INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS
(IRISH GROUP)

Presents

Groundwater: Opportunities and Pressures

PROCEEDINGS

OF THE

IAH (IRISH GROUP)

27th ANNUAL GROUNDWATER CONFERENCE

Tullamore Court Hotel, Co. Offaly

Tuesday 24th and Wednesday 25th April 2007

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The IAH (Irish Group) are grateful to the Dept of Civil & Environmental Engineering, Trinity College Dublin, for providing assistance with the registration aspects of the conference

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International Association of Hydrogeologists (Irish Group)

The International Association of Hydrogeologists (IAH) was founded in 1956 to promote co-operation amongst hydrogeologists, to advance the science of hydrogeology world wide, and to facilitate the international exchange of information on groundwater. The IAH is a worldwide scientific and educational organisation with more than 3,500 members in 135 countries.

The Irish Group of the IAH was started in 1976 and has over 130 members. It hosts a well-attended, annual groundwater conference in the Irish Midlands, and holds technical discussion meetings on the first Tuesday of every month between October and June, in the Geological Survey of Ireland in Dublin. The following members are serving on the 2007 IAH (Irish Group) Committee:

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CONFERENCE OBJECTIVE

This year, the 27th Annual Conference of the IAH (Irish Group) is discussing:

- current approaches to groundwater resource management at both regional and local scales;
- risks to groundwater, in terms of both quantity and quality;
- groundwater as an exploitable energy resource.

Groundwater is often thought of as the hidden resource, yet it supplies around 30% of our water supplies, both public and private. With the growing population and burgeoning development in Ireland, there are increasing requirements to develop water resources, and groundwater in particular. Consequently, there is a need, driven by EU legislation, to manage water in a holistic, inclusive manner, which has been taken to mean in the context of 'river basins'. The water cycle and all associated water sources are to be managed in an integrated way. Therefore, the subject of this year's conference is the sustainable development of groundwater resources in this context.

What is meant by sustainable development of groundwater and how can such resources be effectively developed at the basin scale as well as at the local level? Groundwater may also be regarded as a renewable energy resource: how can this energy be effectively exploited? There are also risks and pressures affecting the development of a groundwater resource and some of these will be discussed. Risks to quality in terms of public health, pressures from intense agricultural practice and industries such as quarrying need to be considered in the context of protecting and managing the groundwater resource.

A number of national and international speakers have been invited to address the questions raised above, and to provide a wide spectrum of experience in groundwater resource development, especially in the light of current pressures on water resources.

WHO SHOULD ATTEND?

It is expected that these topical issues will be of great interest to local authority engineers, consultants, planning officials, environmental scientists, public health officials, architects, and hydrogeologists.

Groundwater: Opportunities and Pressures

PROGRAMME DAY I - TUESDAY, 24th APRIL

10:00 Registration
Tea, Coffee, & Exhibits

11:00 Welcome and Introduction
Paul Johnston – President, Irish Group of the IAH

SESSION I - Resource Evaluation – Regional Basis

11:15 ***From wrong to right – the development of groundwater resource assessment methodologies in England and Wales***

Steve Fletcher, Environment Agency, UK

11:45 ***Recharge estimation at local and regional scales - examples from Minnesota, USA.***

G. Delin, United States Geological Survey, USA

12.15 ***The Water Abstraction and Impoundment (Licensing) Regulations (Northern Ireland) 2006***

Peter Close, Environment and Heritage Services, Northern Ireland

12:35 Panel Discussion

12.50 Buffet Lunch & Exhibits

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SESSION II - Tools of Management – County Scale

14:00 ***Understanding and Exploitation of Groundwater Flow Systems for Local Water Supplies in Ireland***

David Ball, Hydrogeologist, Ireland

14:35 ***Groundwater Resource Assessment for Public Water Supply Schemes in the Midlands of Ireland***

Richard Church, Entec UK Limited, Scotland

14:55 ***East Meath, South Louth And Drogheda Water Improvement Scheme: Investigation Of Groundwater Potential***

Mark Conroy, TOBIN Consulting Engineers, Ireland

15:15 Panel Discussion
15:30 Tea, Coffee & Exhibits

SESSION III – Environmental Risk Evaluation Tools

16:00 ***Cryptosporidium Risk Assessment – Square Pegs and Round Holes***

Karen Lee Ibbotson, White Young Green, Ireland

16:25 ***Microbial Contamination of Aquifers in Ireland: Identification of vulnerability factors and development of detection protocols for key pathogens***

Niamh Bhreathnach & Vincent O Flaherty, NUIG, Ireland

16:50 ***Quantitative Risk Assessment, the importance of understanding your site.***

Rob Glavin, RPS Group

17:15 Panel Discussion. (Close at 17:40)

The panel discussion will be followed by a ***wine reception*** *in the Tullamore Court Hotel sponsored by ALControl Geochem*

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PROGRAMME DAY 2 - WEDNESDAY, 25th APRIL

SESSION IV - Energy Potential of Groundwater

09.15 ***Geothermal Resources in Ireland – applications for hydrogeology***

Roisin Goodman, Geothermal Association of Ireland & CSA, Ireland

09.40 Thermogeological assessment of open loop well doublet schemes – an analytical approach

David Banks, University of Newcastle, UK

10:05 ***Underground Thermal Energy Storage in the Netherlands***

Loeki Vos, Fugro Ingenieursbureau B.V., Netherlands

10:30 Panel Discussion
10.45 Coffee, Tea and Exhibits

SESSION V - Current Pressures

11:15 ***Mineral workings – consideration of the impact on the water environment***

Peter McConvey, Geological Survey of Northern Ireland

11:40 ***Agricultural Pressure – farm and national scale case studies & risk assessment***

Monica Lee & Pamela Bartley, GSI & Hydro-G

12:05 ***A national assessment of groundwater abstraction pressures***

Henning Moe & Donal Daly, CDM & EPA, Ireland

12:30 Panel Discussion

12:45 Closing Address: Pamela Bartley, Conference Secretary

12:50 Buffet Lunch

14:30 ***Sponsored Golf Outing***

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Session I

FROM WRONG TO RIGHT, THE DEVELOPMENT OF GROUNDWATER RESOURCE ASSESSMENT METHODOLOGIES IN ENGLAND AND WALES

Steve Fletcher - Science Group
Environment Agency

ABSTRACT

This paper examines the sometimes tortuous history of groundwater resource assessments from before the 1963 Water Resources Act to the future implementation of the Water Framework Directive. The early attempts at the subject were undertaken with imperfect knowledge of how the groundwater systems functioned. This is due largely to the "newness" of the science of hydrogeology and looking at the advances in understanding between then and now shows the leap in understanding and techniques that has come about. The initial attempts were well meaning but incorrect. The move to a groundwater unit concept with its attended water balance calculations was the first reliable case where regional resources played an important role in licence determinations. The method was tested at numerous public enquiries and resisted attempts to prove it wrong. This lead to it being included in the Water Framework Directive (WFD). However, additional elements added to it in the drafting process, required a new uniform approach to the subject and the Environment Agency response was to develop the Resource Assessment and Management (RAM) Framework. This is currently used within the Catchment Abstraction Management process and this is being modified to be fully compliant with the WFD for the first round of the River Basin Planning cycle. The ideas to be included in the RAM Framework can be improved by using ideas developed as part of a groundwater modelling project. Common misconceptions have in the past lead to erroneous methodologies and unjustified confidence in the assessments produced.

WHY PERFORM GROUNDWATER RESOURCE ASSESSMENTS?

It was probable that regional groundwater resource assessments were only considered important when significant proportions of groundwater recharge were being abstracted from an aquifer. Where this was not the case, occasionally, a new abstraction may have caused an existing borehole source to fail, flows in adjacent streams may have been reduced and even wetlands may have dried up. However, these effects were always described as local effects and attempts to prevent them happening revolved around predicting the magnitude of these local effects. There is of course no such thing as a local effect but the early years of regulatory hydrogeology paid no regard to this.

The term regulatory hydrogeology should be expanded upon. A regulator had a job to do. For a hydrogeologist, this can be put as "protecting existing groundwater users whilst encouraging the further sensible development of groundwater resources". In the early years following the 1963 Water Resource Act, the problem associated with the licensing of a huge backlog of existing but unregulated abstractions was substantial. River Authorities at the time often had only one geologist and there was no formal training available for hydrogeologists. This meant that there was insufficient time to be spent on a single abstraction in order to fully understand how it affected the environment. If the source was a major public water supply borehole, there may have been some elementary consideration of its effect on nearby surface water but in general, this was not the case. Certainly no calculation was done to assess the combined effects of all abstractions in an aquifer.

Early hydrogeology was (and in many cases still is) the hydrogeology of circles. The only textbooks were from the USA and involved abstractions in very larger and productive aquifers. The prediction of effects relied on the application of a steady state method (Theim) with its unfortunate phrase "radius of influence". The method makes it clear that this does not indicate the distance outside which there is no effect. However, the concept of being able to calculate a distance where the drawdown was zero was too attractive to the budding regulatory hydrogeologist and there was an implicit assumption that pumping test analysis methods could be used inversely to predict long term effects of pumping.

With the advent of MSc Hydrogeology courses, the use of non steady state methods was advocated. This was initially Theis, but gradually a whole arsenal of analytic methods was promulgated of increasing complexity. However, for the regulator, trying to predict the effect of pumping on adjacent sources they all had one problem, namely “what time do you substitute back in the equation to give your drawdown prediction”? For totally erroneous reasons, this was usually set at 60 days for a spray irrigation licence or 365 days for a continuous one.

