala or the Environmental Protection Agency to grant planning permission or the operating Licence within a fixed time limit.

Therefore, recognising the uncertainty associated with hydrogeological systems and the degree of interrogation that any conceptual model and related numerical modelling are likely to undergo within the planning process, it is advisable that significant time and resources are committed to collecting base line information, developing a robust hydrogeological model and then modelling a range of potential scenarios. The time and effort spent ensuring that the inputs and outputs from the numerical model will in general agreement could avoid delays often experienced through recurring requests for additional information or even worse, an adjourned oral hearing.

On a positive note, the issue of site selection which can take days to debate and argue over is essentially a done deal when dealing with a mining proposal……the development site is largely where the mineral deposit is……where the tailings dam should go is another question altogether!

BASELINE INFORMATION

Any financially viable mining project is usually founded on an extensive drilling programme directed at determining the minable reserves, the underlying geology and the most appropriate mining method. The geological model that describes the setting for the mineral deposit will also provide the principle geological features of the hydrogeological conceptual model including the stratification, the degree of jointing, the strike, dip and throw of faults and the distribution of any unconsolidated overburden.

The distribution of poor core recovery as reported from the exploration boreholes is also a useful indicator to areas of enhanced permeability, as is the identification of any buried channels in the bedrock surface.

Unlike the geological framework, the associated hydrogeological environment is dynamic, interconnected within itself, connected with the surface water environment and is responsive to climatic events. The regime has most likely has been established over many millennia and so can be considered to be in balance. The dewatering associated with an underground mine will interfere with the established regime and result in major groundwater flow changes both within the mine area and for possibly for a number of kilometres away from the mine.

To properly describe the existing hydrogeological environment it is necessary to have data on:

- i) Regional and local groundwater flow patterns, both vertical and horizontal, within the overburden deposits and the underlying solid geology;
- ii) The relationship between the groundwater flow patterns and the major geological features identified in the geological model. For example, are the faults acting as barriers to groundwater movement or is flow concentrated along these structures?
- iii) Areas of groundwater recharge and discharge, especially springs and sinks;
- iv) The response of the groundwater system to recharge events;
- v) The contribution of groundwater to the surface water drainage network. Information on the nature and permeability of stream and river beds is most useful. Also, available flow data can indicate whether surface flows are gaining or losing;
- vi) The location and operation of protected habitats and especially any groundwater and surface water dependant ecosystems;
- vii) The use and dependence upon by the local community on groundwater and surface water;
- viii) The location of all groundwater and surface water abstractions;
- ix) The distribution of surface water and groundwater catchments and the related surface water and groundwater bodies;
- x) The distribution of known karst features;
- xi) Monitoring of groundwater levels, together with the sampling of existing groundwater supplies.

The study area should be extensive enough to include for all possible issues of concern and a minimum radius of 5 km away from the mine area should be considered at the outset. The study area should be extended to incorporate protected habitats or sensitive groundwater features located on the edge of the initial study area.

It is most likely that a number of monitoring wells will have to be installed to provide information on groundwater flow directions and patterns. Care should be taken in deciding the distribution, location and structure of the groundwater monitoring points to ensure that the data gathered is sufficiently representative of the various geological environments identified in the geological model.

The monitoring period should exceed 8 months to ensure the capture of the winter high and summer low in the groundwater cycle. Monitoring should continue for the duration of the regulatory process and then as required under the various permissions.

STRESSING THE EXISTING GROUNDWATER REGIME

Predicting the likely scale of a mine dewatering operation requires information on the bulk permeability and storage of the host bedrock, together with information on the connectivity within the geological column and between the groundwater and surface water regimes. This information can be collected through a long term pumping test together with an integrated network of monitoring wells, flow meters, weirs and water level recording devices.

The location and structure of the pumping well(s) is critical to the success of the pumping test. Ideally the pumping well(s) should be located in an area of high permeability as indicated by the exploration boreholes and the intake should extend down as deep as possible. The diameter of the well(s) should be sufficient to accommodate a high yielding pump located close to the bottom of the well. The discharge from the pumping well(s) should be piped a significant distance away from the pumping well(s) to a free flowing stream to avoid any recharge of the pumped groundwater.

The distribution of the monitoring well network is equally important. The network should allow for the measurement of groundwater levels across identified geological features such as faults and on either side of the main surface water features. It is also important that the network allow for the measurement of groundwater levels in both the overburden and the bedrock at a sufficient number of locations to indicate the relative permeability of these two units.

The number of data points required will depend on the sensitivity of the local environment, especially in relation to groundwater dependant habitats. A significant increase in the number of data points will be required where a protected groundwater dependant habitat lies within the cone of depression likely to be associated with the mine.

A series of weirs should be established on small streams located within a reasonable distance of the pumping well(s) to measure the impact of the abstraction on surface water flows. Weirs should also be placed on springs deemed likely to be impacted. Flow measurements on larger streams could be considered, depending on the practicality and safety of the operation.

Consideration could be given to establishing a weather station at the mine site for the duration of the pumping test. However, a Met Eireann station may be close enough to provide reliable data.

Ideally groundwater levels and flows should be measured for at least a week before the pumping test is started and for a week after the test is ended.

Where a number of pumping wells are involved, the wells should be turned on and off in a sequence that allows for the easy interpretation of the draw down and recovery data.

Samples of the pumped groundwater should be collected at the start, mid way and at the end of the pumping test and forwarded for comprehensive analyses.

LIKELY SIGNIFICANT IMPACTS

The purpose of the pumping test is to provide some indication as to the permeability (k) and storage (s) of the various formations (particularly the vertical and horizontal variations in these parameters), the interconnectivity between the various units across faults and the relationship between the groundwater system and surface waters. Of equal importance are the samples of the pumped groundwater which will indicate the likely composition of the groundwater that will enter the mine workings and will ultimately require treatment before being discharged into the receiving waters.

The achieved pumping rate and the length of the pumping test play a critical role in the determination of the k and s values and the identification of hydrogeological boundaries. If the achieved pumping rate is representative of the permeability of the formations found at the mine then a reasonable level of confidence can be placed on the predicted initial dewatering rate. However, if the output during the pumping test is low then there is the risk that the calculated k value will lead to an under estimate of the dewatering rate that will actually be required.

The length of the pumping test is also important as sufficient time must be available for the spreading cone of depression to intercept recharge or no-flow boundaries. For example, failure to recognise no flow boundaries will lead to an over-estimate of the long term dewatering rate.

A numerical model can be used to calculate the likely long term dewatering rate using the range of k and s values determined from the pumping test. In addition to reflecting the known geological structure of the mine and surrounding lands, the model would also incorporate the hydrogeological boundaries identified during the pumping test, together with the established interconnectivity within the various geological formations and between the groundwater and surface water.

Ideally, the model should, in addition to providing a reliable estimate of the dewatering rate, be able to reliably quantify the:

- i) extent of the cone of depression associated with the mine dewatering;
- ii) extent of the lowering of groundwater levels away from the mine area;
- iii) effect of recharge and no-flow boundaries on the spread of the cone of depression;
- iv) changes in groundwater flow directions;
- v) loss of surface water flows;
- vi) loss of spring flows;
- vii) capture of groundwater from neighbouring catchments;
- viii) risk of subsidence due to groundwater withdrawals;
- ix) risk of induced sink hole development;
- x) risk of sudden inflows into the mine workings;
- xi) rate of recovery of groundwater levels following mine closure;
- xii) movement of any contamination plume associated with the mine on closure.

The numerical model could also be useful in determining the most appropriate dewatering method, with the objective of capturing as much groundwater as possible before it enters the mine workings, and so minimise the amount of groundwater requiring treatment before being discharged at ground level. Equally, the model could assist in determining the likely effectiveness of a recharge programme required to limit the spread of the cone of depression where a protected habitat might be at risk.

The degree of confidence that can be placed in the outputs from the numerical model depend on the:

- a) accuracy of the geological model derived from the exploration programme;
- b) scale, duration and representative nature of the hydrogeological monitoring effort;
- c) scale and length of the pumping test and related monitoring of groundwater and surface waters;
- d) capacity of the numerical model to reflect the variations in the geological framework, the interconnectivity within the hydrogeological regime and the connectivity between groundwater and surface water.

GROUNDWATER ISSUES IN THE TYNAGH MINE AREA

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ABSTRACT

Between 1965 and 1982 approximately 7.9 MT of ore grade mineralization was abstracted at the Tynagh Mine in east Galway. The zinc-lead mineralization is hosted in Mississippian carbonate rocks. Waulsortian (WA) Formation limestones form the host-rock for the main orebodies at Tynagh. The succeeding Lucan Formation (LU), which hosted a residual orebody, was weathered and karstified subsequent to deposition leading to its decalcification and collapse adjacent to a major fault in the area. The principal minerals at the site were sphalerite, barite and galena, and the major minerals mined were lead, zinc, copper, silver and barium sulphide. Water samples were recovered from twenty bored wells and dug wells wells close to the Tynagh mine site and to the mapped Tynagh-North Tynagh fault. Elevated levels of Fe, Mn, Ba, Ni and As were detected in a number of wells associated with the North Tynagh Fault. The fault structure appears to a major control on both groundwater flow and on the chemistry of groundwater in the fault.

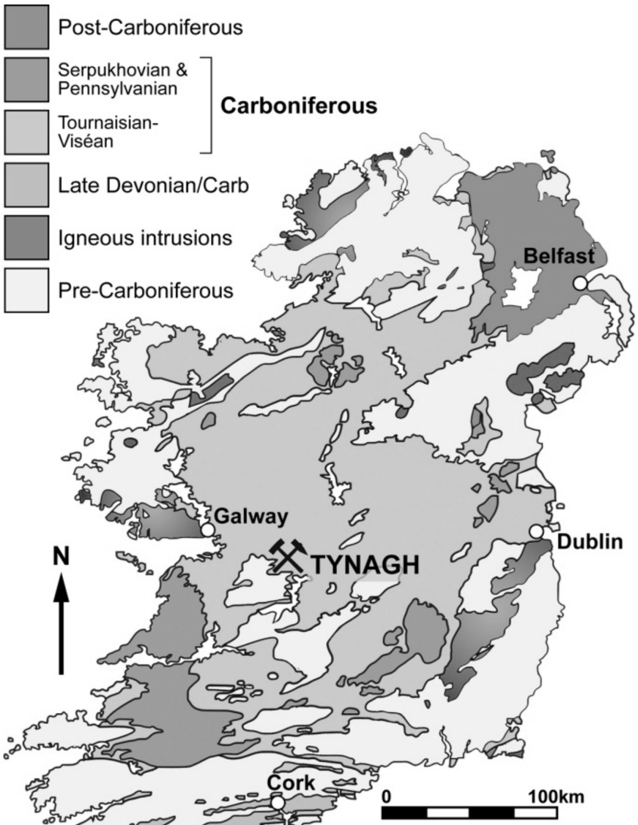

Figure 1- Simplified geological map of Ireland showing location of Tynagh Mine. Modified from Holland & Sanders (2009)

INTRODUCTION

A significant lead-zinc deposit of approximately 9.9 million tonnes (MT) of economic grade mineralisation was discovered near the village of Tynagh in east County Galway in 1961 (*Fig. 1*), representing the first major discovery of metalliferous minerals in Ireland (Kearns 1976). A mining lease operated at the site from December 1962 until November 1983, with open pit and underground mining conducted between 1965 and 1982 (Brogan 2003). Approximately 7.9 MT of ore grade mineralization was extracted during the life of mine (Johnston 1999). The mine site covers an area of approximately 115 hectares. Some limited remediation work was undertaken at the site upon completion of mining activity (Dallas & Good 1995).

Following consultation with interested parties the Environmental Protection Agency (EPA) undertook a study of the area reporting on the distribution of heavy metals in streams, sediments and tailings around the mine site (Brogan 2003). Groundwater was not investigated but one of the recommendations of the report was that a detailed groundwater study be completed.

The purpose of this report is to detail the work completed to date in characterising the hydrogeology of the area and to suggest possible linkages between groundwater chemistry and the structural geology. This represents the first detailed assessment of groundwater around the Tynagh mine site which involved identifying, mapping and surveying well head locations and elevations, recording of water levels and sample recovery and analysis. Data are presented and the findings are discussed in the context of geology, structure, and mineralization as well as in the regulatory framework.

SITE DESCRIPTION

BEDROCK GEOLOGY & MINERALISATION

Zinc-lead mineralisation in the Irish midlands is hosted in Mississippian (Carboniferous) carbonate rocks (Wilkinson 2010). In the Tynagh area (*Fig. 2*) Mississippian limestones overlie (upper Devonian) Old Red Sandstone (*ORS*), which in turn unconformably overlie Lower Palaeozoic greywackes and shales of possible volcaniclastic origin (Schultz 1968).

The *ORS* sediments consist of conglomerates, mudstones and sandstones. A granitic source has been proposed for the latter, with a moderate to high energy, shallow water depositional palaeoenvironment (Clifford *et al* 1986). The Lower Limestone Shale (*LLS*) is a transitional unit and consists of sandstones and shales, grading progressively upward to mudstones and thin limestones. This is overlain by a series of dark, well-bedded argillaceous calcarenites with laminated calcareous shales (Ballysteen Formation (*BA*)). This unit becomes increasingly muddy towards the top (Gately *et al* 2005). The overlying Waulsortian (*WA*) Formation is predominantly a carbonate mudbank facies, composed of massive biomicrites. These limestones form the host-rock for the main orebodies at Tynagh. The succeeding Lucan Formation *(LU)* is characterised by thinly-bedded, graded, intraclastic skeletal packstones and grainstones which are interbedded with shales and micrites.

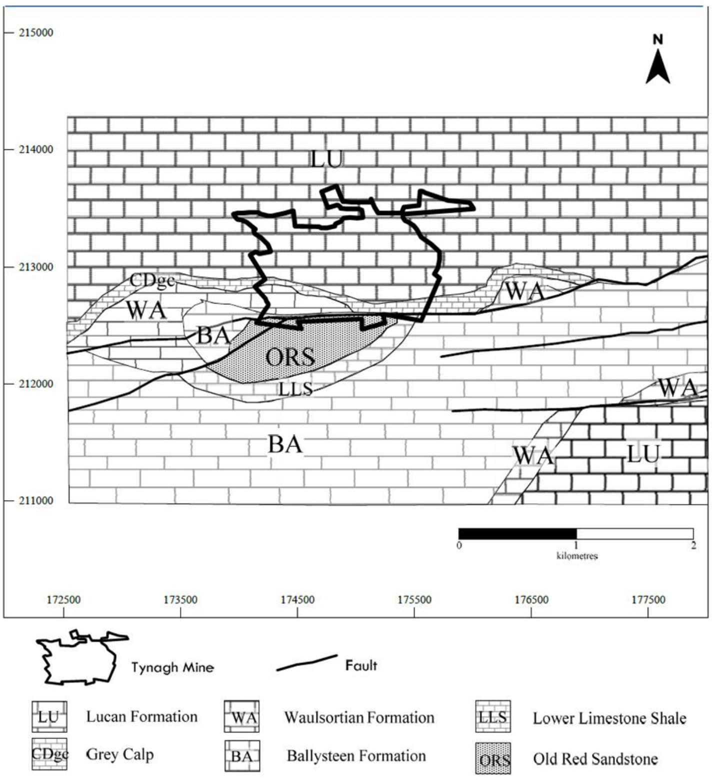

Figure 2: *Geology of Tynagh Mine*

The *LU* was weathered and karstified subsequent to deposition leading to its decalcification and collapse adjacent to a major fault in the area (*Fig. 2*). This unconsolidated material occupied an area approximately 600 m long and 50 m wide (Gately *et al* 2005). A residual orebody (rich in lead, zinc, copper and silver oxides and sulphides) developed in this weathered material (Clifford *et al* 1986). This graded down to bedrock to an underlying zone of massive sulphide mineralization hosted in the *WA*, this extended for approximately 900m along fault in the northerly hanging wall of the easterly trending North Tynagh fault (Clifford *et al* 1986). The deposit thinned out rapidly within 120 m north of the fault (Williams & Brown 1986).

The principal minerals are sphalerite, barite and galena, and the major minerals mined were lead, zinc, copper, silver and barium sulphide (Brogan 2003). It has been noted by several authors that Irish type base metal deposits are typically stratabound in lower Carboniferous carbonates formed in a marine transgressive sequence that overlies the late-Devonian *ORS* (Garven *et al* 1999). The Irish deposits are closely associated with faults which penetrate into the Lower Palaeozoic basement (Murphy *et al* 2008). Post depositional normal faulting facilitated the migration of ore-forming solutions upwards from the *ORS* (Johnston *et al* 1996; Garven *et al* 1999; Wilkinson 2010). The faults are thought to have allowed convectively driven metal-rich brines to flow from the underlying rock into the carbonates where mineralisation occurred.

HYDROLOGY & HYDROGEOLOGY

The entire area is part of the River Shannon catchment. Surface drainage is from west to east to the Kilcrow River (*Fig. 3*). As part of this study 39 wells in the area were surveyed and mapped and water levels have been recorded at these wells and flow maps derived, showing that groundwater flow direction is coincident with surface water patterns (west to east).

Aquifer Classification

The Geological Survey of Ireland (GSI) class the *ORS* and *LLS* as being *Poor Aquifers* because of their low conductivities (10^{-2}m/d) (Gately *et al* 2005). All of the remaining limestones in the area are classed as being *Locally Important Aquifers, moderately productive only in local zones* (*Ll*) (WFD Ireland 2005). The GSI report that groundwater developments in the *BA* and the *LU* formations are rarely successful (Gately *et al* 2005). Yields are low due to the presence of muds and fines in the rocks. The *WA* tends to be relatively pure and therefore susceptible to karstification; however, in this area there is little evidence of extensive karstification of the limestone. Indeed the classification is reflected by the well-developed surface drainage pattern in the area, suggesting the relative importance of stream discharge. This classification is based on a regional approach; local variations (or localised regional variations) are not accounted for in this scheme. While the majority of the wells tested in this work are poorly to moderately productive, reflecting the classification, structural controls on groundwater flows are evident. Six of the wells tested in this work are associated with the North Tynagh fault; Well 3 is west of the mine site, while Wells 9, 16, 17, 19 and 20 are found to the east. Wells 3 and 9 are deep, bored wells (greater than 50m deep) which are very productive and have yields more commonly associated with more productive aquifers.

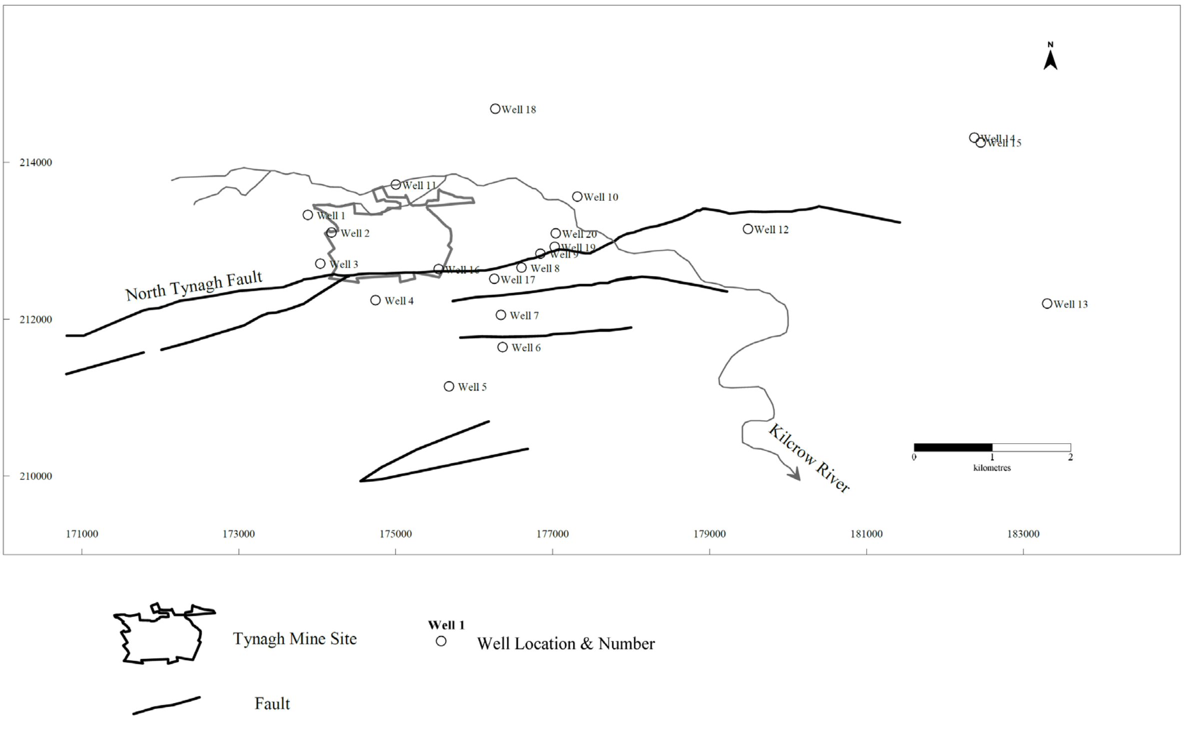

Figure 3 - Sample Well Locations

In the recently published Shannon International River Basin Management Plan (ShIRBD 2010) the region is almost entirely classed as being of Good Water Status in relation to groundwater, under the terms of the Water Framework Directive (WFD) (European Parliament 2000). The area immediately north of the mine area is classed as Poor Water Status in relation to groundwater and the mine site is classed as being of Good Water Status. This classification is based on a desk study and on surface water sampling carried out by the EPA in 2003. The zone identified as being of Poor Water Status is bounded by the two small streams running along the northern boundary of the mine (*Fig. 3*) and was delineated by surface drainage patterns and chemistry.

GROUNDWATER CHEMISTRY

Younger and Adams (1999) suggest that the behaviour of flooded, abandoned mine voids display marked similarities to karstified limestones. While the surface footprint of the Tynagh site is relatively small there were approximately 84 kilometres of underground workings excavated during the life of the mine (Brogan 2003). Following backfilling it is now estimated that 13 kilometres remains open. The open pit has flooded and remains flooded. Acid Mine Drainage (AMD) is considered the primary mechanism of groundwater contamination associated with mining (Younger & Adams 1999). Contaminated groundwater may be carried in the direction of the local or regional groundwater flow. The pollutant concentration, which has been in contact with the mine workings, is determined principally by the geology and hydrology of the area. The long-term chemistry of the groundwater leaving the site is governed by the recharge chemistry, the relative abundance of acid-generating and buffering mineral assemblages (Younger & Banwart 2002). In the case of Tynagh the buffering capacity of the local limestones is demonstrated by the relatively satisfactory surface water quality downstream of the site (Brogan 2003). There is no indication that groundwater quality has been affected by AMD based on the results of the current work. Groundwater may also at risk of contamination from leaching of wastes from the TMF and other surface storage facilities. There is some indication of uncontrolled runoff from the TMF during wet periods and there is potential for groundwater to be contaminated from this source.

Water sampling

Twenty (20) wells were selected based on a number of selection criteria: their location relative to the Tynagh mine site; their location relative to the mapped Tynagh-North Tynagh fault; well type (bored wells and dug wells); and location relative to groundwater flow direction (*Fig.* 3). Several wells were sampled on a number of occasions over a two-year period (labelled a, b, c and d). Samples were recovered as per the USGS Water Quality Field Manual (Wilde & Radtke 1998).

Groundwater analysis

The results of the analyses are presented in Table 1. Figures 4 and 5 graphically represent the surface water samples taken by the EPA in 2003 and the groundwater samples taken as part of this work, respectively. The EPA values (*Fig. 4*) are all surface water samples and they reflect the sample points. The values with high SO_4 levels are located on the mine site or in the immediate vicinity of the mine site. Samples recovered from streams upstream and downstream of the site are calcium and bicarbonate waters showing little indication of contamination. The surface waters leaving the mine site are enriched but are buffered almost immediately on leaving the site. The groundwater samples (*Fig. 5*) are predominantly calcium-bicarbonates, with one distinct outlier (Well 2) sourced from a shallow dug well located within 10 metres of the tailings facility (*Fig. 3*).

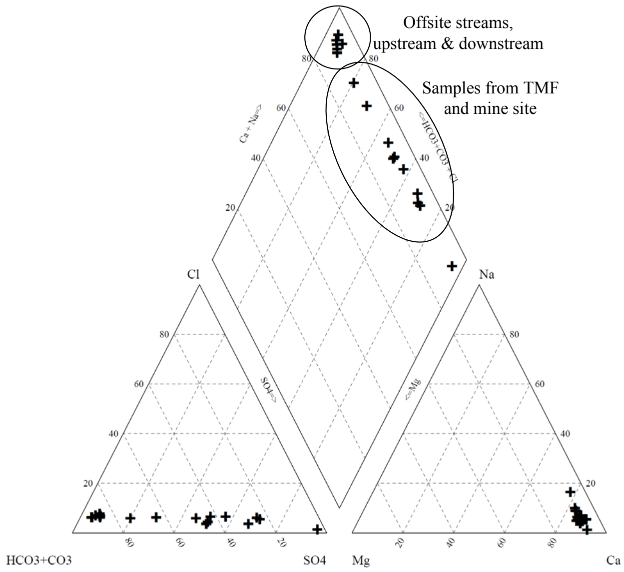

Figure 4 *EPA Surface Water Samples (2003)*

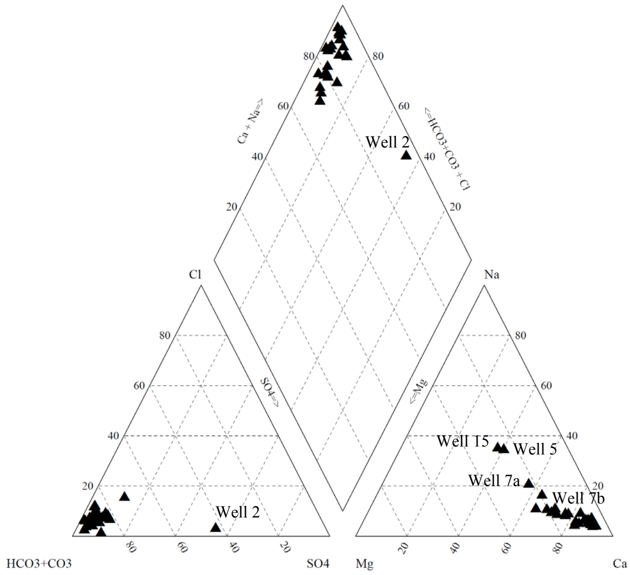

Figure 5 *Groundwater samples*

Groundwater Threshold Values (GTV) have been established in Irish law under SI No 9 of 2010 (as required under EC Directive 2006/118/EC (European Parliament 2006)). Prior to publication of the Directive the Geological Survey of Ireland (GSI) and the EPA published Guideline Values (IGV) as suggested target values (EPA 2003).