The changes brought about by a new abstraction can be categorised as “changing the shape of the piezometric surface”. This has the effect of reducing the flow to the associated surface waters but the only case of general unconstrained lowering of the piezometric surface occurs where abstraction from an aquifer exceeds recharge together with induced recharge from surface water. Only one instance where this happens is known to the author and that is in an aquifer with no connection to the surface.

This changing of the shape of the piezometric surface and how far it extends is a vital consideration and will be mentioned again later.

EARLY METHODOLOGIES – BEFORE HYDROGEOLOGISTS!

Before the 1963 Water Resources Act, major public water supply boreholes were promoted via Parliamentary Acts. A review of one of these revealed that the methodology used was to calculate the area that would be affected by the abstraction. The proposed annual abstraction rate was divided by the assessed annual recharge to produce the area required to give sufficient recharge to replenish the quantity of water removed from the aquifer. This was then apportioned as a circle around the abstraction borehole and an assumption made that any sources outside this circle would not be affected. This assumption was made by one of the foremost geologists of the day but is totally incorrect.

The thinking was that, by using annual figures, the recharge entering the circle in the aquifer in a recharge season would somehow “fill” the “hole” in the piezometric surface left by the abstraction and thereby prevent the drawdown effects spreading out further. This is totally erroneous but despite the lack of theoretical foundation, this thinking prevailed in some parts, well into the existence of the NRA. Indeed it is similar thinking that resulted in predictions of regional drawdown being made using Theis with a time of pumping set at 365 days.

AQUIFER UNIT ASSESSMENTS

By 1978 it was realised that, existing abstractions were not being protected from the continuous eroding of resources taking place through an accumulation of the effects of a number of small abstractions, so a new era was started. It was decided that the concept of regional groundwater resource assessments would be developed. The aquifers were split up into aquifer units. These were defined to ensure that rivers were internal; that existing major abstractions were not near unit boundaries and that the aquifer units behaved as a system. The recharge into each aquifer unit was assessed using MORECS type data, runoff was estimated using areas of drift and permeability classes, urban runoff was estimated and a water balance calculation performed for each aquifer unit. These were the pre-computer years of planimeters and graph paper and this represented a considerable body of work. Estimates were made of the amount of water that would maintain the rivers in a satisfactory condition. A sustainable water balance was defined as one that left sufficient water remaining in the aquifer to maintain the associated surface waters at a reasonable flow on a long term annual average basis. The concept of the “consumptiveness” of an abstraction was developed which allowed for water returned to the hydrological system. Despite the improvement of this method over previous ones, it did not find favour everywhere and in some parts of the country, it was never implemented. As late as the mid 90s, the NRA was trying unsuccessfully to ensure that a standard method of estimation of groundwater resources estimation was used throughout the country.

At this time, MORECS calculations were prohibitively expensive so this was also the time when different methods of recharge assessment started to be developed. These however have given way to invariably using MORECS as the cost has become more reasonable.

The groundwater resource estimates derived from this methodology were examined in a number of public inquiries and were consistently supported by various inspectors. Based on them, each aquifer unit was given a classification of over-abstracted, over-licensed, or resource available and this was the first test conducted for any new abstraction licence application – are there sufficient resources available in the aquifer unit to support the abstraction without "eating into" that portion reserved for the rivers.

WATER FRAMEWORK DIRECTIVE REQUIREMENTS

When the UK had the presidency of the EU, the Water Framework was being developed. We were seeking a way to ensure that groundwater abstractions were regulated on the basis of their effect upon surface water. The method had to be simple enough to be applied everywhere but had to be suitable to allow regulation to be based upon it. The concept of aquifer unit was replaced by groundwater body but this was meant to have the same properties. The method above was put into the early drafts of the Directive and is now in the enacted version and although it is hidden away in various acts and appendices, it can be set out as:-

For a groundwater body

1. Determine the long-term annual average recharge to groundwater (LTAA Recharge).

2. Determine the long-term annual average abstraction from groundwater (LTAA Abstraction).

3. Estimate long term annual average rate of flow required to maintain the necessary ecological quality for the associated surface waters (LTAA Ecological Flow Requirement).

4. If (LTAA Recharge-LTAA Ecological Flow Requirement) exceeds LTAA Abstraction, the groundwater body is in good status for this test.

Much is left open to the member states to interpret. The Recharge can be assessed using any appropriate method. The abstraction can include a consumptiveness allowance. The flow requirements of the surface water can be estimated using any appropriate method. This latitude was included because the methodology has to work in a wide variety of aquifers and climatic zones.

It was always intended to be applied in a risk based way. If the groundwater body is obviously not over abstracted, less precision and time are needed than if the groundwater body is nearing full utilisation.

One of the main features of this method is that it is predictive. The resource calculation is performed and can then be used to determine the status of the groundwater body in the light of future abstractions.

This method was the only one to be included in the early drafts of the directive. However, in the enacted version there are a number of additions or changes:

- Firstly, the water balance calculation is supplemented by the need to use groundwater level to test the results. This shows a startling lack of appreciation of the hydrogeological factors affecting groundwater level of which the long term water balance is only one. For example, if a new borehole abstraction puts the groundwater body into poor status by adversely affecting river flows, the groundwater water level will fall. However as more water is removed from the surface water, the groundwater level trend will flatten to horizontal. In many English aquifers, the initial fall will have taken place before groundwater level monitoring was established so the current trend for such a body in poor status will be level or could even rise. Checking status using level can never be predictive because the level must fall to be recorded. Thus any damage will have already occurred.

- There is a separate test that seeks to ensure that local surface water flows are not affected by abstraction. This can conflict with the first test.

- The effects of abstractions on Groundwater Dependent Terrestrial Ecosystems must not cause significant damage. This is a poorly understood area of hydrogeology and ecology and has taxed the UKTAG Groundwater Task Team and the Wetland Task Teams to come up with a method of assessing the likelihood of it happening or even determining when significant damage has occurred.

- There is an extra step to determine whether over-abstraction is causing undesirable movement of a saline "or other" intrusion.

RESOURCE ASSESSMENT AND MANAGEMENT FRAMEWORK (RAM)

In 2000, the Environment Agency issued various documents setting out how it would produce Catchment Abstraction Management Strategies (CAMS). These were designed to ensure that process of water resource management was more open, consistent, and structured than in the past. There was an urgent need for a new method of resource assessment to support CAMS that would have to be applied over all catchments and aquifer in England and Wales.

The RAM framework was developed in the knowledge that the requirements of the future WFD were to ensure that groundwater and surface water systems were treated as one hydrological system. Thus, while addressing the immediate needs of the Agency, the RAM framework provides the basis of a resource assessment methodology that it largely compatible with the future needs of the WFD.

The Resource Assessment process aims to establish a credible understanding of the key processes and features within a catchment before dividing it up into a number of river reaches, each with an Assessment Point and, where appropriate, an associated Groundwater Management Unit. Resource assessments are carried out at each Assessment Point and on each Groundwater Management Unit before the results are integrated to produce an overall assessment of resource availability for each part of the catchment.

RIVER FLOWS

The river is first characterised with respect to the sensitivity of the riverine ecology to flow variation that may be caused by abstraction. The sensitivity of a particular reach of the river is assessed on the basis of its physical characteristics, the dominant fish populations, macropyhtes and macro-invertebrates, all of which combine to produce an Environmental Weighting. Five Environmental Weighting Bands are used to classify the sensitivity of each river reach to the effects of abstraction impacts – headwaters being the most sensitive. The Environmental Weighting is used with long term natural flow duration data to derive an Ecological River Flow Objective and the portion of flow available for abstraction. This may be modified by other in-river flow needs to define a River Flow Objective or flow regime which the Agency is seeking to manage.

The River Flow Objective seeks to protect low flows and flow variability by allowing percentages of flow bands to be available for abstraction. The flow bands are derived from long term natural flow duration statistics and the percentage of each band available for abstraction varies according to the

Environmental Weighting Band for the river reach. Artificial impacts on river flows upstream of the Assessment Point, due to both surface water and groundwater abstractions and discharges, are then assessed. These impacts can be calculated for fully licensed volumes and also for recent actual abstraction and discharge rates. Where appropriate, hydrological and water resource or groundwater models may be used for such calculations.

Flow duration curves that incorporate these impacts are then compared with the River Flow Objective flow duration curve. This indicates whether the river resource status is Water Available (for additional licensing) or No Water Available, or the degree to which resources are already Over Licensed or Over Abstracted.

GROUNDWATER

Groundwater resources are initially assessed using five tests, each considering a different aspect or indicator of the water balance of the Groundwater Management Unit, as follows:

- The balance between recharge and abstraction;
- The significance of abstraction related reductions in summer groundwater outflow (e.g. as baseflow or to the sea);
- Evidence of ongoing over-exploitation of groundwater;
- Evidence for unacceptable historic impacts on groundwater levels or quality;
- The optional use of 'locally' derived techniques to help inform, but not override the other test results.

Where appropriate, Groundwater Management Units are associated with river Assessment Points to reflect the relationship between groundwater and the river.

INTEGRATION OF RESULTS

The impacts of groundwater abstraction on river flows are integrated into the results for each appropriate Assessment Point. The seasonal and spatial impacts of groundwater abstraction on river flows vary according to the characteristics of the aquifer, its hydraulic connection with the river, the pumping regime and the distance of the boreholes from the river.

An overall strategy for managing the catchment is evolved from consideration of the resource availability status for each river Assessment Point and associated Groundwater management Unit. Starting at the most downstream Assessment Point and working back up the catchment 'critical' Assessment Points are identified where River Flow Objectives are met for the lowest proportion of time. Resource classifications for catchments upstream are then devised in accordance with the resource availability status of these 'critical' Assessment Points. In this way the dependence of river flows on upstream reaches of the river system, and on baseflow contributions from groundwater, is explicitly taken into account and represented in final resource availability status maps of the catchment.

GROUNDWATER MODELLING

It has long been realised that groundwater models were an excellent way of understanding the processes occurring in an aquifer. In 1970 when the initial methods in this paper were being developed, a groundwater model was just that. It consisted of thousands of electronic components on a board that represented the aquifer and model runs were made by inputting electronic signals into the mesh system and monitoring the reaction of the circuit. The analogy between electronic current and storage and groundwater flow and storage allowed the electronic measurements to be converted to their groundwater equivalent. Within ten years, these electrical analogues were superseded by numeric versions running on digital computers.

The advent of relatively inexpensive software from the USA with pre and post processing abilities has resulted in a surge of groundwater modelling ranging from excellent to poor. Groundwater models are excellent for testing ideas as to how a groundwater system functions (the conceptual model) but the answers they produce are no more correct than the conceptual model that they represent. Whilst this could be seen as a criticism of the use of groundwater models for resource estimation, it should be remembered that the same criticism applies to every methodology used in hydrogeological impact assessment. The flow of groundwater can never be seen or measured so every assessment is based upon our own conceptual model of how flow is occurring. The difference is that the conceptual models associated with the earlier methodologies are much simpler and the difference between the conceptual model and our understanding is so profound that it makes the inaccuracies associated with predictions based upon them, much easier to accept. For example, everyone knew that there was no such thing as an infinite aquifer that obeyed all the required assumptions but hydrogeologists were happy to use the numbers and concepts generated using this idea.

Notwithstanding that groundwater models are useful hydrogeological tools, it is still difficult to use them to make licensing decisions. Except in obvious cases, their absolute accuracy is not sufficiently good to enable detailed predictions of effects due to individual boreholes. Furthermore, their ability to represent inputs to and from surface water is even less good. However, they can be used within the bounds of say the RAM framework to provide better estimates or some of the values that it requires.

The only experience the current author has of using groundwater models to defend licensing decisions is to use them in support of other resource assessment methodologies.

COMMON MISCONCEPTIONS

Over the past 3 years, we have been collecting together a variety of common hydrogeological misconceptions, some of which relate to the methodologies in this paper. Some of these have become so ingrained that they are still considered as truisms by some.

RECHARGE CIRCLES ARE RELATED TO THE ZONE OF INFLUENCE

The idea that recharge circles effectively define the extent of the zone of influence of an abstraction was the foundation for many of the early methodologies. That these have recently reappeared in a different guise may be seen as endorsing this idea despite efforts to the contrary. The WFD has encouraged the use of risk-based approaches to determine status and to determine significant damage to GWDTEs. These methods use GIS and a convenient algorithm, dividing the abstraction rate by the recharge rate and expressing the result as a radius around the abstraction. This has the purpose of showing the relative magnitudes of the abstractions and as such it is acceptable. However, showing circles around abstractions is very dangerous for non hydrogeological audiences (and possibly to hydrogeological ones as well) since they invite the interpretation that they are the limit of the effect of the abstraction. Recharge circles used in such risk-based methodologies have nothing to do with the area affected by the abstraction.

Both Theis (1940) in his original paper and Bredehoeft et al (1982) effectively refute this idea. They show that the effects of pumping will continue to spread out until the drawdown caused prevents a quantity of water leaving the aquifer that is equal to the abstraction.

USE OF THEIS TO PREDICT EFFECTS BY SETTING PUMPING TIME TO 365 DAYS

The above papers also show this idea to be incorrect. The time since pumping started has no effect on the maximum extent of the effects due to drawdown. The size and shape depend entirely on the extent of the effect until the point when the volume of water leaving the aquifer equivalent to the pumping rate.

RAINFALL RECHARGE WILL MITIGATE THE EFFECTS OF PUMPING

The only case where this could be true would be where drawdown in the aquifer allows recharge that would otherwise have been rejected. In most cases this is incorrect.

CURRENT IDEAS ON GROUNDWATER RESOURCE ASSESSMENTS AND IMPACT ASSESSMENTS

Where previously, the assessment of the groundwater resource for a groundwater unit or body was completed as a separate exercise from an impact assessment, the use of the RAM framework and a fuller understanding of how impacts spread in an aquifer is bringing about a change in thinking. The RAM framework makes the hydrogeologist explicitly understand and calculate the cumulative effects of all current and future abstractions on river flow. When assessing the impact of a new abstraction, the first step is to consider how far the impact will spread before encountering a source of extra recharge sufficient to balance the new abstraction. This requires a complete understanding of how the whole aquifer functions in order to assess the impact of the abstraction on the various streams that usually form this source of "extra" water. This impact can then be assessed within the confines of the RAM Framework.

Having assessed the wider implications of the abstraction, where impacts, although small are regionally significant, the area immediately around the new abstraction is examined. The area of significant drawdown "near" the borehole can be modelled taking into account the new knowledge of how far impacts will spread. There is no perfect way of doing this but the Agency has developed a suite of programmes called IGARF (Impact of Groundwater Abstraction on River Flow). This uses a Theis formulation that allows for an extra source of water from adjacent streams and can also model impermeable boundaries. So, although there is still a two stage process of looking at the resource balance and then the local effects, the difference between this and the older methodologies is that the two stages use the same information and the methodologies are connected. Also using this approach requires a much better understanding about how the aquifer functions which must lead to greater confidence in the determinations.

ACKNOWLEDGEMENTS

I am grateful to J. Aldrick, Water Resources Regulation Manager in the Environment Agency for permission to quote verbatim from his description of the RAM Framework.

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RECHARGE ESTIMATION AT LOCAL AND REGIONAL SCALES – EXAMPLES FROM MINNESOTA, USA

Delin, G.N., Healy, R.W., Lorenz, D.L., and Nimmo, J.R., U.S. Geological Survey

ABSTRACT

Knowledge of ground-water recharge is important to studies of water availability and sustainability, wellhead protection, contaminant transport, groundwater and surface-water interactions, effects of urbanization, and aquifer vulnerability to contamination. For example, by estimating the seasonal and spatial distribution of recharge, one can estimate the total volume of water entering an aquifer. Recharge is a sensitive component of ground-water flow models and is the one that is most difficult to measure directly. Local-scale estimates of ground-water recharge provide important information about recharge processes and factors, but commonly are not representative of regional recharge. Regional estimates give broad perspectives of large-scale processes, but provide little insight about the recharge process or about factors that influence recharge variability. Regional ground-water recharge estimates were compared to estimates based on local- and basin-scale methods as part of a U.S. Geological Survey study in Minnesota. Using three local-scale methods (unsaturated-zone water balance, water-table fluctuations (using three approaches), and age dating of ground water) we computed point estimates of recharge that represent spatial scales up to about 1,000 m^2. A fourth method (using computer program RORA) was used to generate basin-scale analyses of streamflow records using a recession-curve-displacement technique yielding recharge estimates at scales of 10–1,000s of km^2. The RORA estimates were regionalized to estimate recharge for the entire State of Minnesota on the basis of a regional regression recharge (RRR) model that also incorporated soil and climate data. Recharge estimates using the RRR model could provide reasonable initial values for regional groundwater flow models.

REFERENCES

http://pubs.usgs.gov/fs/2007/3002/ USGS fact-sheet ‘Groundwater Recharge in Minnesota’

Notes:

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THE WATER ABSTRACTION AND IMPOUNDEDMENT (LICENSING) REGULATIONS (NORTHERN IRELAND)

Peter Close, Environment and Heritage Service, Northern Ireland

ABSTRACT

The aim of the Water Abstraction and Impoundment (Licensing) Regulations (Northern Ireland) 2006 is to protect the water environment and to secure efficient and sustainable water use. The EHS is responsible under the Water (Northern Ireland) Order 1999 for promoting the conservation of water resources and the cleanliness of water in waterways and underground strata. EHS is the licensing authority for Northern Ireland and the licensing system will be administered by the Water Management Unit of EHS.

BACKGROUND & LEGISLATIVE DRIVERS

On the 1st February 2007, the Water Abstraction and Impoundment (Licensing) Regulations (Northern Ireland) 2006 came into effect. The introduction of this legislation fulfils Northern Ireland's obligation to the European Commission under the Habitats and Water Framework Directives, establishing a water resource management, assessment and licensing regime.

EC DIRECTIVE REQUIREMENTS

The Habitats Directive requires member states to have a formal/legal method of assessing the potential impact of abstraction/impoundments on protected and sensitive sites (e.g. a wetland). A protected site is defined as one which has a European designation, for example, a Special Area of Conservation or a Special Protection Area. If any activity may have a significant impact on a protected site, it will be subject to further assessment and consent controls. At present the absence of such controls in Northern Ireland means that there is no way of identifying the cumulative effects of abstractions/impoundments on protected sites.

Article 11 of the Water Framework Directive requires that the programme of measures established by river basin plans should include controls over abstractions and impoundments. While the programme of measures does not have to be established until 2009, or become operational until 2012, the introduction of the scheme now will provide valuable information for the river basin planning process and enable businesses and the Department to plan ahead to meet the required Water Framework Directive standards.

DOMESTIC LEGISLATION

Some limited control of abstraction activities does exist in Northern Ireland but only under certain circumstances. Under planning legislation conditions may be placed on certain developments and they may require planning permission if the engineered infrastructure is deemed to be a development. An Environmental Impact Assessment (EIA) may therefore be triggered under The Planning (Environmental Impact Assessment) Regulations (Northern Ireland) 1999.

Water management projects for agriculture which may not be deemed development under current planning legislation but would be likely to have a significant effect on the environment may require an EIA under the Water Resources (Environmental Impact Assessment) Regulations (Northern Ireland) 2005.

Under Article 20 and 21 of the Water (Northern Ireland) Order 1999 the Department have provision to:

- control, restrict or prohibit abstraction of water from underground strata or waterways and
- control, restrict or prohibit the construction or alteration of any impounding works.