In reference to the samples recovered as part of this study, dissolved trace elements were dominated by iron, manganese, zinc, copper, barium, nickel and arsenic (the range of values is shown in Table 1), all of which were found in concentrations that exceed both the GTV and the IGV. The exceedences are in elements that are associated with the mineralisation in the area or are associated with limestones in Ireland. Only one elemental exceedence (for arsenic) has significantly implications in terms of human health.

Well 2 is a shallow dug well located within 10 metres of the TMF and susceptible to direct runoff from the mine site. Well 15 is a deep (>100 m) well sited several kilometres east of the mine site. The elevated levels of Fe, Ba, Mn and As in samples recovered from Wells 3, 9, 16, 17, 19 and 20 exceed GTV and IGV. Iron is an abundant metal commonly found in groundwater (EPA 2001) with no health-based guideline value proposed by the WHO (WHO 2003a). Manganese is commonly found in Irish groundwaters and is commonly associated with iron.

Table 1: Groundwater analysis results for wells in Tynagh catchment

Well No	TDS mg/l	EC µS/cm	Cl mg/l	SO4 mg/l	Na mg/l	K mg/l	Mg mg/l	Ca mg/l	Cu µg/l	Fe µg/l	Mn µg/l	Zn µg/l	Pb µg/l	Ba µg/l	Cd µg/l	Ni µg/l	As µg/l
1	325	700	12.4	12.1	9.9	2.1	6	146.3	6.1	<5	<1	21.9	<0.3	5.7	<0.1	2.8	<0.2
2	600	**947**	15.4	**296**	12.3	2	5.9	**209.5**	4.3	166.2	**134.7**	**152.7**	5.4	26	<0.1	0.8	0.3
3a	290	437	22.9	6.1	11.1	3	7.8	79.9	<3.0	**3302**	**54.32**	24.2	4	35	<0.1	1	0.5
3b	205	415	21.3	5.44	10.8	2.5	8.2	75.6	<3.0	**1880**	20.7	6.7	0.4	26.8	<0.1	0.8	0.3
3c	195	432	16.4	3.16	9.3	2.6	7.8	70.6	<3.0	**2394**	40.8	4.9	0.7	35.1	<0.1	1	<5.0
4	240	591	21.4	15.2	10.9	**9.6**	5.7	115.4	5.6	19.3	3	9.4	0.7	**402.9**	<0.1	0.8	0.4
5	395	534	21.5	24.1	50.5	2.6	18.9	50.2	2.4	103.2	5.5	6.7	0.4	15.5	<0.1	0.8	0.6
6	330	597	16.5	5.12	9.3	**8.4**	4.6	123.4	**23.5**	23.4	19.1	**133**	1.2	***97.7***	0.1	3.9	0.2
7a	410	590	16.5	11	34.9	2.1	19.1	80.6	7.5	**1855**	**51.4**	19.8	<0.3	**271.8**	<0.1	0.7	0.4
7b	290	552	17.1	21.7	23.4	1.9	13.9	76.7	<3.0	120	**52.9**	4.9	0.5	73.2	<0.1	0.5	**11.3**
8	220	595	28	13.4	12.5	0.9	5.9	135.4	<3.0	9.7	2.7	24	2.3	**381.3**	<0.1	1.3	<0.2
9a	210	540	15.1	22.5	14.5	1.8	14	99.4	<3.0	**10200**	**88.9**	***91.1***	**20.2**	**140.9**	<0.1	5.2	**299.2**
9b	215	447	14.2	14.6	13.8	1.7	13.1	73.6	<3.0	**12800**	**392.8**	58.4	1.9	**97.4**	<0.1	4.2	**113.7**
9c	320	553	13.5	20.1	14.1	1.7	14.4	97.2	5	**512**	**196**	32	0.4	**123.4**	<0.1	3.99	**54.2**
9d	270	539	12.8	17.4	13.5	1.9	13.4	82.8	<3.0	**5330**	***40.2***	40.9	0.4	**116**	<0.1	2.1	**14.7**
10	285	695	18.2	30.6	10.9	5	7.3	149	22.7	48.3	<1.0	17.2	1	17.4	<0.1	6.6	0.5
11	305	571	18.9	21.8	18.2	1.7	20.2	88.4	<3.0	**474**	**90.4**	12.6	0.4	**105.8**	<0.1	3.2	3.6
12	230	597	16.6	28.1	10.1	0.9	9.9	131.3	4.1	**33200**	**1565**	40.5	1.6	**222.5**	0.2	17.6	0.3
13	200	432	12.3	24.5	10.6	**8.5**	4.4	77.8	10.4	**247.9**	18.7	9.4	0.8	19.2	<0.1	1.8	0.4
14	340	706	16.4	15.7	8.5	2.5	5.8	149.4	34	<5.0	<1.0	12.7	1	11	<0.1	1.3	<0.2
15	335	572	20.9	30	55	1.4	21.9	50	<3.0	<5.0	16.7	2.3	<0.3	90.4	<0.1	<0.5	<0.2
16	315	497	16.4	7.9	8.6	0.8	8.1	97	4	**697.9**	**120.3**	40.2	1.5	**328.3**	<0.1	**25.8**	**48.7**
17	340	630	26.4	12.2	13.3	2.1	4.1	131	5.9	**250.2**	40.1	19.8	**11.8**	**405.7**	0.3	**35.5**	0.9
18	380	780	**35.8**	35	20.3	**7.3**	8.8	159	<3.0	10	2.8	7.1	<0.3	23.3	<0.1	3.1	0.3
19	320	585	**39.5**	36.9	21	2.2	16.3	99.3	8	**1044**	**145.1**	28.5	3.9	**467.6**	3.5	3.2	**17.8**
20	385	739	15.6	91.7	9.5	0.9	8.2	185.1	10	**28580**	**2474**	**389.8**	7.9	**537.2**	<0.1	**249.6**	**15.6**
GTV		**800-1875**	**24-187.5**	**187.5**	**150**				**15**				**18.75**		**3.75**	**15**	**7.5**
IGV		**1000**	**30**	**200**	**150**	**5**	**50**	**200**	**30**	**200**	**50**	**100**	**10**	**100**	**5**	**20**	

Groundwater Threshold Values: Statutory values in Irish law (SI No 9 of 2010)
IGV: Irish Guideline Values produced by EPA & GSI before publication of EC Directive 2006/118/EC

The IGV is 50 µg/l while the WHO guideline value is 400 µg/l (WHO 2004a). The WHO recommended guideline value is exceeded in Wells 12 and 20 (and is almost matched in Well 9). There are no specific health risks associated with such levels.

A naturally occurring mineral, barium was one of the main gangue (host) minerals associated with the economic deposits at Tynagh (as barite, BaS). It is a List II substance and the EPA (2001) state that "excessive amounts of barium can cause muscular, cardiovascular and renal damage. Although not markedly toxic, barium in excessive quantities is clearly undesirable". The IGV is 100 µg/l and this level is exceeded in 11 of the surveyed wells. However, these levels do not exceed the WHO Guideline Value of 700 µg/l (WHO 2004b). Typically, lower concentrations in water supplies are controlled by the barium sulphate solubility equilibrium. Hem (1992) notes that high barium concentrations can be associated with low sulphate concentrations; sulphate reduction keeps the sulphate concentrations low, enabling the barium to increase. This matches the pattern in the sampled wells (and is reversed in Well 2: high sulphate and low barium).

Copper is naturally present in metalliferous areas (EPA 2001) and was one of the major minerals extracted at Tynagh (Brogan 2003) as chalcopyrite ($CuFeS_2$), tetrahedrite ($Cu_{14}Sb_4S_{13}$) and bornite (Cu_5FeS_4). The GTV is 1500 µg/l (the IGV is 30 µg/l) and the WHO Guideline value is 2000 µg/l (WHO 2004c). Zinc is a naturally occurring mineral and was one of the major minerals mined at Tynagh as sphalerite (Zn,FeS) (Brogan 2003). However, the WHO has not derived a health-based value for zinc concentrations in drinking waters, noting that concentrations above 3000 µg/l have an undesirable astringent quality (WHO 2003b). Nickel is a white, hard, ferromagnetic metal (WHO 2005). The principal sources of nickel in drinking water are industrial wasters (EPA 2001). Nickel compounds are carcinogenic and metallic nickel is possibly carcinogenic (EPA 2001). The GTV is 15 µg/l (the IGV is 20 µg/l) and the WHO guideline value is 70 µg/l (WHO 2005). Nickel was detected in four wells (Wells 12, 16, 17, 20).

Arsenic can occur in several oxidations states in the environment (-3, 0, +3, +5) but in natural waters it is mostly found in inorganic form as trivalent arsenite (III) or pentavalent arsenate (V) (Smedley & Kinniburgh 2002). In well oxygenated surface waters, arsenic (V) is generally the most common arsenic species present (Irgolic 1982; Cui & Liu 1988); under reducing conditions, such as those often found in deep lake sediments or groundwater, the predominant form is arsenic (III) (Lemmo *et al* 1983; Welch *et al* 1988). Smedley and Kinniburgh (2002) report that redox potential (Eh) and pH are the most important factors controlling arsenic speciation. Eh and pH values were recorded in the field during the well sampling suggesting that arsenic speciation is likely to be arsenite (III).

Arsenic was one of the principal ore minerals present at Tynagh in the form of arsenopyrite (FeAsS) (Brogan, 2003). The WHO (2003c) report that the practical quantification limit for arsenic is in the region of 1–10 µg/l, and removal of arsenic to concentrations below 10 µg/l is difficult in many circumstances. In view of the scientific uncertainties, the WHO guideline value (10 µg/l) is designated as provisional. They further state that "in many countries, this guideline value may not be attainable; where this is the case, every effort should be made to keep concentrations as low as possible".

DeHay *et al* (2004) noted a relationship between elevated arsenic and iron concentrations in groundwaters in the Picher Mining District in Oklahoma and they suggest that the source of the arsenic might be the dissolution of iron-containing sulphide or oxy-hydroxide minerals. Hem (1992) suggests that concentrations of up to 1.0 mg/l in drinking waters have produced no apparent ill effects, where the concentration was reached for short periods; however, he suggests that long term use of drinking water with concentrations of 0.21 mg/l (210 µg/l) can be poisonous. Arsenic levels are below the GTV (7.5 µg/l) in all but five wells.

CONCLUSIONS

Groundwater recovered from the wells for analysis is reflective of the bedrock geology and is largely described as $CaCO_3$ (calcite, dolomite) water. While a small number of wells were sampled up-gradient of the mine site, the main focus of the sampling in this study was on the wells down-gradient of the mine site.

Well 2 is a shallow, dug well that is located within 10 metres of the mine site boundary. This well is not used for any domestic or agricultural purpose. A large number of exceedences are recorded for this well and these are most likely associated with uncontrolled surface water runoff from the adjacent mine site. Elevated sulphate levels are associated with the processing of the main minerals recovered from the wells (galena, sphalerite, chalcopyrite, tetrahedrite and bornite (Brogan 2003)). Wells 3, 9, 16, 19 and 20 are bored wells all of which are finished on the (mapped) north side (the hanging wall) of the North Tynagh fault and it is likely that all intersect the fault (3 & 9 are both deep wells and during the sampling phase limited drawdowns were achieved during purging).

The North Tynagh fault acts as a conduit for groundwater flows, and while providing excellent *quantities* of water to wells the *quality* of the water is affected by mineralisation associated with the fault and by recharge to the fault zone. While it is not possible from the current study to positively identify the specific source of these elevated concentrations it is likely that they result from a combination of natural and anthropogenic sources (the naturally occurring mineralization, the underground workings, the TMF and other surface storage of mine waste).

The North Tynagh fault has been extensively mapped and it facilitated the precipitation of economic deposits of minerals. During the underground mining phase at Tynagh large inflows of water occurred in localised zones associated with the North Tynagh fault. It would appear that there is an association between groundwater chemistry, well depth, well location, mine location and structural geology in the area. Further, more detailed work will be have to be undertaken to determine, if possible, the specific sources of dissolved metals in the local groundwater. It should be noted, however, that it may not be possible to absolutely isolate the sources of these metals. However, it would appear that any future assessment such as that recommended by the EPA and GSI in 2010 (Stanley *et al* 2010) must be based on the recognition of the intimate relationship between groundwater, geology and structure and that existing management plans should be amended to recognise these relationships. It is unlikely that the WFD 2027 deadline to have all surface and groundwaters in the area classed as being of good status will be met without a focused remediation plan being devised and implemented for the site. Remediation should be aimed at reducing production of new leachate and should focus on better management of the surface waters on site and on capping and seeding the TMF. Both of these measures will have a positive impact on surface water runoff and will reduce additional downward leaching of elements to groundwater. Managing the costs of this remediation will be critical and assigning the costs will be even more so.

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SESSION III

THE EXTRACTIVE WASTE REGULATIONS: EPA GUIDANCE TO LOCAL AUTHORITIES

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INTRODUCTION

On 23 December 2009, the Waste Management (Management of Waste from the Extractive Industries) Regulations 2009[1] (the "Extractive Waste Regulations") transposed EU Directive 2006/21 on the Management of Waste from the Extractive Industries ("Directive 2006/21") into Irish law. The legislation is complex and hardly user-friendly. Perhaps as a consequence, the Irish regulations require the Environmental Protection Agency (EPA) to develop guidance to local authorities to assist them in the discharge of their functions.

The purpose of Directive 2006/21 was to take a Europe-wide initiative to prevent further catastrophic failures of containment systems at extractive waste facilities. A number of these collapses had occurred in the period prior to the completion of the Directive and there remain to this day concerns that inadequately engineered containment systems may present a significant risk to human health and to the environment.

While many of the more recent incidents at extractive waste facilities involved uncontrolled emissions of hazardous waste from lagoons and tailings ponds, sites where inert waste has been deposited also are subject to the Directive. The instability of some quarry spoil tips may cause a significant danger to proximate land occupiers, while also having the potential to cause environmental damage. Indirect impacts may result, such as the obstruction of local drainage systems and consequent flooding.

Directive 2006/21 therefore has a wide scope, applying to all activities that are embraced by the term "extractive industries". This covers not only the mining sector and its hazardous wastes, but also extends to inert waste arising from quarrying, sand and gravel extraction, and related activities. The EU legislation also impinges upon IPPC-licensed extractive activities.

THE EPA'S GUIDANCE NOTE

A guidance note on the Extractive Waste Regulations was prepared by this author under an EPA contract. The work also involved a telephone survey of some local authorities regarding the more difficult aspects of the legislation and their enforcement needs. A draft of the note was circulated by the EPA for external comment in 2011, with responses being received from the Department of the Environment, Community and Local Government, the Society of Chartered Surveyors Ireland, the Irish Concrete Federation, the Irish Mining and Quarrying Society and from three local authorities. The finalised version is due to be issued shortly.

It is important to understand that the content and focus of the EPA's guidance accords to the mandate set by the Extractive Waste Regulations. This is quite specific[2], requiring that the guidance should assist local authorities in the carrying out of the functions conferred on them by the legislation. This objective is reflected in the style, chapter headings and content of the finalised document. Because the whole issue of the definition of "extractive waste" is a difficult one, being dependent upon statutory interpretations developed by the Court of Justice of the European Union, the guidance also contains a lengthy discussion of this issue in an appendix.

[1] SI 566 of 2009
[2] SI 566 of 2009, Regulation 22(6)

KEY ASPECTS OF THE EXTRACTIVE WASTE REGULATIONS

The bulk of the Extractive Waste Regulations focuses on improving the quality of management of the most hazardous types of extractive waste facility. All of these sites are termed "Category A facilities", and include IPPC-licensed mine tailings repositories. Local authorities are required to identify any additional sites that may warrant Category A status. Such sites will include quarry spoil tips containing inert waste where significant instability arises.

Besides Category A facilities, the legislation breaks down other extractive activities into five classes. These echo the common types of extractive activity and reflect the appropriate level and complexity of their regulation. The classes entail sites involved in:

- extractive waste created by minerals prospecting activities
- inert waste resulting from the extraction, treatment and storage of mineral resources and quarrying
- the deposit of unpolluted soil from extractive activities
- the extraction, treatment and storage of waste peat
- the handling of non-hazardous, non-inert extractive waste.

With the exception of any extractive waste facilities that are a consequence of prospecting for minerals or facilities that are licensed or licensable by the Agency, local authorities are responsible for regulating all non-Category A sites. Most of these will involve quarrying or sand and gravel extraction.

These generic classes reflect the level of environmental risk associated with the material being handled. Accordingly, the Extractive Waste Regulations specify that no licence or permit normally would be needed to authorise a facility solely handling inert extractive waste that has been generated on-site or for sites that handle only waste peat or unpolluted soil. However, extractive waste facilities that contain non-hazardous, non-inert waste are considered to be more environmentally significant and therefore are required to be subject to the waste facility permit regime that is consequent to the Waste Management (Facility Permit and Registration) Regulations 2007[3].

While most extractive waste facilities will not be subject to waste facility permits, other elements of the Extractive Waste Regulations apply at all sites operated by the extractive industry. In summary, this includes:

- a general legal obligation that extractive waste does not cause a danger to human health or an unacceptable risk to the environment[4] or cause environmental deterioration[5]
- the duty on all site operators to draw up extractive waste management plans[6]
- the requirement that operators ensure that good practice is incorporated into an extractive waste facility's design, operation, closure and aftercare[7].

Besides having the duty to enforce the above-mentioned requirements at all extractive sites located in its functional area, each local authority also has a number of other statutory functions under the Extractive Waste Regulations. These include:

- the production of a publicly-available external emergency plan for any Category A site[8]

[3] SI 821 of 2007, as amended by SI 86 of 2008, SI 508 of 2009, by the Extractive Waste Regulations (Regulation 23) and by SI 126 of 2011
[4] SI 566 of 2009, Regulation 4
[5] SI 566 of 2009, Regulation 13
[6] SI 566 of 2009, Regulation 5
[7] SI 566 of 2009, Regulations 10-12
[8] SI 566 of 2009, Regulation 6

- the duty to notify the EPA of any additional potential Category A facility it comes across[9]. As noted, these will be quarry spoil tips or lagoons exhibiting significant instability
- the responsibility to compile a register of all extractive industries in its functional area[10].

It has been noted that the Extractive Waste Regulations are not an easy read. This is partly because they closely follow the wording of Directive 2006/21, which is itself hardly user-friendly. Accordingly, it is useful to understand certain preliminary concepts:

- the legislation only applies to "extractive waste" and, in this respect, there are certain exclusions
- there is a need to differentiate between extractive "waste" and other by-products at an extractive site; this issue can be become quite complex in respect of quarry backfilling
- by no means does all of the legislation apply to every extractive site[11]
- there are different cut-offs which exclude certain extractive sites from the legislation, either entirely or partially. These affect historic waste facilities[12], as well as the active, but short term, storage of materials such as inert waste
- while some elements of the legislation place obligations on operators of extractive waste facilities, other obligations fall on operators that manage extractive waste or on the extractive industry. There are some significant differences between the scope of these different requirements
- by focusing principally on extractive waste or on extractive waste facilities, the legislation does not impinge upon other, non-waste related, activities at quarries and other sites
- both the Irish legislation and Directive 2006/21 must be read in conjunction with a series of EU Decisions. These Decisions have not been incorporated into the text of the Extractive Waste Regulations, but should be regarded as a series of supplements/clarification to the national legislation.

KEY CONCEPTS: 'WASTE' AND 'WASTE FACILITY'

Subject to one exception[13], the Extractive Waste Regulations only relate to the management of "extractive waste". The key word is here is the word "waste". Accordingly, it is vital to understand the scope of this term, particularly to differentiate it from stockpiles of quarry products that are to be sold, in respect of the regulatory status of bunds, acoustic screens and similar structures, and so on.

A key element within the definition of "waste" is that waste is something the holder "discards or intends or is required to discard"[14]. A significant body of case law on this issue has been produced by the Court of Justice of the European Union. Some of this has a direct bearing on extractive waste[15]. It indicates that there are a wide variety of relevant factors involved in determining whether a substance or object is "waste", not all of which will be applicable to every circumstance when a debate about the definition of waste arises. This means that such decisions must be made on an individual basis, following a site-specific and case-by-case approach. Naturally, this approach makes it difficult to set down rules that will apply in all instances.

Since 31 March 2011, the definition of "waste" in the Waste Management Act must also be viewed

[9] SI 566 of 2009, Regulation 9
[10] SI 566 of 2009, Regulation 19
[11] For example, Regulation 2(4) states that some parts of the main body of the Extractive Waste Regulations do not apply at all to sites that handle only inert waste or unpolluted soil. Regulations 7, 8, 11(1) & (3), 12, 13(6), 14 and 15 are all excluded for sites of this type, unless the site is a Category A facility.
[12] Regulation 21(4) sets a series of cut-off dates for sites that closed before December 2010
[13] Regulation 19 and the requirement for local authorities to register all extractive activities
[14] Waste Management Act, Section 4(1), as amended by the European Communities (Waste Directive) Regulations 2011, SI 126 of 2011, Article 4
[15] See, for example, Palin Granit, Case C-9/00, 18 April 2002 and AvestaPolarit, Case C-114/01, 11 September 2003. These are available on the Court of Justice of the European Union's web-site, http://curia.europa.eu/jurisp/cgi-bin/form.pl?lang=en

within the context set by Regulations 27 and 28 of the European Communities (Waste Directive) Regulations 2011[16]. Respectively, Regulations 27 and 28 set down additional decision criteria distinguishing waste from by-products and when what was hitherto defined as "waste" ceases to be so after recovery. The latter often are termed "end-of-waste criteria". These provisions are discussed further in the EPA guidance document.

The EPA's guidance also contains a detailed discussion of all of the relevant judgments from the Court of Justice of the European Union. In summary, the following principles are particularly significant in the context of whether something arising from an extractive activity is to be viewed as "discarded":

1. whether a material falls within the scope of the Extractive Waste Directive and the Extractive Waste Regulations has to be assessed on a site-specific, case-by-case basis
2. a key precept within such an assessment is the need to ensure that the objectives of the EU Directives on Waste and Extractive Waste are fulfilled, with the environment and the public being subject to a high level of protection that reflects the precautionary principle
3. the physical or chemical nature of a material does not determine whether it is waste; extractive waste can range from topsoil to inert materials to hazardous waste. Also irrelevant is whether a material has the same physical or chemical composition to other products that are marketed by the site operator
4. whether a material has a value does not mean that it is not a waste; neither does the fact that it can be re-used or recycled in an environmentally beneficial manner
5. the definition of waste can include materials that are sent off-site and also those which are recovered or re-used on-site
6. a waste is typically a substance or object that is generated by an extractive or other industrial activity in circumstances when its production is not the main purpose of that activity. Instead, it is something that inevitably arises from it, constituting a material that the site operator needs to reduce as much as is physically, technically and economically possible
7. if a substance or object arises from some process where its production is not the objective of that process, it is likely to be a waste. This will usually be the case where additional operations are necessary to make it suitable for use, particularly when they are not integral to the actual production process and have to be undertaken separately or off-site
8. where an extractive waste is processed with a view to changing its physical or chemical properties, the level of processing must be sufficient for it to have identical properties to other, non-waste-based substances or objects for which there is a market
9. a material stored on-site that has no definitive future use is likely to be a waste, particularly when the site operator cannot point to any clear plans for it. This principle applies to both primary products and materials that have been re-processed
10. a material may not be a waste when it is clear that it is to be dealt with by a process that is integral with the main production operation. If this is the case, a distinct and credible timeline for such processing must be certain, and a market must exist for it
11. back-filling processes at quarries and at other extractive sites may be regarded as integral production operations, provided that the back-filling fulfils a clear, credible and defined purpose which is subject to an explicit and binding timeline. That purpose must not be to rid the operator of the material that is to be deposited
12. a defined purpose in respect of backfilling will include the need for an operator to respond to some type of obligatory requirement. Examples of such a requirement include an obligation of a planning condition, a lease or other similar legal document. In all of these respects, the operator of the extractive activity must be able to provide a comprehensive demonstration that the likelihood of the backfilling operation is certain and will take place within a clear and definite timeframe.

Naturally, given the need for a case-by-case approach, not all of the above will be relevant in all

[16] SI 126 of 2011

circumstances. In all instances, the key parameter is the need to follow the principles that underlie EU law and the Court of Justice's jurisprudence.

Along with the word "waste", the term "waste facility" is used extensively in the Extractive Waste Regulations, with a number of the statutory requirements applying solely on the part of an extractive site that falls within this definition. The most important aspect of the definition[17] is its time limits. Unless these are exceeded, a location where extractive waste is deposited does not constitute a "waste facility" under the Regulations.

For the local authorities charged with regulating extractive sites, the most significant of these is the three-year cut-off that applies to the storage of unpolluted soil, peat waste or inert extractive waste. This means that no heap of inert quarry-derived waste falls within the definition of a "waste facility" unless the area in which it is put has been designated[18] for that purpose for a period of more than three years. In turn, this means that places where inert quarry wastes have been deposited for less than this period are not subject to the provisions of the Extractive Waste Regulations which pertain to "waste facilities".