However, these powers are not extensive enough to control damaging operations.The introduction of the Abstraction and Impoundment (Licensing) Regulations will, however, provide a single and consistent environmental risk based approach that covers all abstraction and impoundment operations. These powers will help protect our water environment including protected species and dependent ecosystems and will help deliver efficient and sustainable water usage in Northern Ireland.

In association with these Regulations, under the terms of Article 21 of the Water (Northern Ireland) Order 1999, the Department propose to introduce a fees and charging scheme with effect from 1st April 2008. This will be a 'cost recovery' scheme. During the transitional period for the regulations i.e. 1st February 2007 to 31st January 2008 there will be no fees or charges for either new or existing abstraction and/or impoundment activities.

WHAT IS AN ABSTRACTION / IMPOUNDMENT?

Within the Water (Northern Ireland) Order 1999 an abstraction is defined as follows:

"Abstraction" means the doing of anything whereby water is removed from a waterway or underground stratum". This could be carried out by mechanical means such as a pump, through a pipe, by an intake or other engineering structures in a watercourse, or by any other type of works such as a borehole or well. This applies equally whether the water is permanently removed or if it is diverted temporarily from one part of the water environment to another.

There is a danger from an environmental perspective that over abstraction of a water body can lead to shortages of supply, increasing pollution through reduced dilution, as well as causing damage to habitats dependent on that water body.

Within the Water (Northern Ireland) Order 1999 an "impoundment" means either of the following:

- any dam, weir or other works in any waterway by which water may be impounded;
- any works for diverting the flow of any waterway in connection with the construction, alteration or operation of any dam, weir or other works falling within any dam or weir etc.

The effects of impoundments, which will be variable, depending on the size, design and operation, and the sensitivity of the location, also need to be taken into account. A poorly managed impoundment may impede migratory fish, deflect flow which may result in river bed or bank erosion or cause a build-up of sediment leading to changes in the river bed habitat.

THE AUTHORISATION PROCESS

Under the Abstraction and Impoundment (Licensing) Regulations (Northern Ireland) 2006 there are two levels of authorisation, depending on the environmental risk:

i) PERMITTED CONTROLLED ACTIVITIES (PCA) *

This level of authorisation will apply to relatively simple activities which pose the lowest risk to the water environment. No interaction with the Department will generally be required, except in some instances where "notification" may be required. Operatives, however, must carry out their activities in accordance with the conditions for PCA.

ii) LICENCES

This level of authorisation will be used to control those activities posing the greatest risk to the environment.

When applications are received by the Department, the type of authorisation granted will be determined by the scale of the abstraction and the potential environmental impact of activity. The key determinant will be the volume of water abstracted as below:

$< 10m^3$ per day =	authorisation is granted subject to activities complying with PCA conditions, no contact with the department is required.
$10m^3 – 20m^3$ per day =	authorisation is granted subject to 'notification' to the Department, and compliance with the PCA conditions.
$20m^3 – 100m^3$ per day =	authorisation is granted subject to submission of an application and the issue of a formal "simple" licence which may have conditions.
$>100m^3$ per day =	authorisation is granted subject to submission of an application and issue of a formal "complex" licence which may have conditions.

AUTHORISATION FOR IMPOUNDMENTS WILL BE DETERMINED AS FOLLOWS:

- If an impoundment is not associated with an abstraction, does not control the water level upstream and does not create a height differential between the upstream and downstream water surfaces of more than 1 metre, then authorisation is granted as a PCA and no contact with the Department is required.

- In all other circumstances authorisation through formal licence is required for impoundments of water. The Department will consult with other agencies that have responsibility for fisheries legislation and the Habitats Regulations in Northern Ireland.

- Permitted Controlled Activities will apply to small scale activities which present minimal risk. A summary of the conditions which apply to low risk activities are summarised below:

    - A means of demonstrating the volume abstracted
    - Water leakage kept to a minimum
    - No contamination or pollution
    - Other water uses such as hydraulic tests on aquifers

USEFUL RESOURCES

http://www.ehsni.gov.uk/water/water_resoucres.htm

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SESSION II

"Understanding Groundwater Flow Systems for Local Water Supplies in Ireland"

David M. Ball

INTRODUCTION

Ireland does not have a national water grid. We do not supply Dublin from Donegal. Water supplies come from, essentially, local sources. Ireland also does not have any extensive aquifer systems, therefore we do not look upon the development of new groundwater sources on a large scale or national or provincial scale.

In the past, and until recent times, groundwater supplies for towns, villages and rural group water schemes were often based on one source borehole. Occasionally two or three dispersed boreholes or springs made up the source for larger schemes or towns. This is changing as there is an acceptance by local authorities of the concept of a source that consists of a wellfield made up of several production boreholes, in close proximity, that are operated and managed as a single source. The wellfield concept was widely accepted elsewhere a long time ago. Our local authorities are just catching up. They are realising that it is an advantage "to not placing all your eggs in one basket".

Groundwater supplies are developed on a local scale, to feed into a local distribution system. I have been involved in the exploration and development of new water supplies for some time. Others have been doing the same and our experiences are different. None of us know everything about Irish hydrogeology. We are all still learning and our experiences are complimentary. Each scheme is different and each new water well provides new experience. The purpose of this paper is to briefly describe some of the things that I have learnt in order to contribute to our pool of experience, but also try to stand back and draw out understandings that, I believe, have a wider significance.

One of the main things that I have learnt is that groundwater conditions are not just particular to an area or certain rock type but are particular to individual boreholes. It is usually not possible to obtain results from one borehole, and then expect the same results from other boreholes even in the immediate vicinity. My main understanding arising from this is that our training as hydrogeologists does not equip us well for local water supply development in Ireland. Those of us who have done a taught masters degree in hydrogeology, have had to study outside this jurisdiction. We have been taught 'classical hydrogeology' that could be applied anywhere in the world. This is essential and very useful, but I have realised that this training and technical language partially distorts our thinking in a way that is unhelpful when working on the development of local groundwater supplies in the Republic of Ireland. I have concluded that we need to radically revise our use of a technical term in order to help our profession deal with the reality of hydrogeology in our own country.

GROUNDWATER FLOW

Our professional training teaches us that groundwater flow through a range of materials (rocks) is difficult to measure and understand, but in order to have some conceptual understanding of this flow, we are taught to start with a simple model, such as the fundamental relationship described by Darcy, where

> flow through the saturated zone = the permeability times the cross section area times the hydraulic gradient

As students we latch onto this simple relationship. I have noticed a tendency to try to apply this simple relationship, regardless of scale, amongst both older and younger hydrogeologists. I have noticed that we tend to use this fundamental relationship to conceptualise regional flow through the bedrock, and also radial flow to a well. The tendency ignores scale, and our day to day experience that flow in the bedrock in Ireland is through discrete fractures, faults, or karst conduits. Why do we do this? It could be said that we keep reverting back to simple flow models and concepts because we are not usually great mathematicians; the mathematics of flow through a conduit are complex. However there is more to it; as natural scientists we know that on a small local scale we can never, practically measure the almost infinite heterogeneity of the rocks below our feet. We may have equations that can be used to calculate the speed of flow through a fracture and hence represent the effective porosity, but how can we ever measure the variations in the size of the fracture or conduit away from the borehole or spring. We can't dig up the world down to 40 metres everywhere along the line of a conduit or fracture system to measure its dimensions. Therefore we don't, and we tend to fall back on good old Darcy, and pumping test equations, like Cooper-Jacob straight line method, even though we know that most of the assumptions, behind the equations, do not apply. Our problem stems from the definition, and our use of the term 'aquifer'.

It is surprising that such a fundamental term in our profession does not have a universally accepted definition. There are roughly two schools of thought; one school would hold the simple, all embracing view, that an aquifer is a formation that both stores and transmits water. Another school would hold that an aquifer is a relative term, and that it is a formation (or formations) that yield/s water in sufficient quantity to be economically useful. If you look at definitions in text books and national and international guidelines and laws you will notice that the definition always entertains the idea that an aquifer is a rock that actually has some porosity and permeability.

For example in the EU Water Framework Directive you will find the definitions: -

> “**'Aquifer'** is a porous rock structure within which **water** travels and is stored. Aquifers
> may be shallow, a few metres in depth, or very deep being several hundred
> metres in depth”

The term 'porous rock structure' is used in this definition, but the word ‘structure’ is lost in the next definition of groundwater as follows;

> “**'Groundwater'** is all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil. This zone is commonly referred to as an aquifer which is a subsurface layer or layers of rock or other geological strata are of sufficient porosity and permeability to allow a significant flow of groundwater or the abstraction of significant quantities of groundwater”

These, and other definitions, usually state clearly, or imply, that the lithological characteristics of the formation determine whether it is an aquifer. In other words; the rock, and the properties of the rock create the aquifer.

I have found that adherence to the belief that the lithology defines the aquifer and its properties holds us back when it comes to the development of water supplies in Ireland.

My finding is that unweathered, unaltered, rock in the Republic of Ireland does not have any primary or secondary permeability. I specifically refer to the Republic because all of our rocks with the exception of the Kingscourt inlier, are Carboniferous or older. We do not have any younger softer rocks. All of our rock is old, hard and effectively impermeable. No water effectively is stored in, or moves through, the actual unweathered or unaltered rock. Yet we have large groundwater resources and we have groundwater flow.

So on the one hand we have a training and a language that encourages and perpetuates the notion or concept of flow through the actual rock, yet we have to live and work in a professional world where this concept for the bedrock is, in effect, is an illusion.