For non-inert, non-hazardous extractive waste, a deposit of this type of material constitutes a "waste facility" when the designated area has been used for the much shorter period of one year.

While the temporal part of definition of "waste facility" causes certain parts of the Regulations not to apply[19], other elements of the legislation affect all extractive sites. This includes the need for operators to produce extractive waste management plans and the requirement that such sites are registered by a local authority.

KEY PROVISIONS: PROTECTING THE ENVIRONMENT & WASTE PLANS

Following Directive 2006/21, a principal objective of the Extractive Waste Regulations is contained in Regulation 4. This places a duty on all operators in the extractive industry to ensure that extractive waste is managed in a manner that protects the environment and human health. As Regulation 4's obligations relate to the handling of "extractive waste", it applies to all sites where extractive waste is held. The scope of this provision is not confined to sites that fall within the legislation's definition of "waste facility".

Regulation 5 to the Extractive Waste Regulations sets down obligations on extractive site operators to produce a waste management plan. The EPA guidance indicates that there are only some very minor exceptions to this rule. Plans need to be drawn up for all quarries, sand and gravel extraction sites, locations where peat extraction takes place and other similar facilities operated by the extractive industry.

It follows, therefore, that, as any extractive site may produce extractive waste at some point in its life-cycle, all operators of such sites are obligated to develop an extractive waste management plan. This position holds even in respect of sites that are founded on the objective of producing no waste at all, including those activities that operate is such a way that all of the material extracted is sold on. This is because, in accordance to the definition of "operator", a person[20] running this type of extractive site is still "responsible" for the management of "extractive waste": in the sense that one of the key aspects

[17] SI 566 of 2009, Regulation 3(2). It also should be noted that the backfilling of excavation voids is excluded by the final part of this definition. This matter is discussed in more detail in the EPA's guidance document
[18] What "designated" means in this context is covered by the EPA's guidance
[19] For example, Regulation 11 requires monitoring and inspection records to be kept in relation to the management of a "waste facility".
[20] The definition of "operator" makes clear that this term embraces companies, partnerships and so on, as well as individuals

of this type of operation is to avoid producing such waste in the first place[21].

The EPA Guidance states that an extractive waste management plan is not to be a highly detailed and complex document. Its key focus is on documenting "the minimisation, treatment, recovery and disposal of extractive waste, taking account of the principle of sustainable development"[22]. Accordingly, the plan must reflect the need to prevent or reduce both the production of extractive waste and its harmfulness[23], to encourage the recovery of extractive waste[24] and to ensure its short- and long-term safe disposal.

Within these objectives, the Extractive Waste Regulations place an emphasis on the design of an extractive waste facility, with this being founded on the concept that effective design will reduce the production of extractive waste, encourage its recovery and minimise short- and long-term liabilities. Indeed, one of the goals is to ensure that, where possible, a completed waste facility can be left without the need for on-going monitoring[25]. Within this type of consideration, long-term geotechnical stability is a key factor[26].

Additional content of an extractive waste management plan is specified by Regulation 5(3). The plan must include the following information:

- a statement indicating which category of waste site the facility falls within: inert; non-inert, non-hazardous; unpolluted soil or peat waste
- details on the nature of the extractive waste produced at the site, covering the composition of the material, its leachability and so on
- estimates of the total quantities of extractive waste that will arise from the operational phase of the site
- a description of the extraction operations and of other processes that are the source of the waste, as well as any additional treatment method applied to the waste after it has arisen
- a description of possible environmental and human health impacts arising from any extractive waste being deposited at the site, along with details of preventative and impact minimisation measures over the site's life-cycle
- a justification of the siting of any extractive waste facility, including information on its design, the measures necessary to prevent pollution to any environmental media, the arrangements for the handling any contaminated water or leachate, erosion prevention measures and the provision being made to ensure that there are not unacceptable dust emissions[27]
- details of proposed monitoring, control, site inspection and corrective action procedures. Where excavation voids are to be back-filled for site restoration purposes, the plan must include information on how issues relating to stability and environmental contamination are to be controlled[28]
- a description of measures relating to the proposed closure, rehabilitation and aftercare of the site, including information on site restoration[29]
- information on the measures deployed at the site to preclude any negative affect on local water, air and soil quality
- a detailed survey of the condition of the land to be affected by the waste facility

[21] This approach accords to the waste hierarchy, a key concept of EU waste management policy. This hierarchy sets out the following approaches to waste management in priority order: waste prevention, preparing for re-use, recycling, other recovery not entailing recycling, disposal.
[22] SI 566 of 2009, Regulation 5(1)(a)
[23] SI 566 of 2009, Regulation 5(2)(a)
[24] SI 566 of 2009, Regulation 5(2)(b)
[25] SI 566 of 2009, Regulation 5(2)(c)(i)
[26] SI 566 of 2009, Regulation 5(2)(c)(iii)
[27] This material is a consequence of Regulation 5(3)(d)'s cross-reference to Regulation 11(2)(a) and (b)
[28] See Regulation 5(3)(e)'s reference to Regulations 10 and 11(2)(c)
[29] See Regulation 5(3)(f) and Regulation 5(3)(d)'s reference to Regulation 11(2)(d)

- a general map of the entire site, which must include the details of the site boundary, extraction areas, the extractive waste facility/facilities and site infrastructure.

While this list may seem lengthy, the required details are likely to be relatively short when only inert waste is handled. Moreover, once the plan is completed and submitted, it does not need to be replaced unless something substantial has changed at the site.

While the Extractive Waste Regulations require each Extractive Waste Management Plan to be reviewed every five years[30], this review is carried out by the operator, not by the local authority. Only where there has been a "substantial change" to either the operation of the waste facility or to the waste that is being deposited does the plan needs to be amended. Accordingly, many plans should have a lifespan of a decade or more.

OTHER REQUIREMENTS AT INERT WASTE SITES

The Extractive Waste Regulations contain obligations that affect, to varying degrees, different classes of extractive operation or extractive waste facility. The least onerous of these obligations affects sites handling only inert waste[31], including the majority of the quarrying and sand and gravel sectors.

A lengthy definition of "inert waste" is set down in the Extractive Waste Regulations[32]. Other than the final sentence, this definition is the same as contained in the Landfill Directive[33] and that which features in many waste licences. The main requirement is that the material in question is inherently chemically stable, with no significant leachability. This definition is embellished by its cross-reference to EU Decision 2009/359[34]. That Decision amplifies some of the elements of the Extractive Waste's Regulations' concept of "inert waste" and, for example, sets a sulphide threshold.

Commission Decision 2009/359 also covers the need for laboratory analysis. It states that this is not necessary when a regulatory body is satisfied that sufficient knowledge already exists to indicate that an extractive material comprises only inert waste. When a more in-depth assessment is required, the characterisation procedures contained in Commission Decision 2009/360 are to be applied[35]

The definition of "waste facility" in the context of an inert waste site is subject to the time limit already mentioned, being restricted to an area which has been designated for the deposit of such waste for a period exceeding three years[36]. This causes some elements of the Extractive Waste Regulations only to apply when this period has been exceeded.

For example, when an area has been designated for the deposit of inert waste for a period of over three years[37], new waste facilities and modifications to existing ones must be designed to ensure that the local environment is protected and that there is full compliance with EU environmental law[38]. In addition, record-keeping and regular monitoring of the site must take place, with suitable closure and after-care arrangements being put into effect.

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[30] SI 566 of 2009, Regulation 5(4)
[31] There are also similar provisions aimed at extractive sites that involve the long-term storage of peat waste or unpolluted soil. It is expected that there will not be many such sites in Ireland
[32] Regulation 3(2)
[33] Directive 1999/31, Article 2
[34] Commission Decision of 30 April 2009 completing the Definition of Inert Waste in Implementation of Article 22(1)(f) of Directive 2006/12/EC of the European Parliament and the Council concerning the Management of Waste from the Extractive Industries, OJ No L110/46. 1.5.2009
[35] See Commission Decision 2009/359, Article 2
[36] See the definition in Regulation 3(2)
[37] Inert waste sites that are not Category A facilities are excluded from Regulations 11(1) and (3) by Regulation 2(4)
[38] SI 566 of 2009, Regulation 11(2)

SITES HANDLING NON-HAZARDOUS, NON-INERT WASTE

It is expected that most extractive waste facilities will fall within the inert waste category. Some others may involve the management of unpolluted soil or peat waste. Accordingly, there may only be a few sites that contain the final type of waste that is subject to local authority control: non-hazardous, non-inert extractive waste.

Sites within the non-hazardous, non-inert waste category will be mainly quarries where the level of sulphide exceeds the limits set down in Commission Decision 2009/359[39]. This is due to high natural levels of pyrite.

For a non-hazardous, non-inert waste site, a more restricted meaning is given to the term "waste facility". In contrast to the three-year cut-off that affects inert waste facilities, a "waste facility" for non-hazardous, non-inert waste is an area that has been designated for the accumulation of waste for more than one year[40]. Accordingly, additional monitoring, record keeping and other design requirements will apply when this time period is exceeded.

A further difference in the manner by which the Extractive Waste Regulations approach the control of non-hazardous, non-inert extractive waste facilities is to require all such sites to be subject to the waste facility permit system[41].

CATEGORY 'A' SITES CONTAINING INERT WASTE

While the EPA has primarily responsibility for the regulatory oversight of Category 'A' facilities, local authorities are required to identify any additional Category 'A' sites that are not already subject to the IPPC or waste licensing regimes[42]. Most of the sites – if they exist at all – will be quarries that have waste tips or lagoons with severe stability issues.

The Extractive Waste Regulations specify a series of criteria[43] by which an extractive waste facility is to be determined to have Category 'A' status. This material is supplemented by the contents of Commission Decision 2009/337[44]. Summary details are set out in the EPA's guidance.

CLOSED EXTRACTIVE WASTE SITES

Much of Ireland's historic mining, quarrying and other infrastructure is not subject to this legislation, usually for the reason that it closed many years ago and that no "operator" is identifiable[45]. However, the EPA's guidance recognises that some of these facilities may need to be subject to rehabilitation works, landscaping and similar activities. The guidance indicates that this practice does not cause the Extractive Waste Regulations to apply, particularly when no further minerals or other commercial materials are being won as part of these activities.

In addition, Regulation 21 of the Extractive Waste Regulations contains a rather complex series of transitional provisions that affect operators of extractive waste facilities that were at, or past, the near-

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[39] "Inert waste" is limited to material that "… has a maximum content of sulphide sulphur of 0.1%, or the waste has a maximum content of sulphide sulphur of 1% and the neutralising potential ratio, defined as the ratio between the neutralising potential and the acid potential, and determined on the basis of a static test prEN 15875 is greater than 3": see Commission Decision 2009/359, Article 1(1)(b)
[40] See the definition in Regulation 3(2)
[41] SI 566 of 2009, Regulation 7(2)(a)
[42] SI 566 of 2009, Regulation 9(1)
[43] See Schedule 3
[44] Commission Decision of 20 April 2009 on the Definition of the Criteria for the Classification of Waste Facilities in accordance with Annex III of Directive 2006/21/EC of the European Parliament and of the Council concerning the Management of Waste from the Extractive Industries, OJ No L102/7, 22.4.2009
[45] Much of the Extractive Waste Regulations places the "operator" under particular legal obligations: e.g. Regulation 4

closure stage between 1 May 2006 to 31 December 2010. Again, these matters are fully considered in the EPA's guidance. Operators of sites that were in operation after the relevant transitional deadline are required to comply with the legislation in the manner already discussed earlier.

THE REGISTER OF THE EXTRACTIVE INDUSTRIES

Regulation 19 of the Extractive Waste Regulations requires each local authority to register all extractive industries in its functional area[46]. This is done by specified details being entered on a database on the EPA's web site[47].

While most of the other provisions of the Extractive Waste Regulations relate to either an extractive waste facility or to extractive waste, Regulation 19 is oriented to the "extractive industries", requiring all such bodies to be registered by a local authority. In this respect, the term "extractive industries" is much wider[48], with the result that the register covers all sites involved in actual extraction activities, including mining sites, sand and gravel extraction, quarries and peat extraction.

The details retained by each local authority under Section 261 of the Planning and Development Act will be a key source of information for this register. However, as noted above, the types of activity that are to be covered by the register are rather wider than just quarrying.

ENFORCEMENT

The contravention of the Extractive Waste Regulations is an offence[49]. The EPA's guidance advises local authorities to consider deploying their powers under the Waste Management Act when problems occur at sites handling extractive waste.

Extractive Waste Regulations confer certain duties on local authorities in relation to site inspections[50]. These relate to extractive waste facilities that are subject to waste facility permits and hence apply where non-hazardous, non-inert extractive waste is deposited[51].

In respect of other types of waste facility, both Directive 2006/21 and the Extractive Waste Regulations require that an appropriate level of regulatory supervision by each local authority takes place. The EPA's guidance indicates that this includes periodic visits to all sites handling extractive waste, as local authorities are charged with ensuring that there is legislative compliance at all types of extractive site, regardless of whether they fall into the waste facility permit regime[52].

REPORTING TO THE EUROPEAN COMMISSION

Directive 2006/21 requires each EU state to keep the European Commission abreast of developments and issues relating to its implementation on the extractive waste sector[53]. Accordingly, the Department of the Environment, Community and Local Government will need to be supplied with information about how the Extractive Waste Regulations are operating in each local authority's functional area.

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[46] SI 566 of 2009, Regulation 19
[47] http://www.epa.ie/whatwedo/enforce/pa/extractiveindustriesregister/
[48] Its scope is a consequence of the definition of in Regulation 3(2) and Regulation 19(1) itself.
[49] SI 566 of 2009, Regulation18(1)
[50] SI 566 of 2009, Regulation 16
[51] Non-hazardous, non-inert waste sites are subject to Regulation 16(1) due to Regulation 16(1)'s cross-reference to Regulation 7. Directive 2006/21 is clear that inspections must be carried out about both Category A facilities and at non-hazardous, non-inert extractive waste facilities: see Article 2(3) and Article 17
[52] For example, Regulation 4(2) mandates that a local authority must ensure that operators are managing extractive waste without posing any unacceptable environmental risk, endangering human health or causing a nuisance. Likewise, Regulation 5 requires each local authority to approve an extractive waste management plan, while Regulation 16(2) highlights the need for local authorities to ensure that site records are kept up-to-date
[53] Directive 2006/21, Article 18

The breadth of the material that is required to be transmitted to the European Commission is defined mainly by Commission Decision 2009/358[54]. This information is quite wide-ranging, covering a broad range of material about how each EU member state is implementing the Directive. For example, Annex III to Decision 2009/358 contains a separate four-page list of information that is to be submitted to the Commission every three years. As local authorities will be requested to provide this material, a full copy of this questionnaire is included as an appendix to the EPA's guidance note. Data is required about the occurrence of extractive waste facilities and the number of extractive waste management plans that have been approved or refused, as well as information on matters relating to inspections of extractive waste facilities, how non-compliances are being dealt with, and so on.

EXTERNAL EMERGENCY PLANS FOR CATEGORY 'A' SITES

As noted, the main justification for Directive 2006/21 stemmed from a Europe-wide desire to prevent further catastrophic accidents caused by some form of failure or instability of an extractive waste facility. Accordingly, a key requirement that applies to all Category 'A' waste facilities is for their operators to identify all potentially significant hazards and incorporate appropriate accident prevention methods within an extractive waste facility's design and operation. While the primary responsibility for both accident prevention policies and emergency plans rests with the Category 'A' site's operator, the EPA and the local authority in which the site is situated also have functions in these respects.

Local authorities already have existing responsibilities for emergency planning and management. Along with an Garda Síochána and the Health Service Executive, they are Principal Response Agencies within Ireland's emergency planning system. These existing emergency planning duties are partly a consequence of the Directive on the Control of Major Accident Hazards (COMAH[55]) and the European Communities (Control of Major Accident Hazards involving Dangerous Substances) Regulations 2006[56]. For example, local authorities have to prepare external emergency plans in respect of so-called "Upper Tier Establishments".

The requirements of Directive 2006/21 and the Extractive Waste Regulations on external emergency plans for Category A facilities represent an extension of this function. Each local authority must draft an external emergency plan for any Category 'A' site situated in its functional area. Like emergency plans relating to upper-tier COMAH sites, the purpose of this plan is to set down measures that are to be taken if an accident with off-site implications occurs. This external emergency plan is intended to complement the internal emergency plan, which each operator has to draft to address any incident within the site boundary. More detailed information on this aspect is found in the EPA's guidance document.

Comments and corrections on the above are very much invited and welcomed. Please send them by email to duncan@duncanlaurence.com.

Disclaimer: *this paper is intended to be a helpful summary of the Extractive Waste Regulations and of the main features of the EPA's guidance document. The latter has not yet been published and may differ from the content above. This account is not a substitute for legal advice and should not be used for that purpose. Readers wishing to explore the exact nature of the requirements are urged to consult the relevant provisions themselves, to discuss the requirements with their local authority, the EPA or the Department of the Environment, Community and Local Government and/or to obtain independent legal advice.*

[54] Commission Decision of 29 April 2009 on the Harmonisation, the Regular Transmission of the Information and the Questionnaire referred to in Articles 22(1)(a) and 18 of Directive 2006/21/EC of the European Parliament and of the Council on the Management of Waste from the Extractive Industries, 1.5.2009, OJ No L110/39

[55] Directive 96/82, as amended by Directives 1882/2003 and 2003/105 and Regulation 1137/2008. Directive 96/82 is also known as the Seveso II Directive

[56] SI 74 of 2006

REGULATION OF QUARRIES: UNDERSTANDING SECTION 261A OF THE PLANNING ACTS

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ABSTRACT

The focus of this paper is the changes made by the Planning and Development (Amendment) Act 2010, as amended by the European Union (Environmental Impact Assessment and Habitats) Regulations 2011 (nos. 1 and 2) and the Environment (Miscellaneous Provisions) Act 2011. The amendments introduce four material changes. First, retention permission is no longer available for projects that should have been subject to environmental impact assessment or appropriate assessment. Second, the limitation period for enforcement of planning control is not available for recent and future development at quarries. Third, the registration framework introduced by section 261 of the Planning and Development Act, 2000 has been enhanced to clarify and confirm the enforceability of certain features of that framework. Fourth, a complex and special framework has been introduced under section 261A of the Planning Acts for determining whether quarries that should have been subject to assessment should be subject to enforcement or the new substitute consent process. Although every care has been taken in the preparation of this paper, readers are advised to seek legal advice before acting on any of the material covered.

BACKGROUND

On 3 July 2008, in *Case C215/06 Commission v. Ireland*,[1] the European Court of Justice criticised the unrestricted availability of retention permission for unauthorised development that should have been subject to impact assessment.[2] That decision emphasised the requirement for prior assessment in article 2(1) of the EIA Directives:

> "<u>Before</u> consent is given, projects likely to have significant effects on the environment by virtue, *inter alia*, of their nature, size or location are made subject to a requirement for development consent and an assessment with regard to their effects …" (emphasis added).

The Court determined that retention permission cannot be used to circumvent this requirement and should remain an exception.

This judgment and the subsequent circular from the Department of the Environment, Heritage & Local Government (the "Department") (PD 3/08) cast a cloud over applications that were in any way linked with unauthorised development. Many local authorities simply refused to deal with such applications.

The issue was twofold: to ensure assessment precedes development (and that retention permission remains an exception); and, to punish and/or remedy breach of the rules. A legislative response to the issue had been awaited for some time, was introduced by way of late amendment to the Planning and Development (Amendment) Bill 2009 during summer 2010 and was ultimately enacted as part of the Planning and Development (Amendment) Act 2010 (the "2010 Act").

When promoting the 2010 Act, the sponsoring Minister for State referred also to a subsequent decision

[1] *C215/06 Commission v Ireland*, European Court of Justice, 3 July 2008

[2] For convenience, this expression "impact assessment" will be used to capture the different concepts of environmental impact assessment, screening for environmental impact assessment and appropriate assessment.

of the European Court of Justice. In *Case C66/06 Commission v. Ireland*,[3] the Court criticised the thresholds established in Ireland for screening whether certain agricultural projects should be subject to impact assessment. The Court determined that there was no guarantee that the competent authority would be able to require impact assessment of projects likely to have significant effects on the environment. The sensitivity to screening is clear in the amendments made by the 2010 Act.

Some further changes relevant to quarries have been made by article 16 of the European Union (Environmental Impact Assessment and Habitats) Regulations 2011,[4] article 3 of the European Union (Environmental Impact Assessment and Habitats) (No. 2) Regulations 2011[5] and sections 16,[6] 28 and 29[7] of the Environment (Miscellaneous Provisions) Act 2011 (the "2011 Act").

The Minister published statutory guidance on these changes at the end of January 2012.[8] Unfortunately, it arrived too late for meaningful review by operators and practitioners making submissions to planning authorities.

RETENTION PERMISSION

Section 34(12)[9] of the Planning Acts obliges a planning authority to refuse to consider certain applications to retain unauthorised development. This obligation has been in force since 23 March 2011.[10] Specifically, the obligation arises where a planning authority:

> "decides that if an application for permission had been made in respect of the development concerned before it was commenced the application would have required that one or more than one of the following was carried out -
>
> (a) an environmental impact assessment,
>
> (b) a determination as to whether an environmental impact assessment is required, or
>
> (c) an appropriate assessment".

The requirements at (a) and (c) are not surprising. Where the development exceeds the published thresholds for environmental impact assessment and is carried out without permission, retention will not be available. Paragraph (c) can be understood with reference to sections 177R and 177V of the Planning Acts,[11] which define "appropriate assessment" to include the determination of whether proposed development would adversely affect the integrity of a European site. That appropriate assessment is only required where the development is "likely to have a significant effect" on the site.[12]

The requirement at (b) might yet present difficulties. If sub-threshold development has been carried out without either the planning authority or An Bord Pleanála "screening" the proposed development, i.e., determining whether or not the development was likely to have significant effects on the environment by reference to the criteria specified under Schedule 7 of the Planning and Development Regulations, 2001 (as amended),[13] in principle, retention permission will not be available.

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[3] *C66/06 Commission v. Ireland*, European Court of Justice, 20 November 2008
[4] In force from 21 September 2011. See SI No. 473 of 2011.
[5] In force from 15 November 2011. See SI No. 584 of 2011.
[6] In force from 21 September 2011. See SI No. 474 of 2011.
[7] Both in force from 15 November 2011. See SI No. 583 of 2011.
[8] See http://www.environ.ie/en/PublicationsDocuments/FileDownLoad,29240,en.pdf
[9] Inserted by section 23(c) of the 2010 Act.
[10] SI No. 132 of 2011.
[11] Inserted by section 57 of the 2010 Act which has been in force since 21 September 2011. See SI No. 475 of 2011.
[12] Article 6(3) of the Habitats Directive.
[13] And is carried out without permission.

Arguably, every kind of development requires this kind of screening on a case-by-case basis. For example, the Spire on Dublin's O'Connell Street was considered sub-threshold for urban development, but still required screening and ultimately an environmental impact statement.[14] Usefully, the Department is alert to the practical difficulties this could present. The statutory guidance states that:

> "In making this determination (that is as to whether a quarry development would have required a determination as to whether EIA was required) it is suggested that planning authorities decide whether EIA could be ruled out without any substantial screening; where the need for EIA can be ruled out in this way it is clear that the development did not require a determination as to whether EIA was required."[15]

This is pragmatic, sensible and to be welcomed.[16]

Indeed, the same logic now finds statutory expression in articles 103 and 109 of the Planning and Development Regulations 2001 to 2011.[17] These provide that a planning authority and An Bord Pleanála are only required to make a formal screening decision where "the likelihood of significant effects on the environment cannot be excluded".

Where a planning authority does refuse to consider an application for any of these reasons, it must return the application (and fee) and give reasons.

The routine availability of retention permission has been replaced by a new substitute consent procedure, the availability of which is a good deal more limited. Certain quarries will be forced by the 2010 Act to apply for this new substitute consent. That new framework is considered below.

LIMITATION PERIOD

It is curious that two decisions of the European Court of Justice dealing with wind farms, agriculture and aquaculture have exposed quarrying and peat extraction to a greater risk of enforcement, but that is the effect of amendments made to sections 157 and 160. As originally drafted, section 160(6)(aa)[18] provided that:

> "Where the development was carried out not more than seven years prior to the date on which this section comes into operation, and notwithstanding paragraph (a), an application for an order under this section may be made at any time in respect of the following development: (i) operation of a quarry; (ii) extraction of peat."

Section 157(4)(aa)[19] provided the same in respect of warning letters and enforcement notices.

Under the original language, the risk of enforcement arose only where development was carried out not more than seven years prior to the date on which the relevant part of the 2010 Act comes into operation. This could be read to mean that quarries that had secured the benefit of the limitation period before the 2010 Act comes into operation would remain protected from enforcement. For quarries that had not yet secured the benefit of the limitation period, the changes mean they never would.

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[14] *Ó Núallain v. Dublin Corporation*[1999] 4 IR 137.
[15] Paragraph 3.2.6.
[16] Garrett Simons SC is more pessimistic and suggests that: "it makes no difference whether a screening decision might have established that the development was not likely to have significant effects on the environment and accordingly, an EIA would not have been required: the quarry is still within the scope of Section 261A. The failure to carry out a screening exercise is fatal.".
[17] As substituted by articles 14 and 15 of SI No. 476 of 2011.
[18] Inserted by section 48 of the 2010 Act.
[19] Inserted by section 47 of the 2010 Act.

The 2011 Act has made amendments[20] that modify the effect of this provision, so that historic activity is protected from enforcement, but future activity is not. Section 160(6) provides that:

> "(aa) Notwithstanding paragraph (a) [which establishes the so-called "seven year rule"] an application to the High Court or Circuit Court for an order under this section may be made at any time in respect of unauthorised quarry development or unauthorised peat extraction development in the following circumstances:
>
> (i) where no permission for the development has been granted under Part III and the development commenced not more than 7 years prior to the date on which this paragraph comes into operation;
>
> (ii) where permission for the development has been granted under Part III and, as respects the permission –
>
> (I) the appropriate period (within the meaning of section 40), or
>
> (II) the appropriate period as extended under section 42 or 42A,
>
> expired not more than seven years prior to the date on which this paragraph comes into operation.
>
> (ab) Notwithstanding paragraph (a) or (aa), an application to the High Court or Circuit Court may be made at any time for an order under this section to cease unauthorised quarry development or unauthorised peat extraction development."