I have often said that it takes about 3-5 years for a hydrogeologist trained and experienced outside Ireland to 'get their eye in', to de-programme their preconceptions or perceptions about hydrogeology and aquifers, and re-train their mind to work successfully without the idea of the rock actually transmitting water. I don't suggest that we drop the word aquifer altogether in Ireland, as it obviously applies fully in the context of our sand and gravel deposits, but I do suggest that we use it in a discriminate and careful manner. I have found that to work relatively successfully on water supply exploration and development in our country, it is necessary to throw out the classic concept of formations and lithologies being aquifers, and instead conceptualise a subsurface world controlled by impermeable rock and a combination of structural deformation, fractures, post depositional alteration, faults, flexures opening up joints, solution weathering in limestones, a history of deep tropical weathering in palaeoclimates, and ancient sea levels that formed the historic base level to which groundwater flow moved. In short; I have found it best to think in terms of Groundwater Flow Systems through an impermeable rock matrix. Groundwater storage and flow that are essentially independent of the nature of the unweathered rock; that are not controlled by the unweathered rock matrix, groundwater storage and flow that are not controlled by the lines dividing one formation from another as shown by the GSI in the bedrock maps. I have learnt to expect that flow will cross these formation divides, that, in sedimentary rocks, are usually based on lithology and the age of fossil assemblages.

In other words, my findings are that to work successfully in exploration borehole and water well drilling it is useful to free the mind of the classic perceptions of rocks as aquifers, and instead think of geological processes that may have taken place since deposition; weathering and deformation that have created spaces within water may be stored and pathways through it may move. It is easy to latch onto lithological characteristics and, upon these, base hydrogeological concepts. It is much more difficult to reconstruct the structural and geomorphological history of the country. However I have found that by considering a hydrogeological world that is not primarily controlled by lithology, it opens the mind to the unexpected, and the infinite diversity of the subsurface. It means that every borehole or water well is a voyage of discovery, during which it is the hydrogeologist's job to make the most of what nature gives us. We have to deal with the specific effects of weathering, post depositional alteration and structure, within just the small sample encountered by a six or eight inch borehole.

I would like to add two things at this point: -

1. The GSI bedrock maps, and the Groundwater Section derivatives, are, in my opinion, an excellent foundation for groundwater development, as long as they are taken as an honest attempt, on the basis of existing available information to define the boundaries of units with a different age and lithology and geological structures at a 1:100,000 scale.

2. However the GSI bedrock maps are often incorrect, because they are based on outcrop and very limited borehole information, and there is seldom good outcrop in areas of hydrogeological interest. Hydrogeologists do not usually want to develop new groundwater sources in areas where the soil and overburden cover is either absent or thin. In other words we favour areas where there is little outcrop of rock at the surface. In areas where groundwater is well protected from surface pollution, the geological boundary is often hidden below a thick layer of boulder clay, soil or peat. Therefore the line we get on a GSI map separating two distinct units is merely the best shot that good geologists have made on the basis of the information available to them at the time.

The development of a new groundwater source involves coping with uncertainty. The first stage of any work for a local water supply should involve an assessment of existing information. This information may be published, but there is usually unpublished information available from local people and our friends, colleagues and competitors. I encourage us all to share information whenever possible.

A recent observation is that some of our profession and many engineers do not understand the difference between drilling a borehole and constructing a water well. I have found that those who think a water well is just a borehole, tend to focus on the artificial or man-made construction details; borehole depth, diameter, casing thickness, screens, gravel packs etc. These are the items that can be quantified and measured. In other words the components that can be controlled by humans. The objective may be to construct a high quality water well, but this objective is often lost, by a strict adherence to a contract design that was derived in an office, sometimes by someone who has never seen a drilling rig. I once saw a borehole contract for down-the-hole-hammer drilling in karst limestone, that specified that undisturbed samples of the rock must be obtained every metre, for subsequent grain size analysis and permeability testing! I was not involved, but was asked by a driller to try to bring some common sense to the contract. I had to explain to the engineer who sent out the specification, that the process of down-the-hole-hammer drilling tends to destroy, never mind disturb, the bedrock. It turned out that the consultant had never seen a rig, never drilled a water well, and had simply cut and pasted a borehole specification from a road site investigation contract into a water well drilling contract.

A water well is a borehole where the driller and the hydrogeologist use their skill, experience and the available equipment and materials to create a high efficiency hydraulic structure that can effectively draw upon the part of the groundwater system that is best protected from pollution and will provide an appropriate sustainable yield and water chemistry. It does not matter whether the contract indicates that the borehole will be 90 metres deep, if high yielding conduits are encountered at 45 metres in bedrock buried under 25 metres of boulder clay. The objective is not to drill to 90 metres. The objective is to construct a good water well. We need to focus on reality encountered in each individual hole, and in making the best of what nature gives us, and not become controlled by unreal contract specifications.

One of the reasons why we need to re-think our understanding of aquifers is that our misconception about the rock having permeability is spilling over into recent drilling contracts, which are specifying large diameter deep boreholes, in the misguided belief that a large open hole area will provide a higher yield. This is true in classical text book hydrogeology, based on homogenous, isotropic, porous, permeable aquifers, but it is not true or relevant when the groundwater system is contained in just two or three large conduits perhaps a metre or two in height found between 40 and 60 metres depth. The reason for raising this issue is that wide diameter drilling is very expensive. The equipment and materials are expensive and the drillers charge a premium for the difficult work. A flow rate of 1-2 million litres per day is easily achieved from an 8 inch borehole with a 6 inch pump. Ten such boreholes will cost of the order of 500,000 Euro. Ten 15 inch boreholes will cost close to 2 million. The ultimate control on the sustainable yield from the 15 inch or the 8 inch is the recharge to the groundwater system that is drawn upon by the borehole. Our impermeable rocks have very limited storage in the fractures, joints and cavities. Unless we understand the groundwater flow system, the water chemistry and in particular the recharge to the groundwater system, there no justification in spending €2 million of tax payers money, just because big boreholes are successful in the USA, or the Triassic sandstones or Cretaceous chalk in Britain.

IRISH FIELDWORK EXAMPLES

I have described my overall perspective. Below I will give a series of examples from my fieldwork in the last few years that relate to the development of new groundwater supplies. I will summarise both 'successes' and 'failures'. It is important to describe failures because they increase understanding of the hydrogeology of the groundwater systems in our bedrock.

DEFENCE FORCES CAMP AT KILWORTH, SOUTH OF MITCHELSTOWN

The army camp obtained their water supply from a spring downhill and down gradient of the camp and the septic tank discharge area. The Defence Forces land above the camp is underlain by Devonian Old Red sandstone. The Lower Limestone Shales, previously known as the Kiltorcan sandstone is below the camp, and is already exploited as the water supply for Mitchelstown. The Old Red sandstone is not regarded as a regionally important aquifer. The sandstone and conglomerate clasts are cemented. Therefore groundwater storage and flow would be expected only in the joints, fractures and bedding planes. I could not drill in the base of a low valley that might have been representative of the extension of a fault seen in the Carboniferous to the north because it was inside a live firing range. The firing range presented an obvious danger but there was also a hidden danger represented by 120 years of lead shot and explosives in and on the ground. It was expected that the groundwater pH would be acid and that metals in the ground would be dissolved. I drilled two exploration boreholes, expecting low yields but found that the Old Red Sandstone had been deeply weathered. The cement between the clasts appeared to have been dissolved and the upper bedrock consisted of a soft, sandy mush. I found that the weathering decreased with depth. The nature, consistency and colour of the upper weathered bedrock reminded me of drilling in Africa. It appeared to represent deep tropical weathering in a warm humid climate. This may have been a reflection of the original desert depositional environment, but warm temperatures and acid recharge would have been advantageous in dissolving the silica and iron oxide cement between the clasts. The upper succession was highly unstable. The deep unweathered bedrock was essentially unproductive. Therefore I had to design the production boreholes with a sufficiently deep pump chamber casing to get the desired drawdown, but at the same time, place the casing and cement grout at a depth that did not seal off the lower weathered zone that was stable and productive.

HERBERTSTOWN COUNTY LIMERICK

The original village borehole was drilled into Waulsortian limestone but was an old style hole, located in the middle of a village with no sewerage system, and down gradient of a farm yard on bedrock that was used to over winter cattle. The resultant pollution was inevitable. Land access was an issue. The County Council owned land around the water tower and requested a trial borehole. It was unsuccessful but useful as an example. The water tower was on the top of the hill underlain by basalt volcanics. The volcanics were heavily jointed and weathered. Therefore they could have been a reasonably productive. However the deep weathering had created a multicoloured clay residual that clogged all the joints between the solid blocks of basalt. The yield was barely measurable. The weathering again appeared similar to the weathering found in humid tropical areas. Herbertstown is about 30 miles north of Kilworth.