The new language came into force on 15 November 2011.[21] That language is a good deal more clear. Even where the benefit of the seven-year rule has been secured, unauthorised quarry development will always be exposed to an order for cessation. This does raise a question regarding the Constitutional protection against retrospective penal sanction.

As before, with any quarry that had not yet secured the benefit of the limitation period, the changes mean they never will.

SECTION 261 FRAMEWORK

The 2010 Act has enhanced the registration framework introduced by section 261 of the Planning and Development Act, 2000 to clarify and confirm the enforceability of certain features of that framework.[22] Specifically:

> Section 261(6)(aa) provides that the operation of a quarry in breach of condition imposed on a pre-1964 quarry under section 261(6)(a)(i) is unauthorised development.
>
> Section 261(6)(b) clarifies that where conditions of a quarry planning permission are restated, modified or added, they take effect on the date of restatement, modification or addition.
>
> Section 261(7)(d) provides that the continued operation of a quarry after the planning authority has required the operator to apply for permission and submit an environmental impact assessment is unauthorised development, unless the application was made on time.
>
> Where that application is refused, section 261(7)(e) provides that the continued operation of the quarry after such refusal is unauthorised development.

[20] Sections 28 and 29.
[21] SI No. 583 of 2011.
[22] Inserted by section 74 of the 2010 Act.

Where that application is granted, section 261(7)(f) provides that the continued operation of the quarry in breach of conditions attached to the permission is unauthorised development.

Section 261(8) had established a right to compensation where additional conditions were imposed on a quarry that had been granted permission, or where an application for permission was required under subsection (7) but was refused. Section 261(8)(c) adds a trigger for compensation where conditions are imposed on a quarry with a pre-1964 authorisation.

Section 261(10) will provide that failure to provide certain information about a quarry[23] will render that quarry unauthorised development.

The new language came into force on 15 November 2011.[24]

The definitions of "operator" and "quarry" had been deleted by section 74(e) of the 2010 Act. This was unintended. The 2011 Act reinstated both definitions.[25] That provision cross-referenced the Mines and Quarries Act, 1965. Unfortunately, although in force when the Planning Act 2000 was enacted, he 1965 Act had subsequently been repealed by the Safety, Health & Welfare at Work Act, 2005, thereby raising doubt over its efficacy. Article 3 of the European Union (Environmental Impact Assessment and Habitats) (No. 2) Regulations 2011[26] removed this doubt, by replacing the definition of "quarry" with definitions for "quarry", "minerals" and "mine" using language from the 1965 Act.

SECTION 261A FRAMEWORK

DETERMINATION

Each planning authority is required to examine every quarry within its administrative area within a period of nine months from the date of coming into operation of section 261A.[27] The section came into force on 15 November 2011, [28] so the nine month period would ordinarily expire on or about 14 August 2012. Of course, section 251 of the Planning Acts excludes the nine days over Christmas from the calculation of such periods, so the deadline will be 23 August 2012.
Within four weeks of commencement of section 261A, i.e., 12 December 2011, planning authorities were required to advertise in newspapers that this examination has begun, summarising the decisions that will be made on foot of the examination and the consequences of those decisions.

Submissions and observations can be made by any person within six weeks. The deadline for submissions to local authorities expired before the end of January 2012.

EU LAW REQUIREMENTS

The first requirement is to identify those quarries in respect of which an impact assessment should have been carried out, but was not carried out.[29] The planning authorities must make this determination within the nine month examination period.
The test to be applied in this regard is whether any development was carried out after 1 February 1990 (in the case of the EIA Directives) or 26 February 1997 (in the case of the Habitats Directives). The date of 1 February 1990 appears to have been chosen as it is the date upon which the EIA Directives

[23] Whether in the application to register under subsection (1) or in response to a request for further information under subsection (3).
[24] SI Nos. 582 and 583 of 2011.
[25] Section 16 was in force from 21 September 2011. See SI No. 474 of 2011.
[26] In force from 15 November, 2011. See SI No. 584 of 2011.
[27] Section 261A(2) of the Planning Acts.
[28] SI Nos. 582 and 583 of 2011.
[29] The language in section 42(1)(a)(ii)(IV) is similar, but different and uses the expression "if required", not "would have been required".

were first properly implemented into Irish law.[30] Similarly, the date of 26 February 1997 appears to have been chosen as it is the date upon which the Habitats Directives were first implemented into Irish law.[31]

In making this determination, the planning authority must consider[32] submissions and observations received, information received at the time of any section 261 registration, information on the planning register, information obtained in any enforcement action relating to the quarry and "any other relevant information". The draft guidance notes suggest this should include rateable valuation records, aerial photos or maps and local knowledge from planning authority staff.

Where quarry development has taken place after the prescribed dates and impact assessment was required (but not carried out), the quarry development will be required either to apply for substitute consent or to suffer an enforcement notice.

Until the amendments made by article 16 of the European Union (Environmental Impact Assessment and Habitats) Regulations 2011, there was an express requirement to consider certain domestic law requirements as part of this determination. Specifically, it had been necessary to also consider whether the development was carried out under an planning permission granted prior to the relevant dates. There was no reference to the so-called "pre-1964 authorisation" and this might have given rise to confusion, given the otherwise similar treatment for both kinds of authorisation under section 261A(3)(a)(i), (4)(a)(i) and (5)(a)(i). The deletion means that there is no distinction made between these two kinds of authorisation in any part of section 261A.

Whether the quarry development will be required to apply for substitute consent or to suffer an enforcement notice turns on the second requirement, which relates to other requirements of domestic law.

DOMESTIC LAW REQUIREMENTS

Specifically, the planning authority must determine whether the quarry commenced operation prior to 1 October 1964 or that planning permission was granted in respect of the quarry. Secondly, it must be ascertained whether the registration requirements of section 261 were complied with.
If these various domestic requirements were complied with,[33] then continued operation of the quarry can be regularised by way of an application for a substitute consent under the general provisions of what will be Part XA.

If, however, these domestic requirements were not met,[34] then the planning authority is required to issue an enforcement notice in relation to the quarry requiring the cessation of the operation of the quarry and the taking of such steps as the authority considers appropriate.

It is important to note that there is no requirement for the planning authority to consider whether the any conditions, restrictions or limitations had been complied with.

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Oddly, it seems that irrespective of whether quarry has complied with these domestic requirements, if the operation commenced post 3 July 2008, i.e., the date of the judgment of the European Court of Justice in *Case C215/06*, then the quarry is condemned to an enforcement notice.[35]

[30] The actual date for implementation was July 1988.
[31] The actual date for implementation was July 1994.
[32] Section 261A(2)(b) of the Planning Acts.
[33] Section 261A(3) of the Planning Acts.
[34] Section 261A(4) of the Planning Acts.
[35] Section 261A(5) of the Planning Acts.

OUTCOME

Both members of the public (who participated) and quarry operators may refer these issues to An Bord Pleanála for a second opinion within three weeks of the notice given to them of the planning authority determination. It is hoped that planning authorities will not rely on the likelihood of appeals, to avoid difficult or complex decisions, when exercising functions under the new framework.

For some quarries, the process will require them to suffer an enforcement notice. This is not any special enforcement notice; it will be a notice issued under section 154. The limitation periods (discussed above) will remain relevant to quarries that already have secured the protection of the seven-year limitation period.

For those quarries that have not secured the protection of that limitation period, there are three options: permanent shut down; comply with the enforcement notice and then reapply for ordinary permission; or, request leave from An Bord Pleanála to apply for substitute consent under section 177C of the Planning Acts.[36]

The request for leave can be made where development has been carried and an impact assessment was or is required. One of two further conditions must be satisfied. Either the permission granted for the development must be suspect; or, the applicant must be:

> "of the opinion that exceptional circumstances exist such that it may be appropriate to permit the regularisation of the development by permitting an application for substitute consent".

The criterion relevant to "exceptional circumstances" are listed in section 177D(2) and include the *bona fides* of the applicant and the nature of the impacts on the environment.

SUBSTITUTE CONSENT

Where the outcome is an application for substitute consent, the application must be made to An Bord Pleanála.[37] The application must be made quickly, within 12 weeks, unless An Bord Pleanála allows added time. The application must be accompanied by a remedial environmental impact statement and/or a remedial natura impact statement (for the purpose of appropriate assessment). The amendments made by the European Union (Environmental Impact Assessment and Habitats) Regulations 2011 clarify these requirements.

Unusually, An Bord Pleanála will have a quasi-enforcement function. For example, under section 177J, the Board may direct the operator to cease all or part of his activity or operation pending the outcome of the substitute consent application process. Also, where the Board refuses substitute consent, the Board may direct the operator to cease all or part of his activity or operation and to take remedial measures.

EXAMPLES

Quarry that was granted planning permission before 1 February 1990?

These permissions were not subject to the requirement for impact assessment of any kind, so section 261A does not apply.

[36] Inserted by section 57 of the 2010 Act. There has been some suggestion that this option is not available in respect of quarry development, but there is no such limitation in Part XAB of the Planning Acts.
[37] Section 177E of the Planning Acts.

Quarry that was granted planning permission between 1 February 1990 and 26 February 1997?

These permissions were subject to the requirement for impact assessment under the EIA Directives. Where an environmental impact assessment should have been carried out, but was not, or screening should have been carried out, but was not, the planning authority must consider whether "the quarry commenced operation before 1 October 1964 or permission was granted in respect of the quarry" and "if applicable, whether the requirements in relation to registration under section 261 were fulfilled". The requirements for registration only applied to quarries with no planning permission or with older planning permissions, i.e., granted before 28 April 1999.

Quarry that was granted planning permission after 26 February 1997?

The same analysis for the post-1990 permission applies, but impact assessment under both the EIA Directives and the Habitats Directives must be considered. The fact that an environmental impact statement had been prepared and submitted to accompany the application for permission will in most cases satisfy both requirements.[38]

Quarry that was granted retention permission?

The same analysis for quarries with ordinary planning permission applies. It does not matter that the permission was for retention of unauthorised development.

Quarry granted planning permission under section 261(7)?

These are pre-1964 quarries that were required to prepare an environmental impact statement and submit a planning application after registration under section 261. These quarries should not be exposed to section 261A.[39]

Quarry that commenced operation before 1 October 1964?

Section 261A will only be relevant where development has been carried out after 1 February 1990 or 26 February 1997. This requires analysis of the concept of development, including intensification and abandonment.

If there was development after the prescribed dates, the question to be asked is whether impact assessment should have been carried out. If not, section 261A does not apply. If yes, then the planning authority must consider whether "the requirements in relation to registration under section 261 were fulfilled".

Where those requirements have not been fulfilled, the quarry will suffer an enforcement notice. Where they have been fulfilled, the quarry must apply for substitute consent.

Quarry that commenced operation after 3 July 2008?

If impact assessment should have been carried out, but was not, the quarry is doomed to enforcement. This is regardless of whether there is planning permission for the quarry.

APPENDIX – REGULATION OF QUARRIES BEFORE THE 2010 ACT

The concepts of the "Pre-1964 Authorisation", "abandonment" and "intensification" are well known.[40] It may be worth refreshing the other feature of pre 2010 Act regulation, namely, section 261 of the 2000 Act.

[38] Assuming the information on ecology (whether within the EIS or otherwise) was sufficient to allow the decision-maker consider whether appropriate assessment was required.
[39] This is subject to the same assumption on appropriate assessment at footnote 38.

Section 261 of the 2000 Act established a new regime for the control of quarries that were already in existence when the Planning and Development Act 2000 came into effect.

The section applied to two categories of quarries: (a) those which received a planning permission under the Local Government (Planning and Development) Acts more than 5 years before the coming into operation of section 261 (28 April 2004); and (b) those which did not receive such planning permission but which were in operation on or after section 261 comes into force. This latter category included both pre-1964 quarries which may not have required planning permission and quarries illegally operating without planning permission.

By 27 April 2005, the owner or operator of any of these quarries was under an obligation to provide certain information relating to the operation of the quarry to the planning authority. The planning authority was then under an obligation to enter the quarry on the planning register under section 7 of the Act within certain time limits. The information to be provided by the operator included information on the hours of operation, the level of traffic generated, the level of dust and noise generated, etc. As these are the touchstones of materiality for the intensification of use doctrine, it was thought that the information submitted in 2005 would provide a useful benchmark against which to assess the materiality of an intensification of use in the future.

Where a pre-1964 quarry has an "extracted area" of greater than five hectares or is situated on a site which has a special environmental or wildlife designation, and its continued operation will be likely to have significant effects on the environment, section 261(7) imposes on the planning authority an obligation to require the owner or operator to make an application for planning permission and submit an environmental impact statement. This provision further reduces the scope of the exclusion originally provided by section 24 of the 1963 Act by subjecting pre-1964 quarries which ought to be subject to impact assessment to the requirement to obtain planning permission. The criteria here broadly reflect the criteria for when a planning application for a quarry must be accompanied by an EIS.

Section 261(6) authorises a planning authority, following public notification of the registration and following a consultation process with the owner/operator of the quarry, to impose, restate or modify conditions on the operation of the quarry. Section 261(9) allows an owner or operator to appeal to An Bord Pleanála the planning authority's decision to impose, restate, add to or modify conditions.

In *M&F Quirke and Sons Ltd v An Bord Pleanála*, [41] the High Court considered the jurisdiction of planning authorities and An Bord Pleanála to impose conditions pursuant to section 261(6) in three test cases, which included (a) a condition restricting blasting, (b) a condition restricting depth, (c) a condition restricting surface extent, (d) a condition restricting the number of years for which the quarry could operate.

In respect of (b), (c) and (d), the quarry could not operate beyond a certain depth, area or time without first applying for a grant of planning permission. Unless the quarry entered mainstream planning control in this way, the conditions envisaged that quarrying would cease at a particular point in time. The applicants alleged that this went beyond the scope of section 261(6) as it did not relate to a condition on the operation of the quarry. O'Neill J rejected this argument holding that the power in section 261(6) included a power to impose conditions such as these. The same range of planning conditions that were open to a planning authority in a planning application under section 24 was open to a planning authority under section 261. The mere fact that an operator might have to make an application for planning permission in circumstances in which it would not previously have had to do so did not affect the legality of the conditions.

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[40] For a useful summary, see Oran Doyle, "Elusive Quarries: A Failure of Regulation", (2011) 34 *DULJ* 180., where these features are described and he articulates cogent proposals for a replacement licensing system.

[41] [2009] IEHC 426.

The owner of a quarry that commenced operation post-1964, which was unequivocally subject to the requirement to obtain planning permission but had not done so, was under an obligation to register her quarry under section 261. However, the planning authority did not have any power to impose conditions on such a quarry under section 261(6), or indeed to require it to submit a planning application pursuant to section 261(7).[42] The powers in section 261(6) to impose conditions are limited to quarries which commenced operations prior to 1 October 1964 and to quarries which received planning permission.

[42] In some cases, planning authorities have subjected such quarries to the provisions of sections 261(6) or (7). The quarry operators subsequently argued that this amounted to an implicit determination that the quarry was not unauthorised, a determination that could not (by reason of section 50 of the Act) be challenged in subsequent proceedings before a planning authority, An Bord Pleanála or the courts. This argument has been rejected in a number of cases. See, for instance, *Pierson v Keegan Quarries Ltd* [2009] IEHC 550 and *Frank Harrington ltd v An Bord Pleanála* 23 November 2010 (HC).

ENVIRONMENTAL IMPLICATIONS OF QUARRY LEGISLATION

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ABSTRACT

A summary of the relevant legislation governing quarrying is presented. The review illustrates how Section 261A of the Planning and Development Act 2010 integrates other environmental regulations, (Environmental Impact Assessment and Appropriate Assessment) into the planning process more definitively than was previously the case. The driver for this was in part due to anomalies in the original Section 261 of the 2000 Planning and Development Act which resulted in inconsistencies in the quarry registration process, and partly due to requirements for compliance with European Court of Justice Decisions in relation to implementation of the EIA and Habitats Directives in Ireland. Section 261A of the 2010 Planning and Development Act requires local authorities to review all quarry operations and establish their planning status or require the relevant information to establish their status by August 24th 2012.

While planning authorities nationally may have to review a large number of quarries, it is likely that a relatively small percentage of these will be required to undertake remedial Environmental Impact Assessments and/or Appropriate Assessments.

Where remedial EIA and or AA are required it is likely that the Planning Authorities (Local Authorities and An Bord Pleanála) will need the assistance of hydrologists, hydrogeologists and ecologists to advise on the appropriate course of actions required to mitigate environmental impacts. The primary environmental impacts associated with quarry activities are presented and discussed in the paper.

OVERVIEW OF QUARRY LEGISLATION

A brief overview of the legislation is presented below in order to put the relevant environmental requirements in context. More detailed information on the legislation is presented by previous speakers in this session.

THE PLANNING AND DEVELOPMENT ACT 2000

The primary legislation for quarrying is the planning consent/permission to operate. Permission to operate was required after 1964 in accordance with the 1963 Planning Act. Section 261 of the Planning and Development Act 2000 which commenced in 2004 required that all quarries operating in the State register with the relevant local authority with the exception of those quarries that had received planning permission in the previous five years (since 1999).

Problems arose with the implementation of Section 261 of the 2000 Planning and Development Act in relation to quarries. There was no provision for the imposition of further controls on unauthorised quarries, i.e. quarries which commenced operations after 1 October 1964 but which had no planning permission. There were also enforcement issues in relation to definition of unauthorised development and also the 7 year enforcement limitation in section 157 and section 160 of the 2000 Act.

Issues also arose in relation to conditions imposed in relation to quarries that existed prior to 1964, quarries required to register but who failed to do so became unauthorised development and with quarries which did not comply with the decision of the planning authority/ABP on a planning application under S.261(7). To remedy this, provisions were brought in to remedy the anomalies highlighted in the 2000 Act.

THE PLANNING AND DEVELOPMENT (AMENDMENT) ACT 2010

The Planning and Development (Amendment) Act 2010 contains a number of provisions relating to quarries and these are mainly set out under Section 74 and Section 75 of the 2010 Act. These provisions require that;

The local authorities prepare a complete inventory of all quarries in their jurisdiction

- Within 9 months of Sections 74 and 75 coming into operation (November 15th 2011) that all planning authorities have to identify the qualifying quarries and determine whether Environmental Impact Assessment (EIA), or sub-threshold assessment for EIA, or Appropriate Assessment (AA) for same was required and, if required, was it carried out. (A further 9 days was subsequently added to the deadline to account for lost time over the Christmas Holiday period).

- Where a Planning Authority makes a determination that EIA (or sub-threshold assessment for EIA) or AA (as distinct from screening for AA) was required but not carried out the Planning Authority shall issue notice to the owner or operator of the quarry directing them to apply to An Board Pleanála for substitute consent in respect of the quarry. Public participation is provided for as part of this process.

- Quarry operators have the right to request a review by An Board Pleanála of the planning authority's direction to apply for substitute consent as set out under Section 261A(1)(g). The requirements for an application for substitute consent are set out in the new Act under Part XA.

These provision assume that either planning permission was obtained for the quarry or it pre-dates October 1964 and the quarry operator, if required to do so, applied for registration under Section 261. If this is not the case, the quarry is not authorised. Quarries that never had planning permission or failed to register under Section 261 of the Planning and Development Act 2000 will not qualify for substitute consent. Improved enforcement provisions contained in the 2010 Act will require local authorities to immediately take enforcement proceedings against quarries which are deemed totally unauthorised or others refused substitute consent. Essentially such quarries will be forced to close. Quarry sites which are non-compliant with existing conditions will have enforcement taken to achieve compliance.

ENVIRONMENTAL IMPACT ASSESSMENT REGULATIONS

S.I. No. 349/1989 - European Communities (Environmental Impact Assessment) Regulations, 1989 required developments of certain thresholds to undertake an Environmental Impact Assessment. In the case of quarries the threshold was five hectares. All quarries developed after the date of implementation of the regulations and exceeding the threshold would have been required to prepare an Environmental Impact Statement (EIS) to comply with the EIA Regulations.

The second EIA Directive in 1997, 97/11/EC, introduced a requirement for EIA of changes or extensions to projects already authorised, executed or in the process of being executed, which may have significant adverse effects on the environment adopted under European Communities (Environmental Impact Assessment) (Amendment) Regulations, 1999, (S.I No. 93 of 1999) and which became operative on 1st May 1999. In relation to quarries this meant that "Any change or extension of development which would result in an increase in size greater than 25%, or an amount equal to 50% of the appropriate threshold, whichever is the greater". This means that after that date mandatory EIA was required for the extension of a quarry which brought the total quarry to in excess of 5 hectares and represented an increase of over 25% of the existing quarry, provided that the extension in itself exceeded 2.5 hectares. By extension this meant development of previously unauthorised land. This did not apply where new ground developed was part of bona fides pre 1963 extraction lands or where a previous permission was in place for the new ground area.

WATER FRAMEWORK DIRECTIVE 2000

Quarrying was identified as having the potential to contribute to impacts on the Quantitative Status of Groundwater Bodies and on Groundwater Dependant Terrestrial Ecosystems (GWDTE) as part of studies undertaken as part of Ireland's requirement to comply with the Water Framework Directive. Camp, Dresser, McKee (CDM 2009). A risk of over abstraction to the Midleton 2 Groundwater Body in the Carrigtwohill area of Cork was identified, primarily due to the very high rate of dewatering that was occurring in several quarries in relatively close proximity in this area. The status of this groundwater body is currently considered to be poor because of the abstraction risk presented. Dewatering at quarries was also considered to be contributing to the risk of impact on GWDTE's in other parts of the country in the CDM Further Characterisation Study. These included two quarries in Co. Louth, one in Laois. The GWDTE's have been identified for further assessment as part of the ongoing implementation of Water Framework Directive process.

HABITATS DIRECTIVE (EUROPEAN COMMUNITIES (NATURAL HABITATS) REGULATIONS, 1997)

The requirement for Appropriate Assessment (AA) as part of the planning process was adopted into Irish Law by the introduction of the Habitats Regulations, 1997. Following a judgement of the European Court of Justice (ECJ) in case C-418/04, the Department of Environment, Heritage and Local Government (DEHLG) issued Circular Letter in 2008 to all County and City Managers, Directors of Services for Planning, Town Clerks and Engineers to inform them of the requirement to undertake AA of land use plans in accordance with the obligations of Article 6 of the Habitats Directive. The ECJ ruling established that Ireland has not correctly transposed Article 6(3) by not providing explicitly for AA of land use plans, as opposed to projects. The obligation to undertake AA was further reinforced in the revised Section 261A of the Planning and Development Act 2010 with respect to quarries. Screening to establish whether AA is required is the responsibility of the public authorities and not a proposed development applicant. There is a very wide range of Public Authorities with the power to look for AA review under the legislation, not just the local authorities. These include but are not limited to; An Bord Pleanála, EPA, HSE, NRA, GSI, IFI, Coillte, Teagasc, RPII Bord Gáis, Marine Institute. Screening for AA may be required where a plan or project is within 15km of a Natura 2000 site. However, it is likely that the impact posed by quarries is likely to be much less than this.

THE POLLUTANT RELEASE AND TRANSFER REGISTER (PRTR) REGULATIONS

The PRTR Regulations were adopted under S.I. No. 123 of 2007 and, S.I. No. 649 of 2011, the European Communities (European Pollutant Release and Transfer Register) Regulation 2007. Following the coming into force of the PRTR Regulations on 22 March 2007 & 13 December 2011, there is now an obligation on quarries with a surface area greater than 25 Hectares to make returns, to the Environmental Protection Agency (EPA) of their annual (emissions) and Off-Site Waste Transfers. Surface area is defined by the EPA as the area under extractive operation including all on-site transport, processing, storage and associated facilities and settlement lagoons excluding ancillary manufacturing development (concrete and macadam facilities).

Operators are obligated to report off-site transfers from all deliberate, accidental, routine and non-routine activities at the site of the facility. For off-site transfers of waste the threshold values are 2 tonnes per year for hazardous waste and 2,000 tonnes per year for non-hazardous waste.

This task for quarries is not particularly onerous as emissions are generally limited to groundwater discharges, regulated discharges from settlement lagoons with very limited removal of non-hazardous waste or hazardous waste. All submissions are reviewed by EPA to ensure requirements under the directive are complied with.

EXTRACTIVE WASTE REGULATIONS

The issue of extractive waste i.e. quarry materials deemed unsuitable for processing and off-site use but stored pending site restoration is dealt with under the Extractive Waste Regulations 2009 (SI No.566 of 2009). These regulations are not discussed in this paper as they are being addressed in this session by a previous speaker.

IMPLICATIONS OF THE LEGISLATION FOR PUBLIC AUTHORITIES AND QUARRY OPERATORS

As outlined above, the Planning and Development Act 2010, EIA and AA regulatory requirements are interlinked and may have implications for many quarries.

Based on an evaluation of the Registration Process completed under the Section 261 of the Planning and Development Act 2000, the Irish Concrete Federation (ICF) estimated that more than 1,550 quarries were registered with 1200+ coming through the process, i.e. not initially invalidated and complied with any requests for further information.

The ICF also concluded that a large number of small but active sites appear to have failed to register despite having an obligation to do so. Section 261A requires the local authorities to address these sites as well as those sites that participated in the initial 261 registration process. According to the ICF this has the potential to result in up to 3000 sites requiring assessment nationally.

In accordance with Section 261A the local authority must issue a notice of its decision in relation to the continued operation of any quarry impacted by the legislation within 9 months of the date of the implementation of the amended provisions in the legislation, November 15th 2011. This means that all quarries must be assessed and or information sought regarding the operations by August 24th 2012. Clearly there is much work to be done to review the operation of the quarries, ensure they are bone fide operations and that the planning conditions (including any provisions for EIA or AA) are completed to demonstrate that environmental impacts can be mitigated.

WHAT ARE THE LIKELY ENVIRONMENTAL IMPACTS FROM QUARRY ACTIVITIES?

Whether being assessed as part of the preparation of an Environmental Impact Assessment (EIA) or as part of a planning application where EIA does not apply the potential impacts associated with quarry activities must be assessed. Guidance on the preparation of EIA in relation to quarries is available from the EPA (2002 and 2003), The Institute of Geologists of Ireland (2002 and 2007). Guidance on the preparation of Appropriate Assessments (AA is available from the Department of the Environment, Heritage and Local Government (2010).

Best practice guidelines for quarry operation include the 2006 Environmental management Guidelines for the Extractive Industry published by the Environmental Protection Agency and the Irish Concrete Federation Environmental Code 2005 and associated Geological Heritage and Archaeological Code of Practice guidelines published in 2008 and 2009 respectively.

In general quarries operating above the water table are likely to have less impact than those operating below the water table. Typically sand and gravel quarries operate above the water table. It becomes unsustainable to work below the water table due to problems with trying to dewater excavations and the cost of less efficient operation of plant required to operate below the water table. Hard rock quarries also operate as much as possible above water table to avoid the ongoing cost of pumping water out of excavations. However many hard rock quarries in Ireland do operate at substantial depths below water table in some areas.

There are however potentially sensitive environmental issue common to operations above and below the water table. The primary issues are presented below and are ones that Local Authorities typically have to consider when assessing the grant of planning permission for any quarry site and in particular when reviewing EIA or AA submissions. While this is not an exhaustive list, it provides a summary of many of the main issues that can arise and possible will need consideration as part of the Section 261A review process currently underway, particularly in sites requiring EIA and/or AA. It is acknowledged however that for most sites who operate in accordance with best practice guidelines that most of the issues of concern presented below are being appropriately managed in quarry sites.

NOISE AND VIBRATION

Typically associated with;

- Production of aggregates (rock crushing), rock breaking), blasting in Rock Quarries , washing of sands and gravels; and general plant operation and vehicle movements.

- To mitigate impacts hours of operation are controlled and emission limits are set at noise sensitive locations (dwellings).

AIR QUALITY/ DUST

Sources are similar to above. Mitigation measures usually involve water bowsers and/or water sprinkler systems to suppress dust and monitoring for dust deposition rates set as part of the planning conditions if considered a significant issue.

SURFACE WATER FLOW, QUALITY AND ASSOCIATED ECOLOGICAL IMPACTS

There is the potential for impact on surface water flow where water is abstracted from a river/stream for process use (washing, concrete, batching). Assessment may be required as to whether the abstraction rate and volume is significant. Usually this can be assessed by comparing abstraction rates against dry weather or ninety fifth percentile flows in the stream/river.

Where a quarry surface water intake or discharge point is close to a Surface Water Dependant Ecosystem and/or a site listed under Natura 2000 (candidate or full Scientific Area of Conservation (cSAC or SAC) or Scientifically Protected Area (SPA) delineated by National Parks and Wildlife Services) there is the potential that an Appropriate Assessment could be required. In such cases there may be a need for consultation with NPWS and hydrologists to address possible impacts on the protected area. The impacts on such sites may take years to identify and it is likely that monitoring of such impacts will be ongoing over the lifetime of the quarry or in exceptional cases may limit the intake of water or result in the sourcing of water from an alternative source, possibly groundwater. However, if acted upon early enough, there is sufficient time to request a Stage 1 screening document from the operator to assist in the review.

Water used in concrete batching process can result in the generation of a high pH eluate that must be treated (buffered) before discharge either to ground or returned to the river via settlement lagoons after treatment to levels set in planning conditions. Good practice is to recycle this type of eluate as much as possible rather than to discharge it.

Water used in washing processes will result in high suspended solids levels. This water is usually diverted to settlement lagoons designed to ensure maximum settlement prior to discharge, again to levels set in planning conditions. Where EIA or AA is not required a planning authority can condition quarry sites to undertaken monitoring of surface water quality (typical upstream and down-stream of the site and any discharge points), and surface water levels at appropriate frequencies and for site specific parameters of quality to confirm that no environmental impacts occur during site operation..

GROUNDWATER RESOURCE, QUALITY AND ECOLOGICAL IMPACTS

Probably one of the more contentious issues/ potential impact associated with quarrying is dewatering. This is primarily an issue with bedrock quarries where activity is ongoing below the water table. Pumping can result in a loss of water supply to nearby private wells as the drawdown cone expands laterally and the water level declines vertically over time with continuous and/or increased dewatering.

Where dewatering continues for long periods 5-10 years the extent of dewatering can be significant. Predicting the impacts of dewatering is however a difficult process particularly in karst limestone environments where the dewatering is unlikely to result in a uniform or gradual expansion of the drawdown cone.

Where dewatering is occurring in proximity to a groundwater dependant ecosystem there is the potential for impact. As part of quarry review process being undertaken by the local authorities under Section 261A this could trigger the need for a screening for an Appropriate Assessment (AA) of the activity and possibly the completion of an AA. However, this trigger will not occur where the developed quarry remains inside land authorised prior to the particular legislation (EIA or AA).

The assessment of potential impacts on GWDTEs has the potential to be complicated process and will require collaborative input between ecologists experienced in the assessment of GWDTE's, and hydrogeologists. The impacts of dewatering on a GWDTE are likely to be gradual. It may therefore take years to identify the full extent of such impacts. As such the process may take years of monitoring and or result in the imposition of controls on the abstraction rate and ultimately the lifespan of a quarry. It is acknowledged that the potential for this situation to arise is unlikely to be a common occurrence; however, the potential may exist at some sites.

Dewatering in quarries also has the potential to impact on surface water. For example where a surface water course flows adjacent to a quarry where dewatering is occurring it has the potential to affect base flow in the surface water course. This in turn could lead to a surface water course drying up during low flow periods of the year. This has been identified in at least two quarries in the southwest, one in Cork and one in Kerry. One of the impacted sites was identified during the review of an EIS submitted for a quarry applying for continuance of use under S.261 (7) in 2007.

Where there is an intensification of use (i.e. multiple quarry operations occurring in close proximity to each other and where dewatering is occurring there is the risk that this may affect the groundwater resource i.e. the aquifer at a local scale or in the context of the Water Framework Directive 20000 the Groundwater Body at a regional scale. Such impacts have been identified in the Carrigtwohill Region of County Cork as referred to above.

It may be argued by some that abstraction does not affect the overall water balance as the groundwater is not lost, but merely transferred from a groundwater body to a surface water body. However, this ignores the fact that removing large volumes of water from a groundwater body presents a risk to the quantitative status of that groundwater body.

It also raises other issue in relation to flood risk in the receiving surface water course particularly in the winter period.

Blasting in quarries has the potential to close off productive fractures in the bedrock formations in and around a quarry with the possible reduction or even elimination of water flow to nearby private wells. The only real mitigation measure in such an instance is the re-drilling of a well to restore the supply.

Groundwater quality issues relate primarily to potential impacts from on-site activities that can result in discharges to ground. Explosive charges used in blasting can result in localised high concentrations of nitrate in the groundwater which have the potential to impact on close by local private wells.

Potentially contaminating activities at quarry sites include concrete batching plants, oil, waste oil or other contaminating or liquid chemical storage area, wastewater treatment systems. Where best practice guidance is followed these issues are not usually a concern at quarry sites. Where groundwater abstraction occurs in deep bedrock excavations, particularly in karst limestone environments close to the sea there is a risk of saline intrusion locally around the quarry.

To confirm that no impacts occur, planning authorities can look for appropriately levels of containment for contaminating activities and monitoring of groundwater quality where particular risks are considered to be significant.

CONCLUSIONS

Section 261A of the 2010 Planning and Development Act requires local authorities to review all quarry operations and establish their planning status or require the relevant information to establish their status by August 24th 2012.

It is likely that the sites which are currently implementing best practice guidelines in terms of environmental management will require little or no further assessment as part of the review currently underway.

While planning authorities nationally may have to review up to 3000 sites it is likely that a relatively small percentage of these will be required to undertake remedial Environmental Impact Assessments and/or Appropriate Assessments.

Where remedial EIA and or AA are required it is likely that the Planning Authorities (Local Authorities and An Bord Pleanála) will need the assistance of hydrologists, hydrogeologists and ecologists to advise on the appropriate course of actions required to mitigate environmental impacts.

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SESSION IV

AUTHORISING DISCHARGES TO GROUNDWATER: ISSUES AND TECHNICAL ASSESSMENTS

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ABSTRACT

The Groundwater Regulations (S.I. No. 9 of 2010) introduced groundwater quality objectives to which public authorities have a duty to respond, both in terms of promoting compliance with the regulations and taking steps to 'prevent or limit' inputs of pollutant substances to groundwater. Technical guidance has been prepared by the Environmental Protection Agency to assist public authorities in this capacity, with a primary aim of introducing a consistent approach as to how new discharge activities should be assessed, how defensible decisions can be reached, and mitigation measures that may be needed in order to grant authorisation. The technical guidance covers a range of relevant topics, and the basic approach and methodology focuses on ***risk screening and technical assessment*** *to demonstrate:*

a) Hydraulic 'site suitability' (i.e. a site has sufficient infiltration capacity); and
b) Attenuation potential (i.e. inputs should not result in impacts on receptors or groundwater quality standards and objectives).

The technical guidance is based on the source-pathway-receptor model of risk assessment. As each site and discharge activity will be different, the guidance is not prescriptive, and the scope and degree of complexity of technical assessment should be proportional to the risk(s) posed and the hydrogeological characteristics of the site. Where risk of impact is identified, the impact should be verified through monitoring. The nature of monitoring should be guided by the site conceptual model and a site-specific understanding of pollutant pathways. The monitoring should be both ***proportional*** *to the nature of the discharge activity and the risks posed, and* ***representative*** *of the relevant pathways that would transport pollutants away from the source.*

BACKGROUND

'Discharge to groundwater via percolation' licenses have been granted nationally by local authorities since 1978 under the Local Government (Water Pollution) Acts 1977 to 1990. Licenses are typically granted with three principal conditions: that onsite wastewater treatment systems (OSWTS) are constructed 'to standard'; that evidence is provided to show that a maintenance contract has been entered into with a supplier or manufacturer (of a specified treatment system); and that treatment delivers an effluent of a specified quality. For older licenses, specified treatment standards tend to be limited to Biological Oxygen Demand (BOD) and Suspended Solids (SS). Newer licenses might include standards for phosphorus (either as total phosphorus, TP, or orthophosphate, MRP), nitrogen (as total nitrogen, TN), and fats, oil and grease (FOG).

A scan of local authority files across the country demonstrates that the vast majority of OSWTS, including conventional septic systems, do not function as intended. As a result, effluent discharge standards are routinely exceeded. Primary causes for treatment failures can be attributed to one or more of the following: inappropriate or inadequate treatment design, poor construction, breakdown of treatment equipment, and poor operation and maintenance practices. Such issues may be compounded by failure of percolation systems where these are old or just poorly constructed and/or maintained. This also applies to many OSWTS that were constructed unsupervised during the building boom of the last 10-15 years.

With regards to existing licenses, local authorities routinely call for corrective action to be taken on the basis of data returns and site audits. Despite best intent and effort, problems tend to persist after temporary (and repeated) fixes are implemented, for the same reasons that failures occurred in the first place. Accordingly, inadequate effluent treatment and mechanical failure of percolation systems undoubtedly contributes to water quality problems in streams and groundwater, especially in settings of 'extreme' groundwater vulnerability.

A different cause of water quality problems can be attributed to inappropriate design and construction of percolation systems where a site has insufficient hydraulic capacity to 'accept' and percolate the effluent. **Figure 1** highlights three 'typical' hydrogeological settings where vertical and/or horizontal movement of effluent through subsoils and bedrock is impeded, frequently resulting in ponding and direct surface pathways to nearby ditches, streams, and other topographic depressions.

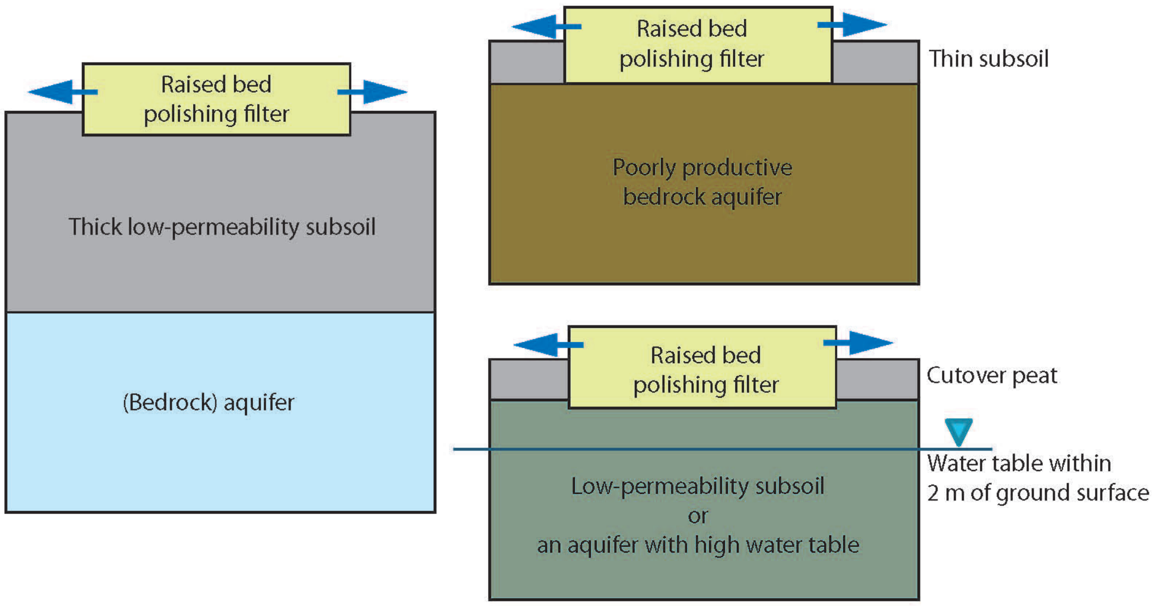


Figure 1: Common scenarios resulting in insufficient percolation and surface ponding of effluent

There has been a tendency in the past to rely on 'mounded' or raised filter beds where percolation has proven difficult. Too often, percolation systems are constructed on the basis that a site is deemed '*suitable subject to site improvements'*, where the latter is represented by an 'engineering solution' such as above-ground mounds. The justification that is frequently cited relates to the EPA Code of Practice (CoP) for waste water treatment systems for single houses (EPA, 2009), which includes suggestions and design details of site improvement measures. It is important to note that the EPA CoP is intended for small discharges associated with single houses, *i.e.* less than 2 m^3/d. There is a considerable difference between percolating 2 m^3/d and 20 m^3/d, or even larger discharges associated with developments such as housing estates, hotels, nursing homes, etc. Scaling up the details of the CoP for large discharge volumes is neither appropriate nor intended. Rather than granting licenses that simply call for site improvements, applications and cases involving large discharges should look to develop or obtain evidence that improvement works will function as intended before an authorisation is granted by a public body.

NEED FOR TECHNICAL GUIDANCE

Until the introduction of the European Communities Environmental Objectives (Groundwater) Regulations, 2010 (S.I. No. 9 of 2010) (Groundwater Regulations), authorisation of discharges to groundwater has been regulated and authorised by local authorities and the EPA under the Local Government (Water Pollution) Acts 1977 to 1990. Despite the legislation, there has been no consistent approach towards assessing potential impacts on groundwater from new or existing discharge activities. Due to the comprehensive nature of the Groundwater Regulations, and its context with the

Water Framework Directive (2000/60/EC) (WFD) and the Groundwater Directive (2006/118/EC) (GWD), a consistent approach towards technical assessment is needed. A common understanding of what a technical assessment should result in is also needed. This is particularly important as the Groundwater Regulations places a duty on public authorities to promote compliance with the requirements of the regulations and to take all reasonable steps to:

> "(a) prevent or limit, as appropriate, the input of pollutants into groundwater and prevent the deterioration of the status of all bodies of groundwater;
>
> (b) protect, enhance and restore all bodies of groundwater ..... achieving good groundwater chemical status by not later than 22 December 2015;
>
> (c) reverse any significant and sustained upward trend in the concentration of any pollutant resulting from the impact of human activity in order to progressively reduce pollution of groundwater;
>
> (d) achieve compliance with any standards and objectives established for a groundwater dependent protected area included in the register of protected areas ....."

The 'prevent or limit' objective is the core groundwater quality objective which drives the need for common thinking and approaches towards technical assessment. In principle, 'prevent or limit' measures are the first line of defense in restricting inputs of pollutants to groundwater. The 'prevent' objective relates to ***hazardous*** substances, whereby all necessary and reasonable measures should be taken to avoid the entry of such substances into groundwater and to avoid any significant increase in concentrations in groundwater, even at a local scale. The 'limit' objective relates to ***non-hazardous*** substances, whereby all necessary measures should be taken to limit inputs into groundwater to ensure that such inputs do not cause deterioration in status of groundwater bodies, nor significant and sustained upward trends in groundwater concentrations.

As a response to the Groundwater Regulations, the EPA has developed a technical guidance document on the "Authorisation of Discharges to Groundwater" (EPA, 2011). The guidance provides a framework for the processes, types of information, and criteria that are considered important for granting or denying an authorisation to discharge, or alternatively, to point out what information might be needed to address technical areas of uncertainty. Specifically, the guidance covers:

- Risk screening for potential impact to groundwater based on considerations of pollutant loading, toxicity, pathways and receptor types;
- Appropriate levels of technical assessment that are proportional to the risk(s) posed;
- Predicting an impact on groundwater quality; and
- Appropriate monitoring to check compliance with receptor-based water quality standards.

Due to the wide range of hydrogeological settings and levels of complexity in Irish aquifers, the guidance is not prescriptive. Rather, the guidance aims to provide an overall indication of the assessment process and the underlying principles that should be followed. As such, a specific goal of the guidance is to achieve a future level of consistency in terms of how discharge to groundwater applications are prepared, reviewed, and discussed, and on what basis decisions should be made.

SCOPE AND CONTEXT OF THE GUIDANCE DOCUMENT

The guidance addresses both direct and indirect discharges (inputs) to groundwater which can originate from ***point sources*** of potential pollution. It does not cover diffuse inputs from agriculture, such as land spreading, which are covered by other legislation, notably European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2010 (S.I. No. 610 of 2010). Point sources that are highlighted in the guidance are:

- Small scale discharges from OSWTS - septic tanks and package treatment plants;
- Discharges to ground from larger OSWTS, including integrated constructed wetland (ICW) systems;
- Infiltration of urban storm water through infiltration basins;
- Infiltration of quarry processing water; and
- Escape of leachate from landfills (beyond engineered and/or geological barriers).

The EPA (as the responsible agency) may establish detailed technical rules under which new inputs may be exempted from the requirement that all measures be carried out to meet the ‘prevent or limit’ objective. The EPA is currently considering possible technical rules for exemptions. Categories of possible exempted inputs include unforeseen accidental spills, return water from geothermal installations, and deliberate inputs for scientific research purposes (such as groundwater tracers). Final decisions as to whether a given planned discharge activity may be exempted will be made by the EPA on a case-by-case basis.

The context of the guidance document relates to groundwater protection measures required by the WFD and the GWD, notably that ‘good’ status should be achieved in all groundwater bodies and associated ecosystems by 22 December 2015, subject to exemptions under certain conditions. ‘Status’ applies to both water quantity (quantitative status) and quality (chemical status), and a classification of chemical status of Irish groundwater bodies was completed by the EPA in 2011. The classification identified several groundwater bodies as being at poor status, on account of their association with poor status surface water bodies, whereby groundwater acts as a pathway delivering elevated phosphorus loads and concentrations to streams and rivers. The majority of the poor status groundwater bodies are part of the regionally important karstified limestone aquifers in the central and western lowlands of Ireland.

Generally, the chemical status classification reflects regional trends and patterns rather than local-scale impacts. Inputs from individual point sources such as effluent percolation systems tend to have localised impacts. Localised pollution may exist within a larger groundwater body that is at good chemical status. However, in circumstances where the groundwater body is classed as ‘poor’ or where ‘good’ but with limited capacity to accept more pollutants, the impact of further pollutant input would need to be considered before authorization is granted, specifically where new inputs may result in groundwater concentrations that exceed relevant water quality standards. The EPA’s status classification is reviewed every six years in line with WFD river basin management plan cycles. As such, the EPA is monitoring trends of concentrations of substances in groundwater via a national groundwater monitoring network. Trend assessment of monitoring data is part of the classification process. Where upward trends are significant and sustained, they must be reversed by introducing appropriate mitigation measures. As such, public authorities must review new discharge to groundwater applications in the context of the existing status of the relevant groundwater body, within which the proposed discharge activity is located.

APPROACH AND METHODOLOGY

The technical guidance is risk-based and receptor-focussed, and follows the source-pathway-receptor (SPR) model which underpins all groundwater protection schemes in Ireland. Every discharge activity carries a degree of risk of impact on groundwater quality and groundwater-based receptors. The challenge lies in differentiating between degrees of risk and assigning appropriate effort and resources where the risk is higher.

The technical assessment methodology is aimed at examining SPR relationships, specifically:

- Avoiding inputs within buffer distances defined by existing groundwater protection schemes (a *site restrictions* issue);

- Demonstrating that a site has sufficient infiltration capacity to physically 'accept' the effluent, thereby avoiding surface ponding and runoff (a *hydraulic* issue);
- Demonstrating that a site has adequate natural potential to limit the loading of substances to groundwater (an *attenuation* issue);
- For larger discharges, predicting an impact on groundwater quality; and
- Where necessary, verifying predicted impacts by checking compliance with relevant groundwater quality objectives and receptor-based standards.

The methodology involves an initial risk screening procedure summarised in **Figure 2**. The outcome of the risk screening is a determination of the degree of risk posed by the discharge activity to groundwater quality and receptors, and then deciding on an appropriate level of technical site assessment needed to demonstrate site suitability and, if needed, to estimate chemical loading and a predicted impact.

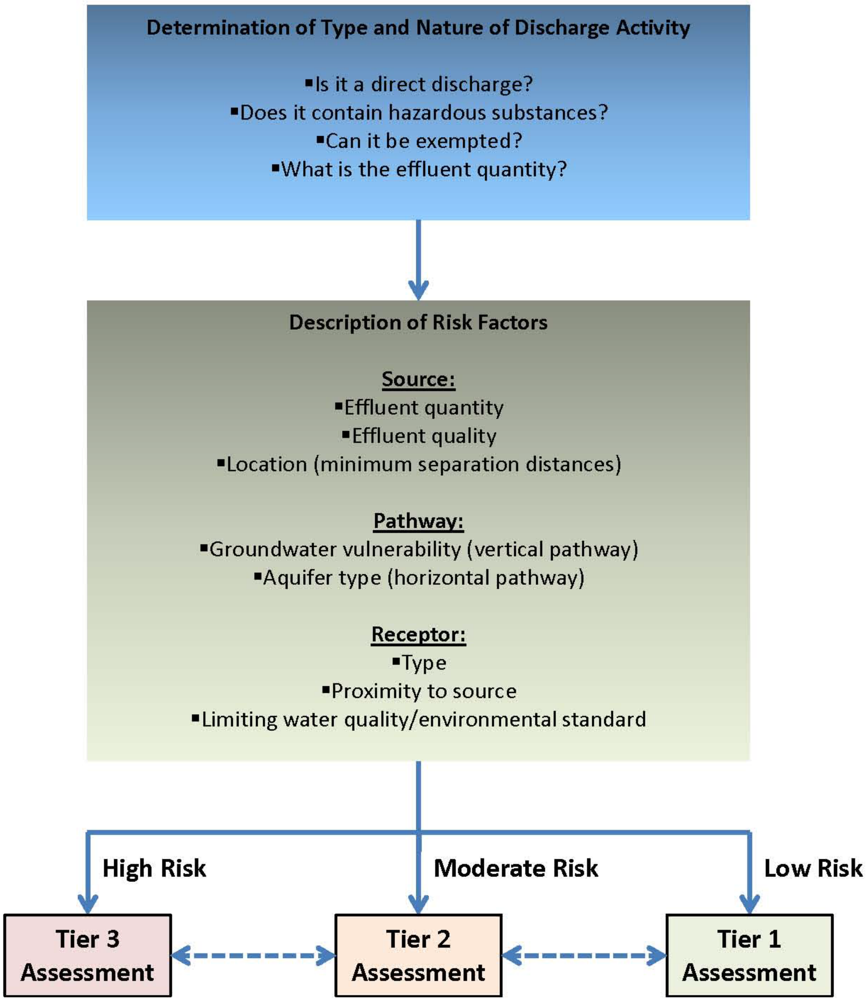


Figure 2: Approach - risk screening and determination of technical assessment needed

Crucially, the level of technical assessment should be proportionate to the risk posed by the discharge activity. Three tiers of assessment (Tiers 1 through 3) are defined, which in theory involve increasing degrees of complexity. Guidance is provided on the types of data and information that might be needed for prior site investigation for each tier of assessment. However, as details of site-specific investigations cannot be prescribed, suitably qualified persons and professional judgement will be involved for the more complex cases, using a "weight of evidence" approach.

Tier	Risk/Activity	Emphasis
1	Low – mostly small discharges <5 m^3/d	Implementation of EPA code of practice for OSWTS for single houses
2	Moderate – mostly discharges >5 and <20 m^3/d	Subsoil characterisation – type(s), thickness, permeability, depth to bedrock
3	High – discharges >20 m^3/d and/or 'significant' risk of impact on receptors	Subsoil and groundwater characterisation – respective type(s), thickness, permeability, depth to bedrock, flow gradients

The naming and assignment of 'Tiers 1 through 3' is somewhat arbitrary, but is intended to assist public bodies with the conceptualisation of risk and the degree of technical complexity associated with a given site. Whether a site is deemed to be a Tier 2 or Tier 3 site is secondary to the work carried out and the answers produced. The end product is a determination of 'site suitability' in context of site restrictions, infiltration capacity and attenuation potential.