KNOCKAINEY COUNTY LIMERICK

The group scheme supply came from a shallow well next to a domestic cesspit serving two elderly people and a borehole drilled into the Ballysteen limestone. The borehole yield was low and was pumped intermittently. The Ballysteen limestone is unproductive unless the water well encounters a fault or series of open fractures. I realised that though there is no Kiltorcan or lower limestone shale shown on the bedrock map, it might be possible to drill a deep borehole through the Ballysteen and reach the Kiltorcan below. The Group Scheme Trustees were prepared to take the gamble. We drilled for a day through totally unproductive black shaley limestone, until halfway down the last drilling rod, i.e with 10 feet to go, we suddenly broke through into white and green sandstones and obtained a yield of 3,000 gallons per hour. This example illustrates the importance of considering the hydrogeology in cross section when siting a borehole. In other words consider the thickness of formations shown in plan view on a map. It is also useful to consider deliberately drilling through a poorly productive formation in order to provide a thick protective layer above a more productive formation. The Lower Limestone Shales contain the Kiltorcan Formation. The Kiltorcan formation is a sequence of coarse pale coloured sandstones and red and green shales. The rock is impermeable but when flexed in an anticline the shales and brittle sandstones accommodate the structural stress in different ways. The sandstones become heavily jointed, whereas the shales undergo plastic deformation. The results from several boreholes into the Lower Limestone Shales on gentle anticlines have shown that a useful yield of 2 – 4,000 gallons per hour can be reliably obtained with the yield generally increasing in small increments with depth to about 70 metres. The results of recent drilling targeting the Kiltorcan below a protective feather edge of Ballysteen has provided two useful experiences. The first is that the Kiltorcan on an anticline has sometimes not undergone brittle deformation and a widespread development of small open joints. Second the boundary between the Ballysteen and the underlying Kiltorcan can be in error, in areas with no exposure, by up to 2 kilometres. Therefore always expect to be surprised and prepared to scrap a well tried conceptual model in the light of new findings. In both 'surprise' cases, I readjusted the targets and the borehole design and completed successful village wellfields. In one case I used thick overburden clays as the protective layer, and in the second I used high yielding thin gravels above the Kiltorcan as part of the supply and used acid and, I am ashamed to say, explosives to open joints and fractures and improve the yield of the Kiltorcan.

BRUFF COUNTY LIMERICK

Another useful learning experience was drilling several quick exploration boreholes into a shallow syncline of Waulsortian limestone north of Bruff. The end of the syncline had been truncated by a fault. The hydrogeological setting would have seemed, on paper, to be very attractive; a faulted Regionally Important Aquifer. The 'Holy Grail' for a hydrogeologist looking for a new source for a village. The results were dismal. The Waulsortian had been so weathered that it had been reduced to a pale grey – white, semi competent mush. The rock cuttings came up like wet Plaster of Paris. Fortunately the drilling was easy and I managed to complete four boreholes and 800 feet of drilling in two days, take out the casing and backfill the holes. The lesson learnt was that weathering can, on the one hand, create a Regionally Important aquifer full of large karst conduits, but, on the other hand, if the fracturing and weathering is excessive, it can render a massive limestone down to an almost impermeable calcareous clay.

MARTINSTOWN COUNTY LIMERICK

Faults are useful targets for successful water wells. Faults are attractive targets because a borehole intersecting an open fault will tend to have a high yield. The important learning with regard to faults is that an initial high yield may not be sustained, if the fault is not connected to a myriad of minor fractures or joints in the rocks adjacent to the fault. For example a borehole drilled into the large thrust fault at the northern side of the Ballyhoura mountains for the Martinstown water supply scheme was originally tested for a week at 15,000 gallons per hour. It was proposed that this 'excellent borehole' had extra capacity and could be used to replace the existing supply for a whole village. I advised that as a water supply needs to be sustained for 365 days a year, it would be wise to carry out a test for more than 7 days. I carried out a pumping test for 58 days at the design yield of 12,000 gph. The test showed a progressive increase in drawdown and a progressive reduction in yield as the cone of drawdown extended further and further along the fault, depleting the limited storage in the adjacent rocks. Eventually the data showed that the sustainable long term yield could only match the water requirements for the existing scheme and that there was no extra capacity in the borehole for use by another village.

CLONBULLOGE COUNTY OFFALY, AND PORTARLINGTON COUNTY LAOIS

Contacts between two formations are often promising targets. I have repeatedly found in Offaly – Laois that the boundary between the Allenwood and the Calp Ballysteen limestones seems to be a zone of massive alteration. It appears that post depositional fluids have etched, dissolved, and altered the Allenwood leaving vugs and cavities containing large calcite and dolomite crystals. Karst dissolution has created further cavities and conduits. The cavities are found at depths of 40 - 90 metres and are often filled, or partially choked with more recent clays, silts, sands and gravels. The bedrock geology maps show a clear boundary between the formations, but below the ground it appears chaotic. This ground is very promising for a hydrogeologist but also very challenging for a driller. Successful development of new water wells depends on a hydrogeologist working on site with the driller and within a contract that permits flexibility. A hydrogeologist will see potential in a large cavity filled with sands or clays. A driller will just see problems and want to drill through as quickly as possible, or preferably case it off. I have noticed that many hydrogeologists are using screens and gravel packs in the bedrock. I have just used the first screen to stabilise caving bedrock since 1987. In most cases unstable bedrock is found in the upper weathering zone. Usually this is cased and cemented off in order to construct a sufficiently deep pump chamber. It is rare to find unstable bedrock at depth in the producing zone. Unstable rock at depth usually means water. Placing a screen and a gravel pack against the inflow of water appears to be completely counter intuitive, counter productive and unnecessarily expensive. I suspect that many screens and gravel packs are installed in bedrock in order to bolster the contract sum by consultants who are focused on borehole drilling and not water well construction.

SWORDS FINGAL

I and Rick Pasquali recently worked together just north of the Airport. I found Rick's knowledge and ideas on the structural geology of the Dublin limestone /Calp in the area very successful. We found that it was important to bring together two factors. Structural geology and an awareness of ancient sea levels. We found for example dolomite alteration and calcite filled fractures at depth on the northern limb of an east west anticline. We got no water. We moved south and found that the same features were closer to the surface, but we still got no water. We finally drilled close to the crest of the anticline, where we predicted by geometry that the dolomitisation and fractures would be above the Pleistocene sea level minima of about 60 metres below present sea levels, and we obtained yields of 4000 -5000 gallons per hour in several boreholes. We realised that if we could intersect this zone of alteration and fracturing above this sea level there would be a chance that groundwater migrating to this base level would have dissolved the calcite and opened up the fractures. There seemed to be base level to which weathering and dissolution took place. Some of the fractures or cavities contained the 'tell-tale' bright yellow clays that often seem to be found in palaeo-drainage conduits. These were easily cleaned out and flow through the system restored. Using two different perspectives on the same project eventually lead to irrigation boreholes providing a million litres a day that had otherwise been obtained from the Fingal public water supply system.

GALLSTOWN COUNTY LOUTH

The best quarry sites from a quarryman's perspective are dry quarries. However quarries also need a water supply particularly if there is secondary processing or manufacture, for example ready mix concrete or concrete blocks. I drilled two deep exploration boreholes in greywackes and found shallow weathering above the water table and no open fractures below the water table. I then decided to move to the lowest area of the site and found water in the upper weathered zone, but the top of the bedrock was unstable and the yields were low. I therefore drilled a line of shallow boreholes where the casing was installed to provide a reasonable pump chamber in the unstable upper bedrock, yet leave open sufficient weathered bedrock to provide a moderate yield with a moderate drawdown. I constructed, and gently pumped, five simple water wells in order to spread the drawdown. Kilsaran, who owned the quarry, then sited two large silt settlement ponds directly up gradient from the line of boreholes. This added to the success by increasing the recharge to the upper bedrock groundwater flow system. In effect the boreholes were scavenger wells picking up artificial recharge and recycling the water for further use in the washing of aggregates and the block making plant.

CONCLUSIONS

My conclusions after some years of groundwater exploration and water well drilling are that conditions in every country and region are different, but that in Ireland we do not have any groundwater flow through the unaltered, unweathered and unfractured rock. We do not have any bedrock aquifers in the classic sense. I suggest, when working at a local scale, that we park the term aquifer and instead, think in terms of groundwater flow systems, that are highly heterogeneous and vary considerably in three dimensions over very short distances. The successful construction of water wells for local water supplies depends upon understanding this, and good, experienced drillers, with a range of appropriate equipment, and experienced hydrogeologists working, full-time, in tandem on site, within the context of a contract that permits a flexible response to actual conditions found in each individual water well. In short, if you want to succeed in providing a new water source; design, construct and develop your water wells on the basis of what you find underground, and not on what you found in your head before you started. Finally, I think that with the high level of demand for good practical hydrogeologists in Ireland and other hard rock areas of the world, we need to have a taught masters course in hydrogeology in Ireland.

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GROUNDWATER RESOURCE ASSESSMENT FOR PUBLIC WATER SUPPLY SCHEMES IN THE MIDLANDS OF IRELAND

Richard Church, Principal Consultant, Entec UK Limited

ABSTRACT

Current rapid development of towns within the midlands of Ireland has placed a high demand on the existing public water supply schemes and a programme of works is underway to upgrade water supply infrastructure. This programme is being led by the Water Services Sections of the County Councils and funded through the Water Services Investment Programme of the Department of the Environment, Heritage and Local Government.

Groundwater has previously been an underdeveloped resource in several counties where Regionally Important Aquifers are present. The difficulty in obtaining permission to abstract from surface water, has led local authorities to look to groundwater as an available resource for both short and long term use.

Sustainable development of these groundwater resources requires an accurate assessment of the catchment water balance. Several of these midland towns, such as Edenderry, are located close to the headwaters of large catchments. It is important that confidence in the water balance is considered against the risk of stress to the groundwater body and supported environment from abstraction.

Recent dry summers, limited winter recharge and increased demand has resulted in a deficit in full supply for some towns. This has prompted Emergency Works by several County Councils to increase supply in the short term.

Development of groundwater for public water supply is often constrained by logistical considerations. High land prices have required pragmatic solutions including the use of existing County Council land and land owned by other public bodies such as Coillte. The definition of Source Protection Zones, to allow the local authority to apply appropriate constraints on land use, has also made some landowners hesitant to the development of groundwater resources close to or within their land.

These have all placed pressures on the hydrogeologist to deliver.

1.0 INTRODUCTION

Current rapid development of many towns both within the reach of Dublin commuters, such as Portarlington and Edenderry, and further a field such as Clonmel has led to a need for the development of additional potable water supplies.