Tier 1 assessments cover low-risk activities. The most significant discharge activity in this category is effluent from OSWTS of less than 5 m^3/d. A typical Tier 1 assessment should, therefore, follow the characterisation procedures described in the EPA CoP for OSWTS for single houses. No other requirements are specified, although emphasis is placed on demonstrating site suitability. Provided the site characterisation form that accompanies the CoP is completed, the subsoil permeability and thickness is suitable and the infiltration (percolation) values are satisfactory, authorisation may be granted. If there is uncertainty about the results, further site investigation may be needed akin to the Tier 2 assessment. Engineering measures to improve infiltration capacity and attenuation potential can be considered, subject to 'best practice'.

As with Tier 1, a Tier 2 site assessment must demonstrate sufficient infiltration capacity and adequate attenuation potential. Emphasis is therefore placed on improved subsoil characterisation, with drilled boreholes where the depth to bedrock is beyond the safe limit of trial holes. As Tier 2 assessment involves site characterisation and preliminary calculations of potential impact to groundwater quality, the work should be carried out by a suitably qualified person. Tier 3 assessments generally cover high risk activities defined by effluent discharges >20 m^3/d, landfills, and any other proposed activity that carries a high risk of impact on account of effluent type, distances to sensitive receptors, and so forth. They would also cover any discharge activities where the results of an initial Tier 1 or Tier 2 assessment indicate significant doubt or scientific uncertainty. The emphasis is placed on demonstrating impact, whereby groundwater monitoring will be involved. The scope and nature of a Tier 3 assessment is case- and site-specific, and is influenced by the conceptual hydrogeological model of the site. The objective is to produce representative hydrogeological data of subsoil characteristics as well as groundwater flow gradients, fluxes and quality. A Tier 3 assessment must be carried out by a suitably qualified person.

HYDRAULIC SITE SUITABILITY

Whereas traditionally the emphasis of discharge licensing has been on effluent treatment and treatment standards, a shift in practice is needed to examine, determine and demonstrate 'hydraulic site suitability', where this is described by a site's infiltration (percolation) capacity. The introduction of the FAS course on site assessment associated with the EPA CoP is a significant step in the right direction, but addresses small discharges that are associated with single houses and small developments. More rigorous site assessment is needed for larger discharges. For Tier 2 and Tier 3 situations, the technical assessment should, at a minimum, include subsoil characterisation, beyond trial pits and P- and T- tests. The subsoil characterisation would involve the description of depth to bedrock, subsoil types and textures, and subsoil permeability. Individual clay layers should also be described. For some Tier 2 and probably all Tier 3 assessments, groundwater characterisation is needed, notably bedrock transmissivity/hydraulic conductivity, flow gradients, and pre-discharge (background) groundwater concentrations. Improved subsoil characterisation would apply primarily to scenarios where subsoils are thick, guided by existing vulnerability mapping (e.g. in areas of 'low' and 'moderate' vulnerability). An improved subsoil characterisation will assist in determining both the 'ponding' and attenuation potentials of a site.

ATTENUATION POTENTIAL

Pollutants percolating through subsoils will naturally attenuate as a function of filtering, adsorption and ion exchange. In principle, therefore, the thicker the subsoil, the greater the degree of attenuation can be expected (permeability issues aside). Once a pollutant reaches groundwater, further attenuation will occur as a function of mixing and dilution between the effluent and the natural groundwater throughflow in the aquifer. The degree of mixing and dilution that occurs depends on the aquifer type and the groundwater flow rate. In fractured bedrock aquifers, little or no further attenuation is expected in a down gradient direction due to the nature of fracture and fissure flow. In sand and gravel aquifers, however, further attenuation can be expected in the down gradient direction, as pollutants are continually filtered and adsorped through the granular aquifer materials.

For technical assessment of a discharge activity, the conservative approach is to assume no attenuation in subsoil and no attenuation beyond mixing and dilution in groundwater. Although conservative (and therefore, protective), this is not entirely realistic in all circumstances. Research conducted in Ireland (Gill *et al*, 2009) shows that attenuation in subsoils can be significant for nutrient compounds, but the degree of attenuation that will take place is both case- and site-specific as a function of effluent and subsoil characteristics, as well as type of OSWTS. In groundwater too, new research (e.g. Jahangir *et al,* 2012; Fenton *et al*, 2009) indicates that denitrification (thus, affecting N) may take place under certain hydro-geochemical conditions, and that the hyporheic zone along streambeds can significantly influence (reduce) discharge concentrations to streams. As the science related to these topics is still evolving, the technical guidance is, for now, recommending the conservative approach. It is acknowledged that this approach may be overly conservative in some cases, and in such cases, it will be incumbent on the applicant to define and demonstrate the degree of attenuation that will or does occur.

PREDICTING AN IMPACT TO GROUNDWATER QUALITY

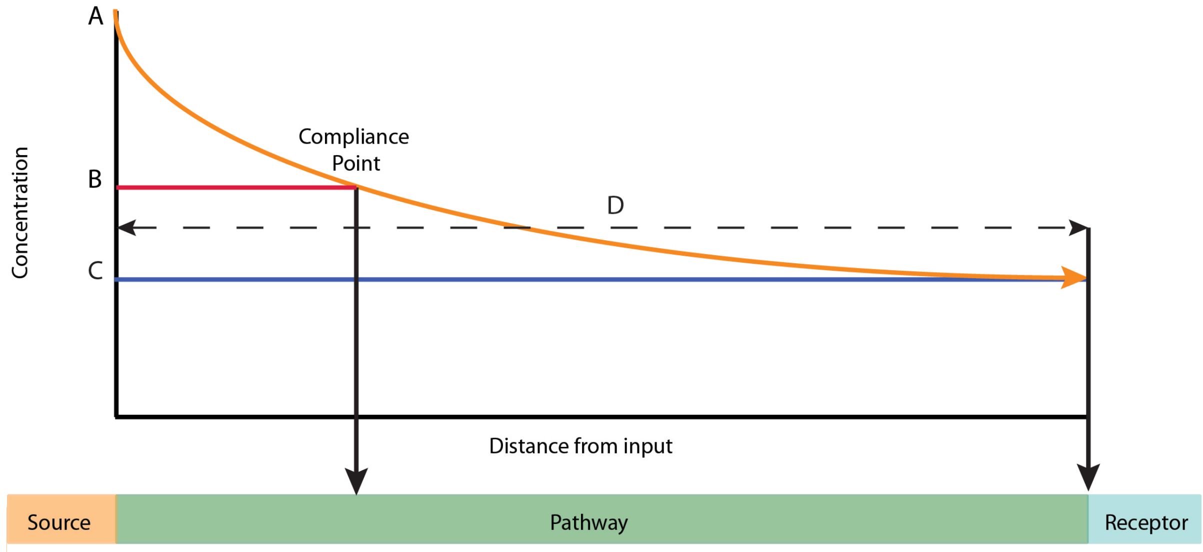
Predicting a potential impact on groundwater quality and associated receptors through Tier 2 and Tier 3 assessments involves estimation and/or calculation of:

- Hydraulic loading to groundwater;
- Chemical loading to groundwater; and
- Resulting concentrations of substances of concern that can be expected in groundwater following mixing between the effluent and groundwater.

The calculations make use of the site-specific data collected during site investigation(s). The prediction requires estimates of the natural groundwater flux in the aquifer and the background concentration of the substance(s) of concern up gradient of the planned discharge activity (i.e. before the projected input). Authorisation can be granted provided site suitability is demonstrated and the predicted groundwater quality impact is deemed to be acceptable with respect to groundwater quality objectives and relevant receptor-based water quality standards. If the input is predicted to result in an unacceptable increase in concentrations and/or impact on receptors, authorisation may not be granted. In this case, the applicant may propose engineering or source control measures (e.g. improved treatment) in order to reduce the chemical loading to groundwater in a revised application.

COMPLIANCE CHECKING

Compliance checking involves comparing groundwater quality data from a compliance point(s) to a specified compliance value(s). The compliance value is the concentration of a specific substance at a compliance point that will ensure its relevant water quality standards at a receptor (shown conceptually in **Figure 3**). If exceeded at the compliance point, compliance has not been achieved. In this case, source control measures may have to be initiated or modified to reduce (further limit) loading to groundwater.



A **Limit value** applied at the source to protect the receptor
B Compliance Value at a **compliance point**, set to ensure the quality standard required at the receptor is/will be met
C Quality standard required at the **receptor**
D Possible range of compliance point locations according to specific conditions – could be at the receptor itself, or some other point along the pathway

Figure 3: Receptors, Compliance Points, and Concentrations

Compliance values and water quality standards are linked to specific receptors. There are four basic types of groundwater-related receptors:

- The groundwater resource itself (the aquifer);
- Groundwater abstraction points (water supplies);
- Surface waters (rivers, lakes, transitional and coastal waters); and
- Groundwater dependent terrestrial ecosystems (GWDTEs, groundwater dependent wetlands).

The term receptor is used in its widest context to include not only the existing uses of groundwater but all plausible and legitimate future uses and functions of the groundwater.

Where the receptor is the groundwater resource (aquifer), and especially where the resource is used for water supply, the compliance value would, in most Irish bedrock aquifers, be defined by relevant groundwater quality standards. This is because attenuation processes in bedrock aquifers are mostly limited to mixing and dilution in groundwater beneath the source, with limited further attenuation expected in a down-gradient flow direction. In sand and gravel aquifers, however, attenuation processes such as dispersion, sorption and biodegradation can be more significant. In such cases, the compliance value could be set as a higher concentration than the groundwater quality standard for the receptor.

Where the receptor is surface water, environmental quality standards apply, and the compliance value is the concentration of a substance in groundwater that does not result in the EQS being exceeded after mixing (dilution) between groundwater and the surface water.

Where the receptor is a GWDTE, no statutory standards exist because different types of GWDTEs have different groundwater dependencies, and often, single ecosystems include species with different needs and sensitivities. Cases involving GWDTEs will involve prior consultation with, and participation of, the NPWS, and may involve detailed ecological characterisation. Where the GWDTE is also a Natura 2000 site, an Appropriate Assessment must be prepared, as required by the EC Habitats Directive.

SAMPLING AND MONITORING

The compliance point is a sampling point located between the source and the receptor. It must be representative of the hydrogeological characteristics of the site and groundwater samples must be collected from the 'correct' pathway – that is, the location and vertical depth interval or intervals that transmit the highest groundwater flux and concentrations of pollutant substances from the pollution source. This can only be determined with a sound conceptual hydrogeological model and a prior site investigation that identifies and quantifies the major pathways. This is particularly important for bedrock aquifers where multiple groundwater pathways may exist and clustered wells at different depths may be needed. Compliance monitoring should also take into consideration data or information on background and/or up-gradient concentrations in groundwater in order to be able to draw appropriate conclusions about resulting impacts on groundwater quality.

Groundwater monitoring does not, of itself, protect the environment. In circumstances where a development exists or is proceeding, emphasis should be placed on pollution prevention measures by means of best practice (careful location, adequate design, proper construction, and implementation of O&M protocols, etc.). Nonetheless, groundwater monitoring is an important component of compliance checking, where needed. Effective monitoring of groundwater in the vicinity of potentially polluting developments is challenging in Ireland due to the complex hydrogeological settings present in many areas.

A commonly-used approach to monitoring in regulatory guidance in many countries is to require a standard number of monitoring points in the vicinity of developments – usually one up gradient and two down gradient (as a minimum). While there are circumstances where this approach is justifiable, it is not applicable for all situations. The substances to be monitored in groundwater should reflect the type of effluent and the substances of concern in the effluent. The frequency of groundwater monitoring should reflect the temporal nature of the discharge activity and the hydrogeological characteristics of the site and associated receptors. A sampling regime in a sand and gravel aquifer would be very different from one involving karstic limestone.

Where a discharge activity involves a risk of impact on groundwater abstraction points and surface water receptors, sampling at the receptor locations will be needed to prove/disprove impact. Lastly, sites involving karstic limestone and surface water receptors would have to include consideration of flow measurements of springs and rivers/streams, if such flow data do not already exist.

CONCLUSIONS

With the introduction of the Groundwater Regulations (S.I. No. 9 of 2010), a duty has been placed on public bodies to comply with the regulations, including groundwater quality objectives and taking all reasonable and necessary measures to 'prevent or limit' the inputs of pollutant substances to groundwater. To assist public bodies, and with the aim of achieving consistency in approach, technical guidance has been prepared by the EPA as to how discharge activities should be assessed and how defensible decisions can be reached. As such, the guidance provides a framework for risk screening and technical assessment to demonstrate 'site suitability' in terms of a site's location, infiltration capacity and attenuation potential.

Existing licenses granted nationally by local authorities since 1978 have tended to emphasize treatment methods and treatment standards, with insufficient regard for 'site suitability'. For larger discharges (those greater than 5 m^3/d), the scaling up of the details of the EPA CoP for waste water treatment systems for single houses is inappropriate. The tendency to rely on '*site improvement measures*' where sites have insufficient infiltration capacity have resulted in numerous failed systems whereby effluent ponds at the ground surface and runs off via direct surface pathways. Rather than granting licenses that simply call for site improvements, applications and cases involving large discharges should look to develop or obtain evidence that improvement works will function as intended before an authorisation is granted. This includes improved site characterisation. The scope and nature of site characterisation (and technical assessment) should be proportional to the risk of impact posed by the discharge activity on a potential receptor. Due to the complexities of Irish hydrogeology, technical assessment cannot be prescriptive, and all decisions should be guided by a sound conceptual hydrogeological model of the site.

Substantial volumes of waste water are discharged to the ground daily in Ireland. This poses a significant threat not only to groundwater quality and human health, but also to surface water quality and ecological health. Greater consideration of the subsurface pathway(s) for pollutants to groundwater, surface water and other ecological receptors is now required. Combined with the existing EPA CoP for waste water treatment systems for single houses (EPA, 2009), the new guidance on the authorisation of discharges to groundwater (EPA, 2011) should contribute towards improved protection of groundwater quality and will hopefully become a valuable resource for public bodies and applicants alike.

ACKNOWLEDGEMENTS

This paper is based largely on the EPA guidance on discharges to groundwater (EPA, 2011). This guidance was prepared for the EPA by Henning Moe and Lorraine Gaston, CDM, with review and input from a Steering Group consisting of Donal Daly (EPA), Colin Byrne (DECLG), Brendan Cooney (Wexford County Council), David Flynn (EPA), Aoife Loughnane (EPA) and Bruce Misstear (TCD).

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PROGRESSION IN GROUNDWATER PROTECTION AND MANAGEMENT: A LOCAL AUTHORITY PERSPECTIVE

Brendan Cooney, Wexford County Council

ABSTRACT

Since the 1977 Water Pollution Act until relatively recent times, licensing of effluent discharges to groundwater have changed very little, despite the recognition that groundwater resources are vitally important.

In the early years of the last decade, Wexford County Council decided that action was needed to address a large deficit in how we managed our discharges and in doing so were prescient to the developments that have occurred in the past 3 years whereby we are now beginning to have a coherent set of legislation and a comprehensive set of guidelines which should, if properly implemented, result in proper management of our groundwater resources. For this to happen, it needs to be recognised that we need to move away from generalist professions and employ considerably more experts such a hydrogeologist in both putting together future discharge licence applications and also in making assessments as regulators.

BACKGROUND

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

In County Wexford, 40% of our drinking water comes from groundwater sources found in two major aquifers: (Figure 1).

1. The volcanic aquifer that runs from south west Wexford to north east Wexford; and
2. The limestone aquifer in Fardystown.

Groundwater also feeds our surface waters and in many cases, particularly in summer months, between 50% and 90% of the base flow of many rivers may be due to groundwater resources. It is therefore of vital importance that we protect our groundwater resources in order to maintain the quality of drinking water supplies and to remember that surface water quality will also be affected if contamination occurs.

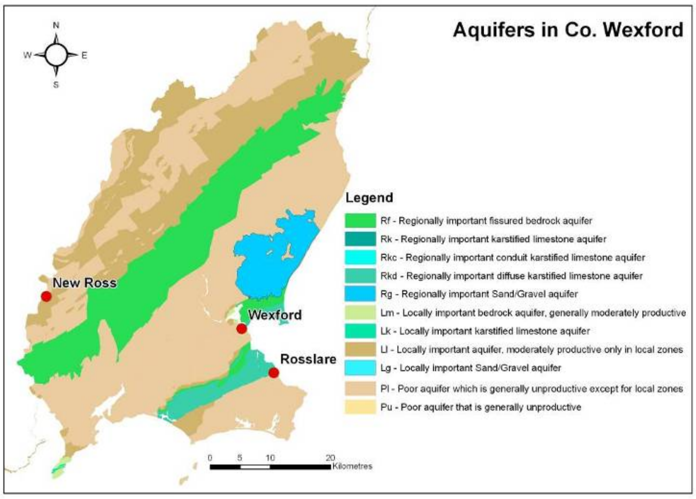


Figure 1: Map of Wexford with a simplified aquifer map.

THE PROBLEM

An increasing number of groundwater problems are however coming to the attention of scientific staff in the GSI/Groundwater, Local Authorities (LAs), and the EPA over the past 15 to 20 years, indicating that the above mentioned perception is not justified. These problems are both localised and increasingly regional, where groundwaters are indicating elevated bacteriological, nitrogen, phosphorus and other contaminant concentrations. The contaminants are from a variety of sources such as discharges of sewage from single houses and housing developments as well as inappropriate control and application of animal and artificial fertilisers in agriculture. Microbial contamination of groundwater in Ireland is high, probably higher than in any other country in the EU with many areas indicating 30% of domestic wells showing faecal pollution, while in some highly vulnerable, thin soiled/ karst areas more than 50% are polluted (Daly, 2003). Since the mid 1980s, the GSI (Daly, 1987) and other researchers have drawn attention to the importance of septic tank systems and farmyards as sources of groundwater pollution (Figure 2). This problem further elucidated in the early 1990s with additional work undertaken by Daly, Thorn and Henry (1993).

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

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

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

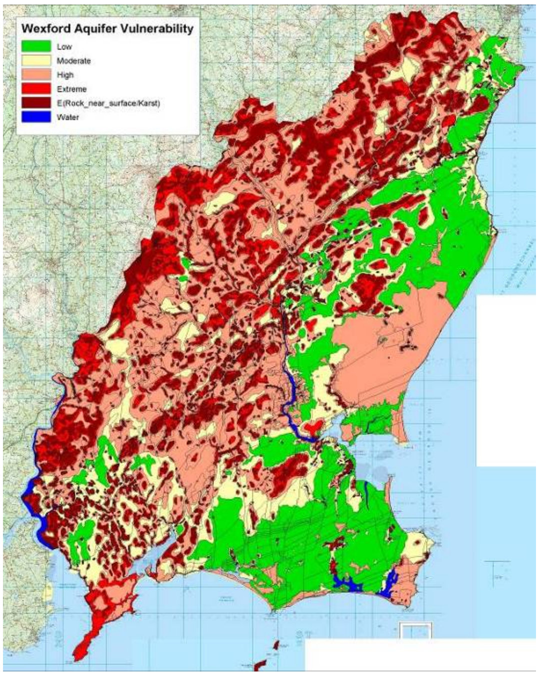


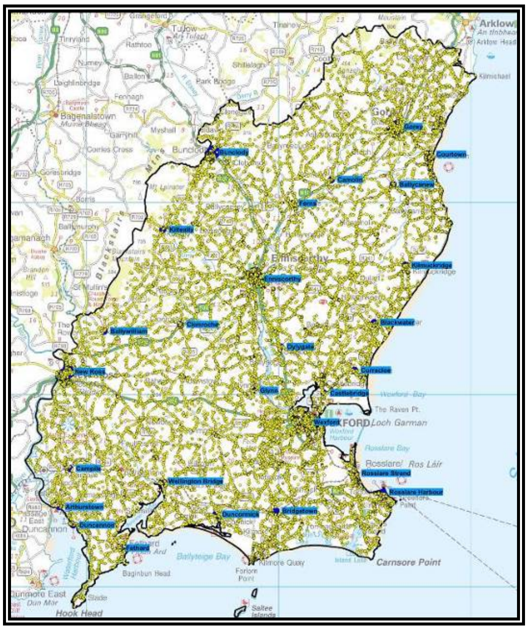
Figure 3: Wexford Aquifer Vulnerability Map

DILEMMA

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

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

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



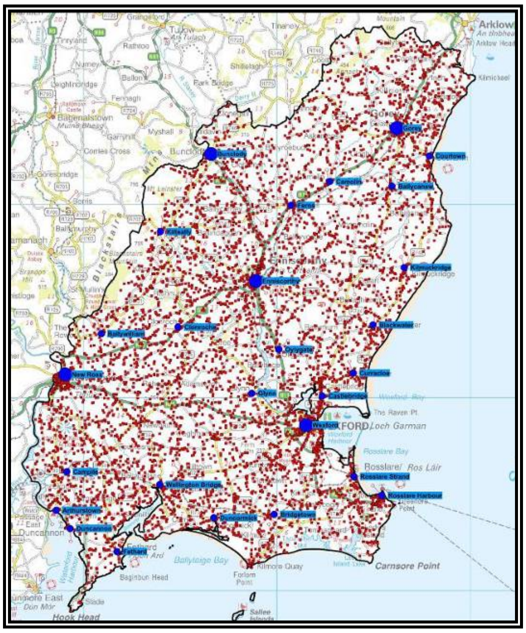


Figure 4: Map of domestic dwellings. **Figure 5**: Map of commercial registered premises.

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

Figure 6: Aerial photograph of rural development.

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

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

PROTECTION AND MANAGEMENT - PAST AND PRESENT

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

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

It was recognised by Wexford County Council however, during the early part of the last decade that action was needed to address a deficit in how our discharges to waters were managed. This was due to the large number of Section 4 discharge licence applications to Wexford County Council during the building boom. During 2006, for example, in Wexford there were 120 Section 4 discharge licence applications received of which 24 applications were for Section 4 discharge licences where it was proposed to discharge effluent to groundwater. These applications were for housing developments ranging from 7 to 24 houses. During the same period there were approx 2,700 planning applications for single houses and 750 planning permission applications for cluster developments of 2 to 5 houses of which 54% were granted, with most of them proposing to discharge the effluent to groundwater. As you can see the numbers were building up rapidly and while there was an attempt by the EPA to provide guidance on single house discharges in the early 2000s in ideal conditions, there was virtually no official guidance on how to deal with discharges of larger amounts, either to surface water or groundwater or to less than ideal ground conditions.

To that end, in 2006 a set of advice notes were published by Wexford County Council offering guidance to developers on how to assess the impact of a proposed development on the aquatic environment (Figure 7).

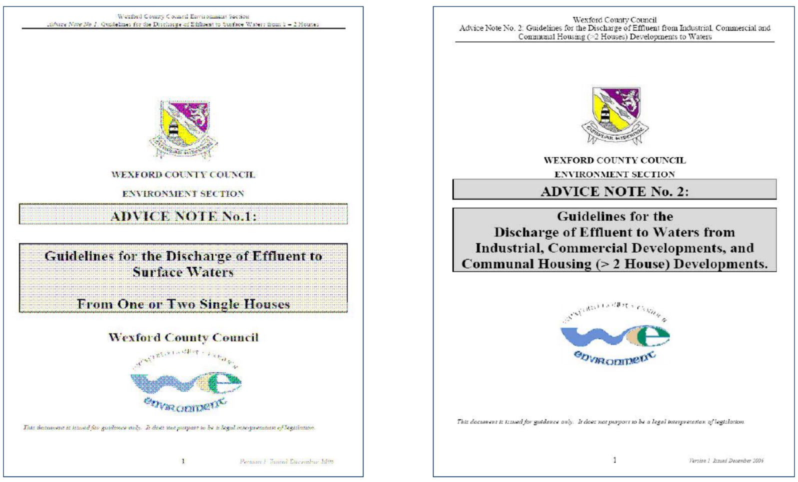
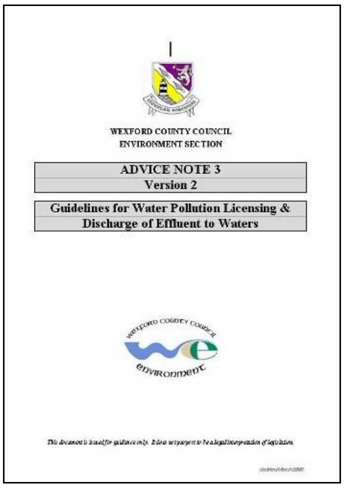


Figure 7: Covers of First Editions of Wexford County Council Advice Notes.

These guidelines were compiled following many hours of telephone calls, letters, meetings and badgering various experts in the fields of both surface water and groundwater. In 2008 these notes were updated and condensed into one advice note which covered all discharges to all waters (Figure 8).



WEXFORD COUNTY COUNCIL
ENVIRONMENT SECTION

ADVICE NOTE 3
Version 2

Guidelines for Water Pollution Licensing & Discharge of Effluent to Waters

This document is issued for guidance only. It does not purport to be a legal interpretation of legislation.

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

Type of Information	*1 to 3 houses discharging to SURFACE WATER*	*>3 houses & Industrial/ Commercial Development discharging to SURFACE WATER*	*3 to 7 houses discharging to GROUND WATER (<5m³/d)*	*8 or more houses discharging to GROUND WATER (>5m³/d)*	*Industrial or Commercial Development discharging to GROUND WATER*
Treated Effluent Standards/Analysis	Yes	Yes	Yes	Yes	Yes
Receiving Water Analysis Requirements *(Appendix 1)*	Yes: 4 Samples	Yes: 10 Samples*	Yes: (Appendix 3)	Yes: (Appendix 3)	Yes: (Appendix 3)
Receiving Water Biological Quality Rating (Q Rating) *(Appendix 1)*	Yes	Yes	No	No	No
Surface Water Flow Assessment *(Appendix 2)* & Assimilative Capacity Assessment	Yes	Yes	No	No	No
Groundwater Assimilative Capacity Assessment *(Appendix 3)*	No	No	Yes	Yes	Yes
Water Pollution Discharge Licence Required?	Yes	Yes	No	Yes	Yes

Figure 8: Cover and advice matrix from Advice Note 3

Dealing with discharges to groundwaters specifically, the information Wexford County Council was requesting was for a full water quality and hydrological assessment of the underlying aquifer so as to ascertain what the aquifer quality and hydrogeological characteristics were before making a decision as to whether a discharge would be allowed to go ahead. Prior to this there was a tendency to look exclusively at the discharge itself with no cognisance of the receiving waters taken. If the effluent met certain minimum standards then it was granted permission regardless of the quality or assimilative capacity of the receiving waters. The information requested is presented in Figure 9 below.

6 DISCHARGES TO GROUNDWATERS

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

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

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

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

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

Figure 9: Extract from Advice Note 3 indicating information needed for a groundwater discharge licence application

Following receipt and assessment of the data with the application, the raw data was put into a spreadsheet (figure 10 below) which we had developed to assess the impact of the effluent on the aquifer quality.

It is acknowledged that the calculations are very simple, looking at the vertical and horizontal dilution only and made no attempt to look at dispersal characteristics, or attenuation of the effluent as it made its way through the soil and bedrock or any other of a multitude of factors which would influence the impact the discharged effluent had on the receiving waters. It was however we believe a good first attempt to start to properly regulate the discharges and start to put some ballpark assessment of the impacts and thus start to protect our resource.

	A	B	C	D	E	F	G	H
2								
3	Total Hydraulic Load per day (l/day)			8380	l/day			
4	Total Hydraulic Load - m3/day			8.38	m3/d	QD		
5	Area available to applicant			0.9	Ha			
6	Soil co-efficient			0.5				
7								
8	Rainfall per year (mm)			994	mm/yr			
9	Evapotranspiration (mm)			440	mm/yr			
10	Potential Recharge (mm)			554	mm/yr			
11	Runoff Losses (mm)			277	mm/yr			
12	Estimated Actual Recharge -Year (mm)			277	mm/yr			
13								
14	Development Estimated Actual Recharge - Year			2493	m3/yr			
15	Development Estimated Actual Recharge - Day			6.83	m3/day	QB		
16	Total flow to ground - m3/day (rainfall and eff discharged)			15.21	m3/day			
17								
18	Effluent Characteristics **(CD)**				Rainwater Characteristics **(CB)**			
19	BOD conc	10	mg/l		BOD conc	0.1	mg/l	
20	NH3-N conc	5	mg/l		NH3-N conc	0.01	mg/l	
21	oPO4-P conc	3	mg/l		oPO4-P conc	0.01	mg/l	
22	NO3-N conc	12	mg/l		NO3-N conc	0.1	mg/l	
23	No2-N	1	mg/l		No2-N	0.001	mg/l	
24								
25	Flowrate	8.38	m3/day		Flowrate	6.83	m3/day	
26	**Vertical Recharge**							
27	CR =	(QD*CD + QB*CB) / (QD + QB)						
28								
29	CR	Resultant addition in waterbody (mg/l)						
30								
31	QD	Average effluent discharge flow (m3/d)						
32	CD	Conc. in effluent discharge (mg/l)						
33	QB	Average rainwater recharge (m3/d)						
34	CB	Conc. in rainwater (mg/l)						
35								
36	**Discharge to Aquifer**							
37	Parameter (mg/l)	QD	CD	QB	CB		CR	
38	BOD conc	8.38	10	6.83	0.1	84.483	5.554	
39	NH3-N conc	8.38	5	6.83	0.01	41.968	2.759	
40	oPO4-P conc	8.38	3	6.83	0.01	25.208	1.657	
41	NO3-N conc	8.38	12	6.83	0.1	101.243	6.656	
42	NO2-N	8.38	1	6.83	0.001	8.387	0.551	
43								
44								

	A	B	C	D	E	F	G	H
1	**Horizontal Recharge**							
2								
3	**Aquifer Characteristics**							
4	Upgradient water level	10	meters	bgl				
5	Downgradient	11	meters	bgl				
6	Distance between two wells	9.5	meters					
7	dh/dl (horizontal hydraulic gradient)	0.105						
8								
9	K (Hydraulic Conductivity/Permeability)	1.67E-06	m/sec					
10	d (thickness of weathered rock aquifer [depth])	5.0	m					
11	w (width of perc area)	30.0	m					
12	A (cross sectional area)	150.0	m2			Waterbody Characteristics **(CB)**		
13	Flow Q = K x A x dh/dl	2.6E-05	m3/s				2.2782	m3/day
14	Flow of aquifer under the site(Q)	2.2782	m3/day	QB			2278.2	l/s
15						BOD conc	1	mg/l
16						NH3-N conc	0.01	mg/l
17	PE	103				oPO4-P conc	0.02	mg/l
18	Flow Rate of effluent	8.38	m3/day	QD		NO3-N conc	12.7	mg/l
19	from previous page					NO2-N	0.1	mg/l
20								
21	CR =	(QD*CD + QB*CB) / (QD + QB)						
22								
23	CR	Resultant addition in waterbody (mg/l)						
24	QD	Average effluent discharge flow (m3/d)						
25	CD	Conc. in effluent discharge (mg/l)						
26	QB	Background flow in Groundwater Horizantal flow Element (m3/d)						
27	CB	Background conc. in Groundwater Horizantal flow Element (m3/d)						
28								
29	**Final Concentration in Aquifer**							
30	Parameter (mg/l)	QD	CD	QB	CB		**CR**	
31	BOD conc	8.38	5.554	2.28	1.000	48.824	**4.581**	
32	NH3-N conc	8.38	2.759	2.28	0.010	23.145	**2.172**	
33	oPO4-P conc	8.38	1.657	2.28	0.020	13.934	**1.307**	
34	NO3-N conc	8.38	6.656	2.28	12.700	84.713	**7.948**	
35	NO2-N	8.38	0.551	2.28	0.100	4.849	**0.455**	
36			result of previous page calculations				**Final aquifer concentrations**	
37								

Figure 10: Extract from spreadsheet showing calculations involved for a groundwater discharge

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

PROTECTION AND MANAGEMENT - FUTURE

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

Environmental regulation has reached a stage of sophistication in Ireland whereby non-professionals or professionals with no qualifications and significant expertise in the area cannot be expected to carry out the often complex assessment which is required for proper regulation and management of environmental matters. Gone are the days when Section 12 notices and blanket farm inspection was the apex of complexity in water quality regulation. We cannot remain where we have been for the past 35 years since the 1977 WPA was enacted. We need to involve considerably more experts, such as hydrogeologists, ecologists, riverine and fisheries specialists, etc in the assessment of all discharges to waters and in particular for groundwater assessments. Not only that, they all need to take a more holistic view of what they are dealing with and more closely integrate their views and expertise together in assessing licence applications.

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

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SESSION V

GRAVEYARDS AND GROUNDWATER

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Arup

ABSTRACT

Cemeteries are long known to be a source of groundwater pollution where poorly or inappropriately managed and where located in unsuitable hydrogeological environments. Responsible site selection based on an understanding of the groundwater environment can minimise the impact of these cemeteries on the water environment. This requires the collection of site specific ground conditions and monitoring data, the development of a site conceptual model based on the accepted principles of Source-Pathway-Receptor and undertaking pollutant loading calculations based on the proposed operation of the site. The level of assessment undertaken should be a direct reflection of the risk the cemetery poses to groundwater based receptors. Where the natural characteristics of a site are not sufficient to protect the groundwater environment, in some situations an engineered solution can be developed to protect groundwater resources.

INTRODUCTION

The current annual mortality rate in Ireland means we are burying and / or cremating up to 80 bodies per day and this number is set to rise in the future[1] (Central Statistics Office, 2011). The land take requirements for accommodating traditional burials for these numbers will increase in the future. However many sites in Ireland will not have the natural characteristics to allow them to be used as cemeteries whilst protecting groundwater resources.

Burial grounds can be considered as having a special type of discharge to groundwater and they are frequently compared to unregulated "landfills" due to the degradation products released. Body decomposition can release a variety of chemicals into the groundwater and soil environment including nitrogen based compounds, heavy metals, acid and formaldehyde amongst others.

There are no guidelines available in Ireland for the assessment of burials on the water environment. Internationally there are several documents which provide guidance and the most commonly referenced are those produced by the UK Environment Agency (EA)[2,3]. While this document is useful in highlighting the specific risks to groundwater associated with cemeteries, many of the generic guidelines provided (and repeated in other guidelines) aren't necessarily suitable in an Irish context.

The Environmental Protection Agency (EPA) in Ireland recently published their *Guidance on the Authorisation of Discharges to Groundwater*[4] to satisfy the requirements of the European Communities Environmental Objectives (Groundwater) Regulations, 2010 (S.I. No. 9 of 2010) (Groundwater Regulations). This document specifically deals with point source pollution from a variety of sources. The main principles behind this document are to use a common approach when assessing discharges to ground, and it provides a useful background tool when undertaking an assessment of the risk to groundwater from cemeteries.

Hydrogeologists are best placed to undertake cemetery site assessments as it is vital that both the practical and social considerations are established. As outlined previously, a cemetery may pose a risk to groundwater however, an important social consideration is the prevention of burial in standing water.

POLLUTION POTENTIAL FROM CEMETERIES

The degradation processes which are active at burials are an important factor in determining the pollutants which may arise from a cemetery[5,6,7,8]. International case studies of groundwater monitoring at cemeteries conclude that cemeteries may cause pollution in the immediate vicinity of the soil in the burial grounds[7] but that the impact on groundwater in the wider area is heavily dependent on the site specific conditions such as the hydrogeological regime, climatic factors and the cemetery operation[5].

Bodies typically decompose fully (to clean bone) within 10 years with approximately half of the pollutant load released within the first year[3]. The degradation rate of contaminants and the pollution potential for groundwater depends highly on the soil type and moisture conditions which the burial takes place in.

The degradation of bodies and the influence of the burial environment has been the focus of much study[5,7,8]. Unless a body is embalmed decomposition begins almost immediately after death. Embalming in Ireland is generally carried out for cosmetic reasons and will only delay decomposition for a short period of time. Once decomposition begins soft tissue is subject to autolysis and putrefaction. These phases are characterised by the alteration of proteins, carbohydrate and fat constituents. Micro-organisms, fungi and enzymes which are already present in the body play a role in this breakdown[7,8].

An oxygenated environment will quicken the decomposition process. However, there is limited oxygen available in a burial environment indicating that decay is mostly anaerobic[5]. The actions of anaerobic micro-organisms from the gastrointestinal tract and respiratory systems[7,8] thrive in this environment. The burial area will also be characterised by a low pH due to the release of acid from breakdown products during the decomposition process[5]. This anaerobic, low pH environment is likely to be limited to the immediate area of the burial and its surrounds (the term 'grave soil' is commonly used to refer to this area).

The presence of aerobic or anaerobic conditions influence the contaminants which will migrate from the burial. Any leachate generated that moves away from the grave soil area is likely to be subject to aerobic conditions. However, if a water-logged clay is present then the anaerobic conditions are likely to be maintained. Aerobic conditions will dominate in an aquifer where flow rates are high.

While cemeteries are frequently compared to landfills there are two important differences between them. The water content of a human body is approximately 65-70% compared to 34% in domestic waste indicating that aerobic and anaerobic decay will be faster in a burial due to the available moisture. The Carbon:Nitrogen:Potassium (C:N:P) ratio in human bodies provides a good balance between the principal microbial nutrients whereas the ratio in domestic waste show a deficiency in phosphorus leading to slower degradation of the waste.

Green burials where a shroud or a wicker basket are used instead of a coffin are becoming more common in Ireland. In these cases, the rate of decomposition will be faster than those where coffins are used.

CONTAMINANTS OF CONCERN

Ammonical nitrogen (which is the sum of all the ammonia nitrogen (NH_3) and ammonium nitrogen (NH_4^+) present) is identified as the parameter most likely to exceed water quality standards[5,3]. There have also been occasional observations of elevated chloride, sulphate and potassium[5,3]. Chloride, sulphate and potassium do not degrade to other toxic or mobile forms and as such the risk they pose can be dealt with in a simpler manner than nitrogen based compounds. Metals may also be present in the ground from pacemakers, hip replacements etc, but the impact of these has not been quantified.

There are also many studies on the potential for contamination by microbes or pathogens from cemeteries. They concluded that based on the case studies examined the lack of evidence of widespread pathogens in groundwater around cemeteries is due to the relative immobility and attenuation of the organisms in the ground[5,3].

Formaldehyde is used in many burials in the process of embalming. It can be an animal carcinogen in very high concentrations and loading calculations have been undertaken for it too. However, studies indicate that its presence is not usually detected outside cemeteries[9]. This is likely to be because 50% of formaldehyde is broken down by the putrefaction process and the remaining formaldehyde is leached within the first year.

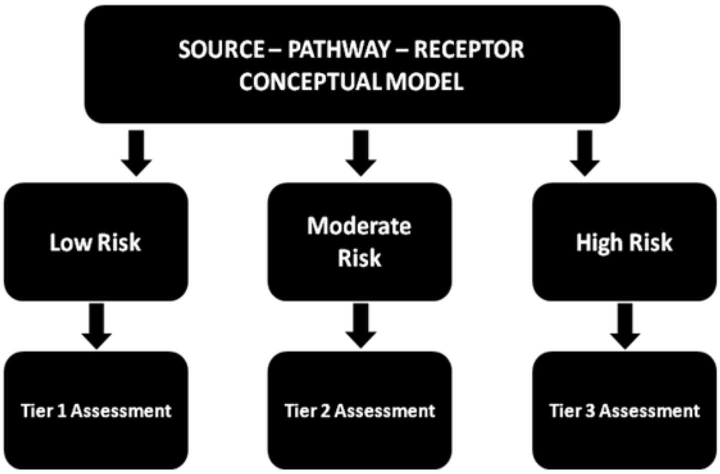
POLLUTION POTENTIAL ASSESSMENT

In Ireland there are no guidelines available regarding the assessment of pollution potential from a cemetery, however several other methods exist which may be considered and used depending on the site conditions and the level of assessment required. It is recommended that a hydrogeologist, familiar with Irish hydrogeological conditions and the various potential assessment types undertake this work.

The Geological Survey of Ireland (GSI) guidance document[10] 'Groundwater Protection Responses for Landfills' may be used in some cases. The response matrix uses the groundwater vulnerability and the aquifer classification to provide specific response criteria. However, this may be over-conservative for a cemetery development.

The UK EA guidance[2] provides a risk assessment approach for dealing with cemeteries and while this is a useful tool for determining the level of data that should be gathered at any stage in the process, some elements are highly dependent on the number of annual interments. In that document all cemeteries with over 100 annual interments are classified as a High Risk development requiring a Tier 3 assessment including numerical modelling regardless of the presence of pathways or receptors. Nevertheless this consideration of the number of annual interments shouldn't be discarded as these developments will have the highest level pollutant loading and will require site investigation to understand the pathways.

When considering the location for a proposed cemetery, the level of assessment required should be dependent upon the risk that cemetery poses to groundwater. The development of a conceptual model based on the **SOURCE – PATHWAY – RECEPTOR** model is the most appropriate and can be used to determine the level of work which may be required to fully assess the risk to groundwater. This receptor based modelling is also recommended in the EPA discharge guidance[4].



For clarity, the information which may be considered has been outlined under the SOURCE-PATHWAY-RECEPTOR headings below. The actual level of assessment undertaken will vary depending on the potential risk to receptors. The S-P-R exercise should establish the level of risk to receptors and the UK EA guidance[2] can be used to determine the level of data it may be appropriate to gather under each assessment type.

The SOURCE-PATHWAY-RECEPTOR model may be a cyclical exercise, to be revised as more information becomes available on the site specific conditions.

SOURCE
The SOURCE of contamination is the cemetery itself and this is affected by the operation of the cemetery. Pollutant loading calculations can be used to establish the volume of leachate which may be generated.

Cemetery Operation
The operation of the cemetery can have a large influence on the pollution generated by a cemetery. While a worst case scenario should be included in an initial assessment, it should be considered that the impact on the environment can be reduced significantly through good cemetery management and maintenance. An example of this would be opening up burial plots distributed around the cemetery rather than consistently opening plots adjacent to each other which serves to increase the dilution potential and reduce the volume of leachate produced.

It is important that the results of the hydrogeological assessment for the cemetery is fed into the cemetery design and operation and may advise on:

- Maximum depth of burial,
- Maximum number of interments per plot,
- Areas of the site unsuitable for traditional interment, and
- Maximum number of interments per year.

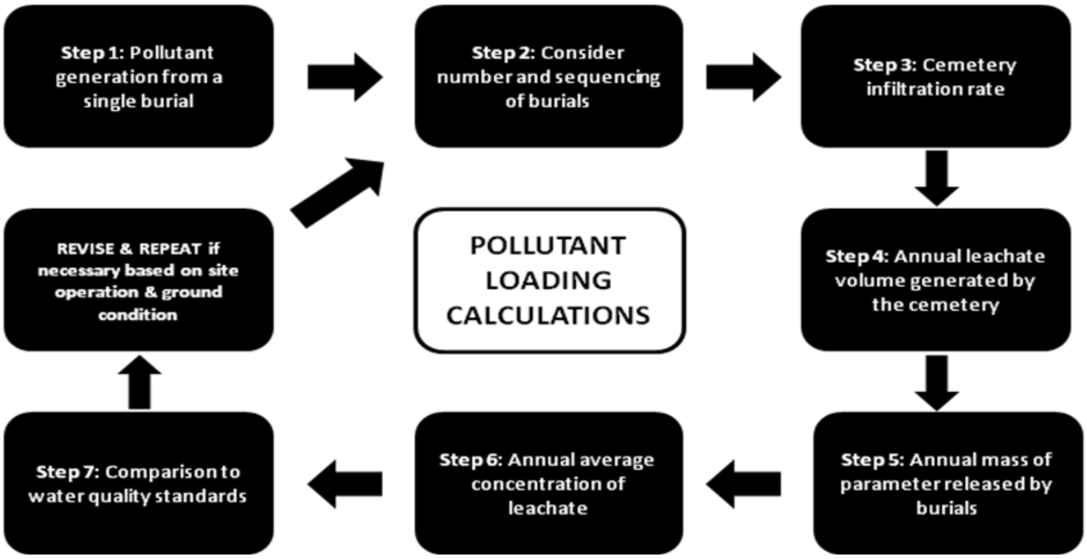
This indicates that the hydrogeological assessment may be an iterative process assessing variations of the items outlined above until a design has been chosen which minimises the risk to groundwater.

Pollutant loading calculations
To determine the volume of pollutants which a cemetery may generate, it is advisable to undertake pollutant loading calculations. Sample pollutant loading calculations were included in the UK EA Science report, P2233 although these are overly simplified and over-conservative in many cases.

Due to the inherent difficulties in predicting exact concentrations which may potentially be generated from a cemetery due to variations in weights, gender and age of those interred, it is necessary to incorporate an element of conservatism in the calculations. This may include:

- Presumption that the degradation of all parts of the body would take place immediately (i.e. that all elements would be released instantaneously allowing maximum leachate generation to be calculated),
- allowing 75% of all available N to convert to NH_4^+. This is overly conservative as more N will be lost as nitrogen gas (N_2) and incorporated in organic modules and oxides and other gases,
- half life of one year for the degradation of NH_4^+ which is conservative,
- establish the maximum number of burials which will occur during the operation of the cemetery and 'front-load' the burial so that all graves are opened at the start of operations. This 'front loading' of burials enables the worst scenario for generating contamination to be assessed.

Pollutant loading calculations should reflect the proposed operation of the cemetery by including details of the number of burials in each plot, the annual interments and site specific infiltration rates. It is important that the calculations also include the remaining contaminants from previous years degradation.



It is advisable that pollutant loading calculations should be undertaken for ammonium, chloride, sulphate potassium and formaldehyde at a minimum. As outlined above, ammonium is the most likely pollutant to be generated during degradation, although chloride, sulphate and potassium have also been detected in the vicinity of graveyards. While formaldehyde degrades quickly, it is toxic in nature and should be included in any assessment.

The volume of leachate generated during these calculations can be screened against the relevant Water Quality Standard. It should be noted that the volume of leachate generated is present in the burial area and does not reflect any attenuation in the unsaturated zone.

PATHWAY

Vertical pathways

The unsaturated zone and the saturated overburden beneath the base of the deepest coffin may be considered to be the vertical pathways beneath a cemetery. However, a site specific conceptual model should be developed to confirm this. According to the World Health Organisation[11] an unsaturated soil layer has been found in past studies to be important in reducing the transport of degradation products into aquifers. It acts as both a filter and an adsorbent. It can also reduce the concentrations of some microorganisms and decomposition compounds that occur during putrefaction. The soil type that maximizes retention of degradation products is a clay-sand mix of relatively low porosity[11].

This type of overburden/soil material is relatively common in Ireland due to the glaciation periods which the island has been subject to. However, our geological history has also led to the heterogeneous nature of the overburden, large changes in rock head over short distances and the formation of perched water tables. These all have a bearing on the vertical pathways for contamination from a cemetery in Ireland and should be considered during a site assessment.

The soil type which a burial will take place in is of fundamental importance when considering a site for use as a cemetery. A clay material with a low permeability is likely to retain contamination within the grave and may not allow contamination to eventually disperse. In a worst case scenario, graves in this material may act as a 'bath' for contamination which may eventually overtop during prolonged rainfall. Conversely, burial into a sand or gravel based material may not offer the required protection for groundwater and may allow contaminants to enter the aquifer. An ideal material is one which will retain the contamination for a long enough time to allow it to attenuate, however will eventually drain away. Soakaway testing is a good method for testing this on a proposed site.

The use of geophysics across a cemetery to establish the depth to bedrock is a valuable tool for a site assessment. While boreholes and trial pits do have their place, it should be considered that these intrusive methods will allow a pathway for future contamination and as such their use inside the proposed active burial areas should be minimised.

Establishing the seasonal changes in the groundwater level beneath a site, particularly any perched groundwater which may be present is of the utmost importance when assessing the vertical pathways. In Ireland groundwater levels, particularly in karst areas may change by meters between seasons. Groundwater monitoring is crucial to identify whether this may occur on a site. Similarly, local knowledge of whether areas are prone to groundwater flooding can also assist the assessment.

Burial into standing water changes the degradation environment and does not allow contamination to attenuate. In some graveyards in Ireland, it is common to excavate the grave and to have to pump prior to burial, as shown in Plate 1. In some cases, it is not possible to fully dewater the grave, and the burial will take place in standing water as shown on Plate 2. Both of these practices should be unacceptable, both socially and for the protection of groundwater.

Plate 1. Dewatering a grave


Plate 2. Burial into standing water

Horizontal pathways
Contamination may migrate along horizontal pathways towards a receptor. Horizontal pathways may include permeable overburden and weathered bedrock and flow in the aquifer. As with the vertical pathways, a site conceptual model should identify their presence. The potential for dilution along these horizontal pathways should be considered when assessing the risk of migration of pollution to receptors.

RECEPTOR
Receptors such as wells, surface water features and groundwater dependent eco-systems should be identified at an early stage in the project. This may be undertaken through desk based assessment,

well surveys and site walkovers to identify any water features such as unmapped springs which may be at risk.

The risk to receptors is an important element in determining the level of assessment that should be undertaken. Generic guidance such as separation distances are also quoted in some international guidance documents but should be treated with caution and should only be applied when no other information is available. A detailed assessment based on site specific information on the ground conditions should supercede these generic separation distances.

If a groundwater receptor which may be adversely impacted by the development of a cemetery is identified it may be appropriate to undertake calculations to determine the potential concentration at that receptor or numerical risk assessment modelling (using programme such as ConSim or R&DP20) to assess if an impact will be observed at the receptor.

ENGINEERED SOLUTIONS

In some situations the site location may be constrained due to regional hydrogeological properties or for social reasons. Similarly, a site may be suitable in many ways but an extra level of protection may be required to give confidence that there will be no impact at local receptors. International best practice accepts that maintaining a minimum 1 m thick unsaturated zone beneath the base of the deepest burial is critically important in the protection of groundwater. However, in an Irish context, particularly with the tendency towards deeper burials (up to 3.5 m below ground level (m bgl)) due to less availability of plots, an unsaturated zone of 4.5 mbgl can be hard to maintain all year round.

In these cases it may be appropriate to consider incorporating engineered solutions into the cemetery design. These will be dependent upon the local groundwater regime and may include earth-works, surface water or groundwater drainage methods such as interception trenches, although a trial may be required to demonstrate the solution will work. It is important to note that any design which intends to intercept groundwater, should intercept that water <u>before</u> it has come into contact with the burial area and allowed the water to become polluted.

While all sites will require different detailed design depending on the site specific conditions, in principle, an engineered design solution should:

- Blend into the natural environment of the site and the surrounding area,
- Protect local well water supplies from contamination, and
- Satisfy the Local Authority as to its suitability and robustness, future proofing of the solution.

SUMMARY

Cemeteries are known to be a source of groundwater pollution where located in unsuitable hydrogeological environments. An assessment based on an understanding of the groundwater environment can minimise the impact of these cemeteries on the water environment. This should assess the relevant SOURCE-PATHWAY-RECEPTORs. Based on the identified risks to receptors, the level of work required should be established. Elements of work which may be considered include:

- A **detailed desk study** and **well survey** for the site and surrounding area,
- A hydrogeological **ground investigation** to characterise the site,
- Groundwater **monitoring** (levels and quality),
- **Pollutant loading calculations**, and
- numerical **risk assessment modelling**.

In some situations where a site has unsuitable ground conditions, it may be possible to incorporate engineered drainage features to mitigate the impact to the groundwater environment.