Public water supply schemes in the midland counties of Ireland are managed by the Water Services sections of the County Councils. Entec with Nicholas O'Dwyer Consulting Engineers are currently active in the development of groundwater as a supply for large county scale water supply schemes in Offaly, Laois and South Tipperary.

This paper aims to presents a case study of the resource assessment requirements for the development of groundwater for these schemes and to illustrate some of the difficulties in the commissioning of the sources. The case study is principally taken from work completed for the Edenderry-Rhode Groundwater Abstraction Scheme in County Offaly.

2.0 BACKGROUND

Groundwater resource development for public water supply schemes requires a rigorous, systematic approach to ensure that the resultant supply is sustainable, cost effective and above all safe for public consumption.

In many areas smaller public water supply schemes and some group water schemes are being bundled together into larger water supply schemes. This has benefits in terms of economies of scale. Development of the schemes is funded through the Water Services Investment Programme of the Department of the Environment, Heritage and Local Government. Each scheme proposal requires a Preliminary Report to be submitted to the Department which details, justifies and costs the scheme. The preparation of the Preliminary Report has included the following:

- Determination of the Future Demand.
- Assessment of the groundwater potential of the area.
- Exploration Borehole drilling, development and testing.

Where appropriate (as discussed in Section 6) an Environmental Impact Assessment and definition of Source Protection Zones have been completed prior to the drilling, development and testing of production boreholes. These above tasks are discussed in the Sections below.

3.0 FUTURE DEMAND

The current cost for development of a countywide water supply scheme can be in excess of €10 Million. This cost requires justification for which the determination of the future water demand is a key component. The future water demand for the supply area is normally evaluated for a twenty five year period on the basis of projected requirements in the following sectors:

- Domestic Demand;
- Commercial Services Sector and Institutional Demand;
- Industrial Demand; and
- Agricultural Demand.

with due allowance has been made for:

- Domestic Losses; and
- Network Losses / Unaccounted For Water.
-

Domestic demand is normally the largest component of the estimation and is based on projections of the population from census returns; the development plans and "Target" populations. Commercial, Agricultural and Industrial Demands are estimated from current usage, development and zone plans for the area. A typical demand forecast is presented in Table 3.1.

The demand estimation takes into account aggressive water conservation measures being implemented to reduce the current distribution losses from approximately 52% to less than 20% by 2028. However, it can be noted from the above that no sector indicates a reduction in future water consumption.

For this example, this results in an increase in demand for the water supply scheme from approximately 5 500 m^3/d in 2004 to over 10 200 m^3/d in 2028 and a subsequent sustainable deficit from existing sources of 4249 m^3/day.

Table 3.1 Example of Future Demand Estimation

Demand Category	Water Supply Requirement (m^3/day)	
	2004	2028
Population	9,722	24,392
Per Capita Consumption[1]	140 l/hd/day	156 l/hd/day
Domestic	1,361	3,805
Commercial	437	1,095
Agricultural	394	1,111
Industrial	88	462
Operational Use (1%)	23	65
Customer Side Losses @ 40 l/prop/day	157	392
Base Demand	***2,460***	***6,930***
Distribution Losses m3/day	2,338	1,243
Average Daily Demand	***4,798***	***8,173***
Average Day Peak Week Factor	461	1,308
Production/Headroom Factor	276	785
TOTAL DEMAND	**5,535**	**10,249**
Available from Existing Sources	6,000	6,000
Deficit	***None***	***4,249***

4.0 DESK STUDY

4.1 INTRODUCTION

Each groundwater resource development study commenced with a comprehensive desk study to derive a conceptual understanding of the aquifer. From this the water resource potential in the area of the water supply network was determined.

4.2 GIS ASSESSMENT

Borehole groundwater abstraction data from the Groundwater Database of the Geological Survey of Ireland (GSI) were plotted in GIS to overlie the bedrock geological mapping for the area. An illustration of the typical well yields reported in an area of regionally important aquifer around Edenderry, Co. Offaly is presented in Figure 1 (see end of document).

Using this, it was apparent that in some areas bedrock aquifers such as the Waulsortian Limestones; Allenwood Limestone and in the south the Suir Limestone which are identified through the GSI Groundwater Protection Schemes as Regionally Important Aquifers (i.e. a productive aquifer with excellent well yields > 400 m^3/d common[2]) have limited current use for abstraction. The true use of groundwater may be under-reported with yield assessments not being reported to the GSI. However, boreholes in many areas are used predominantly for domestic and small agricultural purposes and therefore abstraction can be presumed to be limited. Typical household domestic consumption is in the order of 1 m^3/d and typical agricultural consumption for stock and domestic purposes (excluding irrigation) is 65 l/hectare or 1.7 m^3/day per agricultural connection.

[1] National Water Study, Appendix 20, County Offaly Report, WS Atkins, March 2000

[2] Groundwater Protection Schemes (DELG/EPA/GSI, 1999)

The areas of good aquifer potential and low usage were then linked to the existing water supply network to determine an area of interest for further assessment. Where available, groundwater vulnerability mapping was reviewed to determine areas of High or Extreme vulnerability. These were then avoided during the exploration drilling programme.

4.3 CATCHMENT WATER BALANCE

A water balance was calculated for each catchment of interest. Groundwater recharge was estimated using a water budget approach, which calculates direct and indirect recharge flow components including a soil moisture balance. Surface run-off and subsoil interflow are included in addition to estimations of bypass flows, urban recharge and surface water leakage.

The aquifers have varying thicknesses of drift cover and type and both direct and indirect recharge processes will occur with bypass recharge being an important process, particularly during periods of intense rainfall when there is a high soil moisture deficit. A summary of a typical water balance is presented in Table 4.1.

Table 4.1 Catchment Water Balance

Parameter	Volume (mm/a)	Comments
Precipitation	875	Met Éireann Raingauge – daily rainfall
Actual Evapotranspiration	455	Met Éireann data – monthly data
Effective Rainfall	420	
Estimation of Surface Runoff and Interflow	84	Using coefficient of 0.2
Recharge Estimation	336	
Boyne Headwater Catchment	**Volume (ML/a)**	
Recharge	145 000	Upstream from the Boyne Aqueduct Gauging Station. Based on catchment area of 432 km^2.
Baseflow	129 300	Estimated from gauging data for the Boyne Aqueduct Gauging station (1969-2001)
Existing Groundwater Abstractions	1 500	Estimated from GSI Groundwater Database
Grand Canal Spring Flows	13 140	Estimated from length of canal (12 km x 3 m x 1 m/day)
Balance	+1 060	

In the above example from Edenderry, current groundwater abstractions were estimated at only 1 % of recharge in the headwaters of the Boyne catchment above the Boyne Aqueduct Gauging Station.

Recent work completed for the EU Water Framework Directive predominantly in low altitude catchments by the UK (Entec, 2005) indicated that where the groundwater abstraction exceeded 40% of long-term average recharge that these catchments had a high exposure pressure to groundwater impacts. This test is then linked to other tests which determine ecological and flow impacts to surface water bodies, saline intrusion and reversal in groundwater gradients.

The water balance and the desk study indicated that groundwater potential for development existed within the catchment without significant impacts on the catchment as a whole. Local impacts were then considered within the exploration drilling and testing phases and the Environmental Impact Assessment of the resource development.

5.0 EXPLORATION DRILLING AND TESTING

Land prices and the availability of land for purchase required a pragmatic solution to the development of locations for groundwater abstraction. Discussions were held with the county executive engineers to identify any council owned land within the area of interest. Additionally, other public owned land by bodies such as Coillte was assessed. A walkover assessment of potential land was then completed to determine suitable locations for exploration drilling.

Where possible, exploration drilling was timetabled during periods of low groundwater levels. This was also often the period when the county executive engineers are under pressure to deliver additional water supplies.

Groundwater boreholes for public water supply require an abstraction in excess of 500 m^3/day and often in excess of 1 Ml/day to justify the additional infrastructure costs (housing, treatment, pipeline) for development. Therefore, it is important that exploration borehole diameters are completed wide enough to enable a pump, which will stress the borehole.

Initial estimation of yields were achieved during the airlifting stage of the borehole development. Most boreholes within the limestones require a significant period of airlifting to clear fines infilled within the principal water bearing fractures and periods in excess of 8 hours of aggressive airlifting opposite the principal inflow zones were often required. Samples were taken following airlifting using a submersible pump for the analysis of indicative parameters.

6.0 ENVIRONMENTAL IMPACT ASSESSMENT

Schedule 5, Part 2, Category 10 (l) of the Planning and Development Regulations 2001 states that an Environmental Impact Assessment is required for *"Groundwater abstraction and artificial groundwater recharge schemes not included in Part 1 of this schedule where the average annual volume abstracted or recharged would exceed 2 million cubic metres"*. This is interpreted as applying to schemes where the volume is in excess of 5500 m^3/day.

A full environmental impact assessment (EIS) is an onerous task and several sections of the EIS, such as visual and landscape assessment, cultural heritage and air pollution, can justifiably be scoped out for the impact assessment of a groundwater abstraction scheme. However, detailed assessment of the Human Beings, Water Environment, and Flora and Fauna is required. This was completed for the Edenderry-Rhode scheme and focussed on potential local impacts around each proposed source and the wider catchment scale impacts.

7.0 PRODUCTION DRILLING AND TESTING

Locations of suitable exploration boreholes were then proposed for the development of production boreholes. This often required land purchase and wayleave agreements which delayed the drilling programme.

Given the variable nature of limestones the production boreholes were reamed out from the exploration boreholes where possible. Production boreholes were normally completed with screen at a minimum diameter of 200mm to enable a 150mm diameter pump to be safely installed.
Airlifting was then followed by a two-week period of pumping tests, which initiated with a Step Test and followed with a Constant rate test. Samples for water quality testing were then taken towards the end of the Constant rate test and analysed for the full suite of SI 439 parameters.