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PROJECTED AGRICULTURAL CHANGES, IMPLICATIONS FOR GROUNDWATER QUALITY AND NEW MITIGATION MEASURES

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ABSTRACT

Agricultural practices in Ireland are expected to change in the coming decade with key drivers being the removal of EU milk quotas and the continuing rise in world demand for agricultural products. These changes are likely to result in increased fertiliser use and changes in regional agricultural pressures. Projections indicate that cattle organic nitrogen loadings will only increase by 2%. Agricultural practices have been subject of increased legislative controls and these have played a role in the improvement of water quality nationally. This paper reviews the likely changes to agricultural practices and their potential impact on groundwater quality in Ireland. Agricultural intensity is not always directly linked to water quality impact due to natural attenuation during transport. A range of mitigation measures are being evaluated nationally which relate to farm nutrient management and intercepting losses between fields and receptors. Where it is deemed that new or modified mitigation measures are required these should be targeted spatially in areas where natural attenuation is insufficient to reduce nutrient concentrations and loads to sensitive receptors.

INTRODUCTION

One of the dominant pressures on water quality in Ireland is eutrophication resulting from excess nutrient levels (Stark and Richards, 2008a). Nitrogen (N) and phosphorus (P) are lost to water, either indirectly through diffuse pollution or through direct discharges to either surface or groundwaters (Richards et al., 2009). Agriculture has been implicated as one of the sectors that contributes significantly to nutrient enrichment of waters and much of this is due to indirect diffuse losses through overland and/or subsurface hydrological pathways (McGarrigle et al., 2010).

Water quality in Ireland has been a national and international priority since the 1970’s and a wide range of legislation has been implemented to improve water quality (Stark and Richards, 2008b). These legislative instruments have led to a decrease in gross pollution from agriculture arising from direct agricultural discharges contributing to fish kills. This legislation culminated in the national implementation of the Nitrates Directive (91/676/EEC) through S.I 610/2010, the good agricultural practice for the protection of waters regulations “GAP regulations” (Anon, 2010). The GAP regulations set mandatory limits on stocking rates, fertiliser use and timing, manure use and timing and introduced a requirement for record keeping. These regulations also set the principles of good agricultural practice and place an emphasis on improving nutrient and specifically N and P use efficiency.

The implementation of the Nitrates Directive and the efficacy of the GAP regulations are currently being evaluated by the Teagasc Agricultural Catchments Programme, which has established catchments representative of differing agricultural and catchment characteristics (Fealy et al., 2010). Additional research is being conducted by Teagasc to evaluate new environmental technologies through better nutrient use efficiency, clover, dietary manipulation and technologies for targeting high nutrient loadings along distinct hydrological pathways. The objective of this paper was to review the potential changes in agricultural practice and the likely implications for groundwater quality in Ireland through highlighting recent agri-environmental research findings.

THE CHANGING IRISH AGRICULTURAL INDUSTRY

The agri-food sector is an important industry in Ireland accounting for about 6% or an €9.4 billion per annum contribution in terms of Gross Value Added (GVA)(DAFM, 2011), 2011. Irish utilisable agricultural area is dominated (>90%) by grassland, which is predominantly permanent grassland (Richards et al., 2009). Grassland products account for over 90% of the diet of ruminant livestock, and beef, milk and sheep production account for 74% of gross agricultural output (GAO). Agricultural area (AA) under cereals (barley, wheat and oats) has varied around the 300,000 ha per annum level since the 1990's, and cereals currently account for 3.0% of GAO. Agricultural area under other crops (for example, potatoes), fruit and horticulture is approximately 120,000 ha, 5.7% of GAO. Pig and poultry production accounts for 6.0% and 2.7% of GAO, respectively.

National fertiliser use has been declining since the mid 1990's (Figure 1). The decline in fertiliser use is a result of legislation, the substantial increase in fertiliser costs, changes to fertiliser recommendations and a greater nutrient management awareness of farmers. Inorganic fertiliser use on farms has been steadily falling with N, P and K use on grassland farms down by 30, 69 and 64%, respectively.

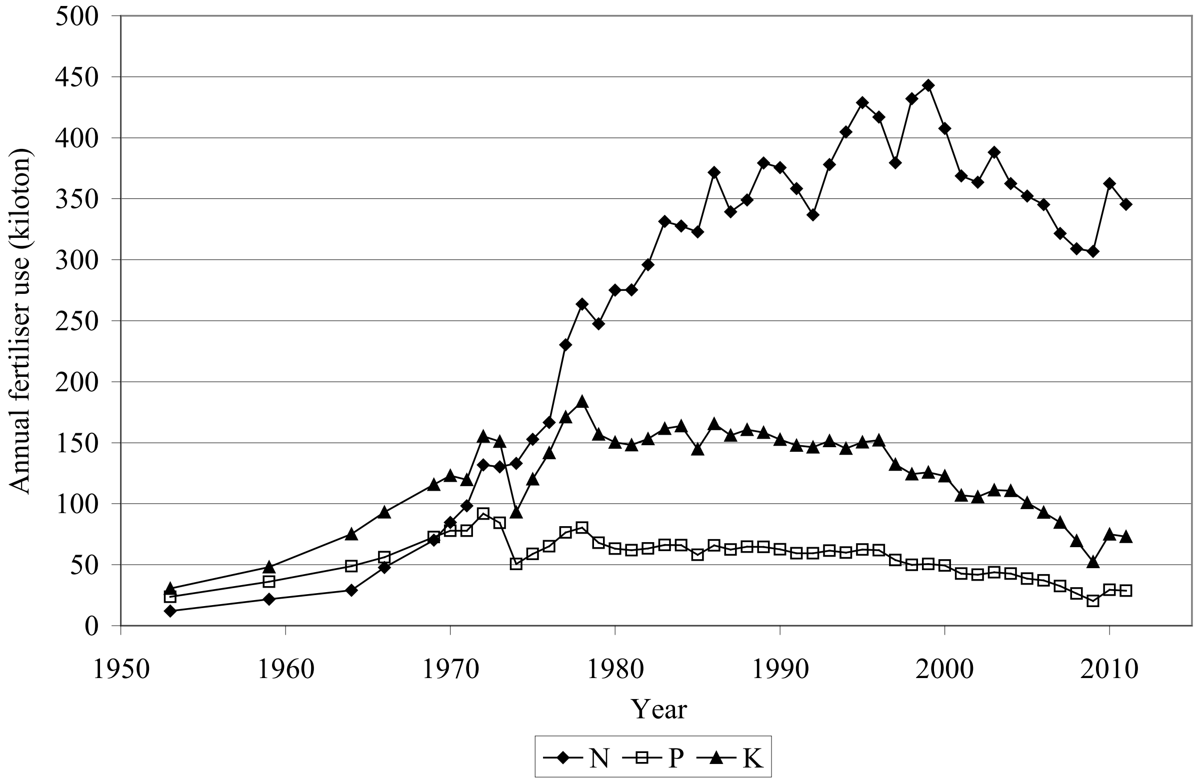

Figure 1 Total annual nitrogen, phosphorous and potassium fertiliser use (kilotons) in Ireland 1953-2011 (compiled from DAFM nutrient usage reports).

Current average level of fertiliser use per hectare (2008) is summarised for dairy and cereal cropping systems in Table 1. Average N fertiliser use on grassland farms has gradually decreased from a high of 145 kg N ha^{-1} in 1999 to c. 86 kg N ha^{-1} in 2008. Currently, cereal crops have the highest use of N, P and K fertiliser use due to the higher N removal in crop products, resulting in lower nutrient surpluses that on livestock farms.

Table 1 Mean N, P and K fertiliser use in 2008 by farming system and landuse (Lalor et al., 2010).

Agricultural system	N	P kg ha^{-1} yr^{-1}	K
all grassland	86	5	14
- grazing	65	3	9
- silage	101	7	24
Dairy	134	6	19
Cattle	43	4	10
Sheep	40	3	7
all cereal crops	138	20	48
all root crops	106	46	138
forage maize	152	41	96

PROJECTED AGRICULTURAL CHANGES TO 2020

Agricultural systems in Ireland are in the process of changing. Milk production has been limited, under the EU milk quota system, which was introduced in 1983 to reduce milk surpluses within the EU. The milk quota system was extended under the 2003 CAP Reform Agreement to 2015. In 2009, a "soft landing" policy was introduced to prepare the dairy industry for the abolition of milk quotas in 2015. Milk quotas were increased by 1% per year from 2009 to 2013. The dairy industry in Ireland is eagerly awaiting the abolition of milk quotas, enabling the industry to expand for the first time since the mid 1980s.

In 2010, the agri-food industry in Ireland published it's vision for 2020 called Food Harvest 2020 (FH2020) (DAFF, 2010). This report has set challenging targets to increase dairy output volume by 50%, and beef, sheep and pig output value by 20%, 20% and 50%, respectively, in a sustainable manner. It is predicted that this policy will increase national nitrogen use by up to 17% compared to 2008, increasing N fertiliser rates from 86 to ~100 kg N ha^{-1} (Donnellan et al., 2012).

Donnellan et al. (2012) have projected that under the achievement of the FH2020 targets, the changes in cattle numbers will result nationally in a 2% increase in organic N, resulting in organic N loadings 15% lower in 2020 than the peak in 1999. Between 1999 and 2011, the national organic N loading for cattle has decreased by 17% due to a fall in national animal numbers (Figure 2).

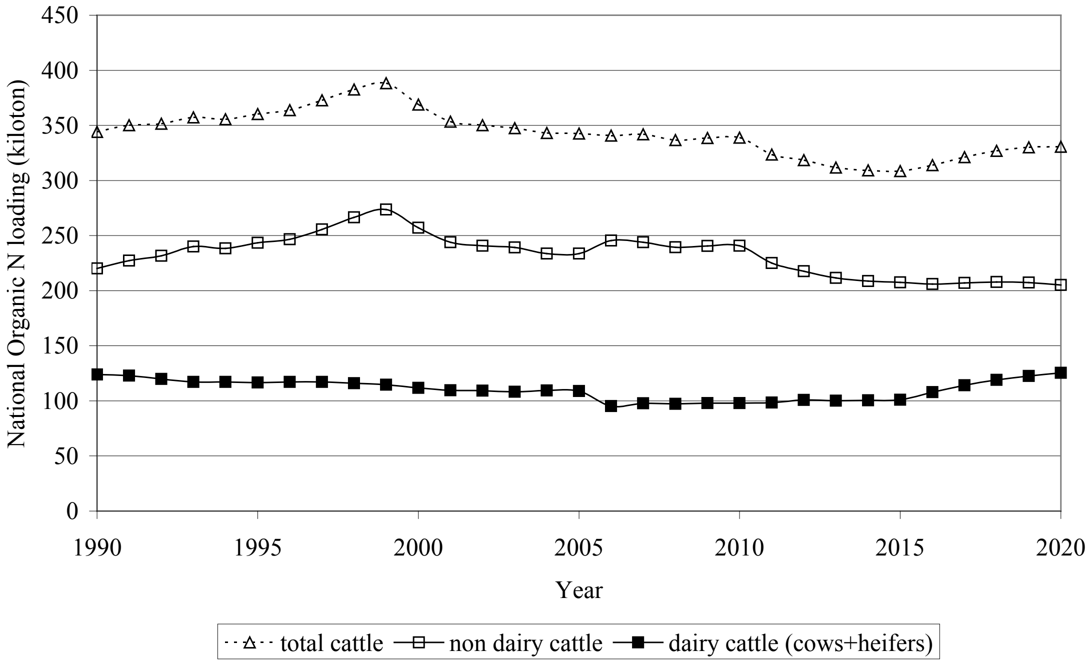

Figure 2 National organic nitrogen loadings for dairy cattle, non dairy cattle and total cattle from 1990 to 2011 and predicted changes from 2012 to 2020 in response to Harvest 2020.

Nutrient deposition (inorganic fertilisers and organic N from animal manure/dung/urine) is not uniform across Ireland. Intensive agriculture is generally concentrated in the east and south of Ireland (Schulte et al., 2006). Given that the profitability of dairying is higher in the south and the east of Ireland it is considered that these are the regions where expansion of the dairy sector is likely to be strongest. The implication is that achievement of FH2020 would require an increase in milk production is excess of 50% in some regions. The further increase in concentration in the south and east will place increased pressure on groundwater quality due to the combination of reduced recharge and better drained soils. In addition, climate change is expected to further reduce recharge and increase droughts in the south and east, further increasing pressure on groundwater quantity and quality.

MITIGATION MEASURES FOR CONTROL OF DIFFUSE POLLUTION

Mitigation measures to reduce loads of nutrients to a waterbody have been reviewed previously by Stark and Richards (2008b) and more specifically for Ireland by Fenton et al. (2008). The Nitrates Directive uses generic measures, tailored for farming system type and intensity and applied across all agricultural lands irrespective or risk of pollution. The risk of water pollution from farming activities is not uniform for all agricultural lands and thus the uniform application of mitigation measures is over protective in some regions and not stringent enough for others, depending on inherent risk. Thus mitigation measures should be targeted in areas where the risk of nutrient loss to water is greatest (Richards et al., 2009), which provides the maximum benefit. Critical source areas (CSA) represent the combination of high nutrient source and hydrological transport vectors. Sharpley et al. (2008) observed that P export in overland flow to rivers was spatially variable within catchments, related to hydrologically active areas associated with a small number of storm events and at distinct locations. Catchment hydrology has been shown to be highly correlated with nutrient occurrence, but the relationship between nutrients and a measure of catchment flashiness (Q5/Q95 ratio) differ for each nutrient. Changes in nutrient response to catchment hydrology, strongly indicates the need to tailor and target mitigation measures.

In some agricultural areas the current suite of mitigation measures may be either too effective or not sufficiently effective. The efficacy of mitigation measures requires sufficient time for evaluation as there can be substantial time lags between mitigation measure implementation and environmental response (Fenton et al., 2011a; Schulte et al., 2010). Fenton et al. (2011a) showed that groundwater nitrate response to mitigation measures can be delayed due to time lags with respect to measure implementation, unsaturated zone recharge delays, aquifer mixing and aquifer flushing. Changes in recharge amounts had a linear effect on both unsaturated zone and aquifer response times. Schulte et al. (2010) showed that P loss to water from soil could be delayed due to variability in soil P declines which were related to the initial soil P level and buffering due to background total soil P. Thus environmental response to mitigation measure implementation is complicated by catchment specific soil, hydrology and meteorological factors.

Natural attenuation within catchments contributes to the transport and delivery of nutrients to receptors such as surface waters. Natural attenuation capacity varies among transport vectors and is controlled by catchment characteristics. Denitrification is the process where nitrate is reduced to nitrous oxide (N_2O) which is a powerful greenhouse gas and the environmentally benign di-nitrogen (N_2). Nitrate attenuation through denitrification can lead to pollutant swapping through emission of the greenhouse gas N_2O. Groundwater can be an important source of N_2O emissions, in Ireland nitrate leaching results in an estimated 2.6Gg N_2O/yr (EPA, 2011). Groundwater nitrate attenuation by denitrification can reduce both concentrations and loads delivered to surface waters. Denitrification has been found to be closely related to shallow groundwater nitrate occurrence, which is turn has been correlated with many soil physical parameters e.g. saturated hydraulic conductivity (Fenton et al. 2009). Nationally, denitrification has been shown to be the dominant controlling process on groundwater nitrate occurrence. Jahangir et al. (2012) has shown that groundwater NO_3-N occurrence various significantly between sites due to attenuation by denitrification, resulting in average concentrations varying from 0.7 to 14.6 mg N L^{-1} on farms with similar nitrogen budgets. Thus mitigation measures need to be tailored to account for natural attenuation during nutrient transport.

Should further mitigation measures be required to improve water quality status, then these must be targeted to CSA and integrate the range of diffuse agricultural pollutants. Identification of CSA must combine hydrology and soil chemistry to predict the spatial and temporal requirements for targeting mitigation measures.

FARM MANAGEMENT MITIGATION

Currently, agricultural practices are subject to the mitigation measures contained in the GAP regulations. These mitigation measures are applied uniformly across the country, with the exception of manure storage and spreading timings. The efficacy of the GAP regulations is being evaluated under the national Catchments programme. Other research is currently being conducted within Teagasc and their collaborating institutions. This research is investigating mechanisms and mitigation measures to improved nutrient recovery within Irish agricultural systems.

The GAP regulations include the target of increasing N use efficiency of N from slurry from 30 to 40% in our grassland systems. Recent research (Hoekstra et al., 2011) using ^{15}N labelling has found that using best practice the maximum recovery of N in grass biomass is 30% and the largest loss is as ammonia gas (NH_3). Leaching rates from manure have been reported to be high on free draining soils in Ireland (Ryan et al., 1996). More recent research (Kramers et al., 2012) found that when manure is applied at recommended rates in spring and summer the rates of nutrient leaching were very low, <1 kg N ha^{-1} and <0.1 kg P ha^{-1}.

Nitrogen loss from soil is associated with nitrate as this anion is easily lost from the soil. Nitrate is formed through nitrification and thus if the rate of nitrification can be reduced, then mineral nitrogen will be kept in the ammoniacal (NH_4^+) form. Nitrification inhibitors have been found to significantly reduce rates of nitrate leaching (by up to 42%) and N_2O emissions (by up to 70%) from Irish soils (Dennis et al., 2012; Richards, 2011). Currently nitrification inhibitors are one of the only accepted mitigation measures, by the Intergovernmental Panel on Climate Change, for reducing N_2O emissions. Inhibitors are cost prohibitive at the moment and are unlikely to be commonly used unless the economics of their use changes through lower costs, improved yields and compensation for reducing carbon emissions.

Clover, a nitrogen fixing legume, has begun to be more commonly used in Irish grasslands to provide cheaper biologically fixed nitrogen. In Ireland this has been found to reduce N_2O emissions (Li et al., 2011). Clover lowers the need to purchase chemical nitrogen fertiliser as it can fix between 100 and 200 kg N ha^{-1} yr^{-1} and there is evidence that clover improves nitrogen use efficiency through a slower release of nitrogen through the growing season. The use of clover and inhibitors, even when economic, are useful tools for some farmers to increase nutrient efficiency and reduce emissions.

Within arable systems, our research has identified that after spring barley harvest an over winter cover crop should be established to reduce nitrate leaching to groundwater (Hooker et al., 2008). The GAP regulations have included the requirement for natural regeneration (a form of over winter cover) to be left in place until December each year. Further research has found that mustard cover crop and natural regeneration under reduced cultivation can both reduce nitrate leaching (Premrov et al. 2011). Under our site conditions, natural regeneration needed to be encouraged through shallow tiling in autumn to stimulate seed germination. This may be due to a low soil seed bank in the site investigated.

INTERCEPTOR MITIGATION TECHNOLOGIES

Engineered mitigation measures aim to form an "interceptor" phase for a specific nutrient(s) within the source, pathway and receptor concept (Figure 2D). Therefore it is important to understand where nutrient losses occur, the migration pathways such nutrients follow along any export continuum and that mitigation may also cause pollution swapping (e.g. partial denitrification instead of full denitrification causing N_2O release) during mitigation.

Incidental losses of N and P may be lost in overland flow from agricultural systems where fertilizer application is followed by a rainfall event. In the same way chronic losses of P from high P Index soils (> 8 mg Morgan's P L^{-1} for grassland soils) may occur. Point sources of pollution may also arise from farmyards or irrigation of dirty water at excessive loads. A schematic for various mitigation options presently being researched to minimise losses from drainage systems, ditches, shallow groundwater or end of fields is presented in Figure 2.

Leaching of nutrients through the unsaturated zone is another loss pathway from any agricultural system. Artificial drainage systems (temporary or permanent) intercept leaching water thereby removing the buffering capacity of a soil or subsoil and changing the surface and subsurface hydrology (Skaggs et al., 1994). Discharges from such systems can contain nutrients in excess of water quality standards. Recent work by Ibrahim et al. (2012) on overland and drainage plots showed that smaller plot size and shallower watertable positions led to greater overland flow, total loads of P and N (g ha^{-1}) in overland flow were higher in smaller plots with a shallow watertable, inorganic P was higher in overland flow with a deep watertable, higher nitrate in drains with higher NH_4^+ in overland flow and there is a need for site specific design of drainage systems to achieve sustainability. Therefore the position of the watertable throughout the year is important for the nutrient speciation during such rainfall events with more bio-available forms of P and N being lost.

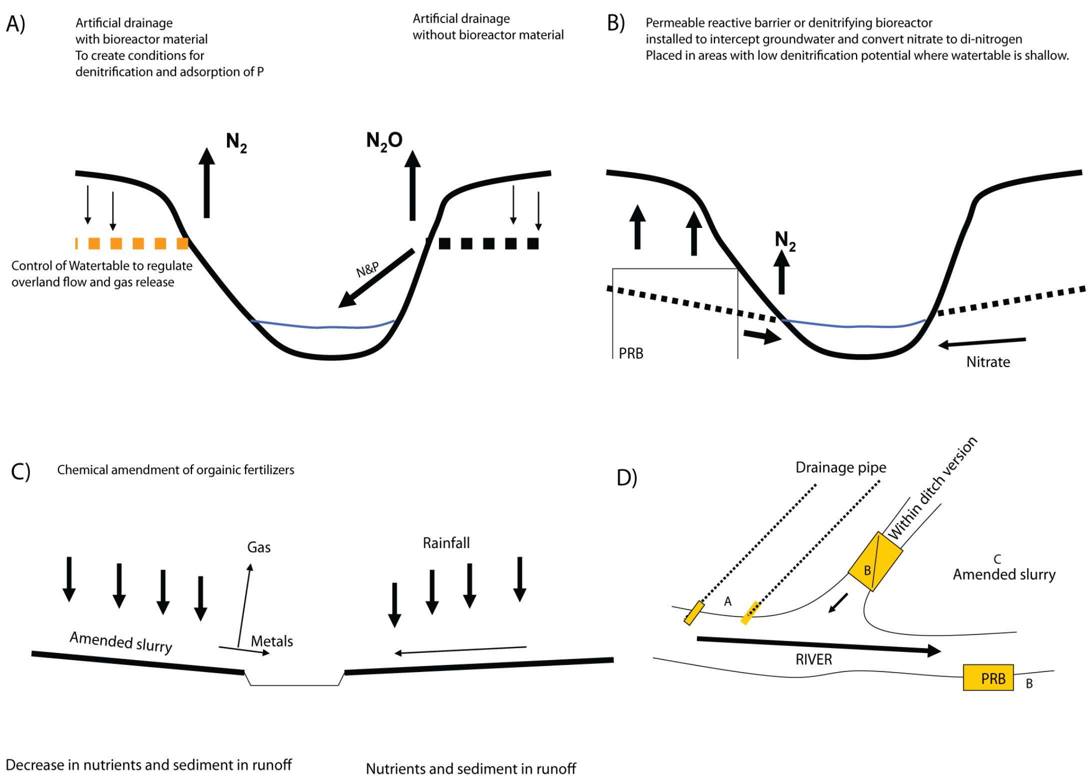

Figure 2. Schematic of mitigation measures A) end of pipe solutions to minimise artificial drainage losses B) permeable reactive barrier or denitrifying bioreactor to remediate nitrate losses in shallow groundwater C) chemical amendment of slurry to prevent nutrient losses in runoff and D) general position of technologies with a farm system.

In recent years engineered or end of pipe solutions have become popular options to control water discharge from drainage systems effectively controlling the position of the watertable at certain times of the year (Figure 2A). This in turn controls overland flow nutrient losses whilst preventing gaseous losses due to saturation. Whereas the effectiveness of different drainage systems has been studied at length the sustainability of such systems has not. To ensure drainage systems are sustainable remediation of discharges through the use of novel techniques (Figure 2B) must be investigated e.g. denitrifying bioreactors (Healy et al., 2012), which utilise a solid carbon source to convert nitrate into di-nitrogen gas and can be placed to mitigate point sources or end of pipe sources. The pollution swapping potential of a field size woodchip version of this technology is currently being evaluated.

Chemical amendment of organic fertilizers (pig, poultry and dairy wastes) before land application or incorporation of such amendments into soil are both common measures to minimise incidental diffuse losses to water in many countries (Figure 2C). Recently studies by Brennan et al. (2012a, b), Fenton et al. (2011b) and O' Flynn et al. (2012), albeit at laboratory scale, have shown amendments such as aluminium chloride, alum, lime, poly aluminium chloride hydroxide, aluminium water treatment residuals, flyash, flue gas desulphurization by-products all to be effective at trapping dissolved P (71% to 83% removal of dissolved P) particulate P and suspended sediment. However the feasibility of using such amendments with the dairy industry based on cost and pollution swapping criteria is unlikely. Within the pig industry there could be some positive indications on high P Index soils and there is a need for full field scale experimentation.

Biofuel consumption is increasing and in order to meet EU targets, alternatives to first and second generation biofuels are being examined. The use of micro-algal biomass in the production of biofuels is an area of growing research. Inputs to grow such biomass are facilitated by chemical fertilizers, the price of which are connected directly with world oil prices. In a recent review (Fenton and Ó hUallacháin, in press) suggest that a variety of agricultural wastes and nutrient sources such as drainage water could be used to facilitate this growth. This may offer an alternative for the management of some agricultural wastes or channelling of end of pipe losses before discharge.

CONCLUSIONS

Changes in national agricultural practice due to abolition of the milk quota and the achievement of the targets set out in FH2020 may not substantially change nutrient emissions to groundwater. Research has shown that agricultural intensity is not necessarily the controlling factor on nutrient occurrence in groundwater. Soil and catchment hydrology have a much more important role in determining nutrient occurrence through the control of natural attenuation in both soils and water. The efficacy of the current suit of mitigation measures in the GAP regulations need to be evaluated in light of the natural time lag of both water movement and within aquifer nutrient dilution. A number of farm management and interceptor mitigation measures are currently being developed and evaluated to help to further reduce nutrient emissions to water. Mitigation measures need to be spatially targeted to critical source areas where nutrient pressures and transport pathways overlap.

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