8.0 SOURCE PROTECTION

Source protection zones (SPZs) were defined for each production source. Existing sources within the Edenderry-Rhode scheme had source protection zones defined by the Groundwater Section of the GSI and are protected by the Water Pollution (Agriculture) Bye-Laws (2001). The GSI defined a Groundwater Protection Scheme for County Offaly, which makes recommendations for restrictions to land use within the Source Protection Zones based on the vulnerability of the groundwater aquifers to contamination. The scheme is detailed fully in the Offaly Groundwater Protection Scheme Report and accompanying maps (GSI, 1999). The groundwater protection policy uses 'response matrices' to guide the location of landfill sites, septic tank systems and land spreading. These activities would generally not be acceptable within the inner source protection zones defined for the boreholes.

New sources at Edenderry had revised source protection zones, which took account of the existing nearby abstractions. These SPZs were submitted as part of the Environmental Impact Statement.

From the 1st of February 2006, S.I. No 788 of 2005 'European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2005' came into force. These regulations set out certain restrictions on agricultural activity around groundwater sources including the following:

- Organic fertiliser or animal slurry not to be spread within 200m of a groundwater source;
- Storage of manure at a minimum distance of 250m from a groundwater source; and
- Various restrictions with regard to the required ground conditions prior to spreading fertilisers or animal slurry.

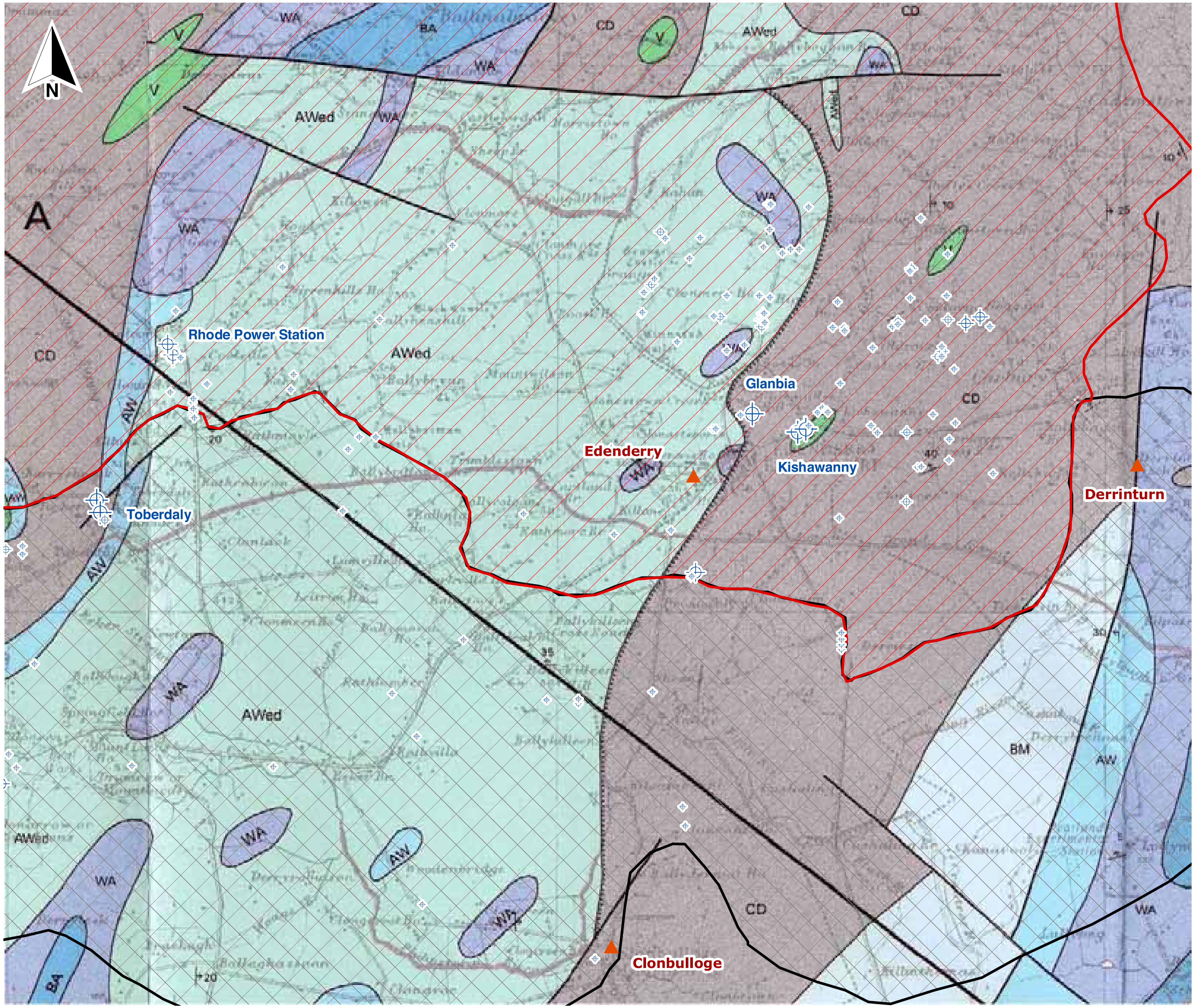
However, these generic definitions do not take account of the groundwater vulnerability of specific sources nor the groundwater flow conditions to an individual source. They can therefore be over-prescriptive in some cases and under-prescriptive in others.

9.0 CONCLUSIONS

Groundwater within the midlands of Ireland provides a valuable resource for countywide water supply schemes. Development of this resource within the current environmental, legislative and economic constraints requires a careful but pragmatic approach. Resource assessment should include a detailed desk study to develop a conceptual model for the aquifer and a catchment water balance prior to the development of exploration and production boreholes. These borehole sources need to be located in areas of available land with consideration of the water supply network. An Environmental Impact Statement, when required, should be scoped to focus on the areas of possible effects and Source Protection Zones are required for all new abstractions.

10.0 ACKNOWLEDGEMENTS

This paper was written from the findings of projects for South Tipperary County Council, Laois County Council and Offaly County Council. Valuable input was gratefully received from Jerry Cronin, Jim Oliver and Daragh Monaghan at Nicholas O'Dwyer Consulting Engineers and Stuart Sutton at Entec.



Key:

- Town
- Boyne catchment upstream from the Boyne aqueduct
- Barrow catchment upstream from Clunbullogue

Borehole yield for existing private and public water supply (m3/d)

- 0 - 10
- 10 - 50
- 50 - 100
- 100 - 250
- > 250

Data taken from the GSI groundwater abstractions' database

Solid Geology

CD	Calp Dark-grey to black limestone & shale
TC	Tober Colleen Formation Calcareous shale, limestone conglomerate
CL	Clogrenan Formation Cherty, muddy, calcarenitic limestone
BM	Ballyadams Formation Crinoidal wackestone/packstone limestone
MI	Milford Formation Peloidal calcarenitic limestone
BA	Ballysteen Formation Fossiliferous dark-grey muddy limestone
QU	Quinagh Formation Lenticular mudstone & coarse siltstone
RK	Rickardstown Formation Cherty often dolomitised limestone
AW	Allenwood Formation Thick-bedded limestone, locally peloidal
ed	Edenderry Oolite Member Oolitic limestone
WA	Waulsortian Limestones Massive unbedded fine-grained limestone
V	Volcanics

0 5,000 Meters

Scale: 1:70000 @ A3

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Edenderry Rhode Groundwater Scheme
Environmental Impact Statement

Figure 1 Solid Geology and Groundwater Abstractions, Edenderry Rhode Area

April 2007
11443-R16i2 HAREE

Nicholas O'Dwyer

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EAST MEATH, SOUTH LOUTH AND DROGHEDA WATER IMPOVEMENT SCHEME

INVESTIGATION OF GROUNDWATER POTENTIAL FOR AUGMENTATION OF PUBLIC SUPPLY

Mark Conroy, Associate Director, TOBIN Consulting Engineers
for McCarthy Tobin (JV), on behalf of Meath County Council

ABSTRACT

McCarthy Tobin (Joint Venture) was appointed by Meath County Council as consultants for the East Meath, South Louth and Drogheda Improvement Scheme. Based on projected population increases within the catchment area, the potable water requirements will increase to 83,000m^3/day up to the design year horizon of 2023. The current water requirements are almost totally provided from a single surface water abstraction from the River Boyne (approximately 29,500m^3/day) to the west of Drogheda. A specific aspect of the project was to assess the potential of developing groundwater sources to augment the overall public supply. The hydrogeological study was conducted on a phased basis, with progressive refinement of data. A site selection study was initially undertaken, which was conducted to define physical and environmental constraints and to delineate favourable sites for investigation. This data was collated and managed within a GIS platform, which allowed spatial analysis of the dataset. This was considered an important aspect of the project, so that intrusive investigation could be focused in a cost effective manner and in areas of hydrogeological potential in close proximity to the existing distribution infrastructure. Further to the site selection study, land access agreements were secured and the intrusive hydrogeological study was designed and undertaken. The intrusive works consisted of the drilling and pump testing (both individual and multi-borehole tests) of 42 No. trial boreholes and 1 No. production borehole. Interrogation of the hydrogeological data collected from the project suggests that a sustainable supply of approximately 25,000m^3/day of groundwater could be sourced from the limestone bedrock aquifer. The detailed design of the overall East Meath, South Louth and Drogheda Water Improvement Scheme is ongoing and the final augmentation design will involve a combination of both surface water and groundwater supply to achieve the full water requirements of the scheme.

INTRODUCTION

Owing to continued national growth, the East Meath, South Louth and Drogheda Region has continued to develop, which in turn is leading to increased demand on services in the Region. The study area of East Meath, South Louth and Drogheda is located within the functional areas of Meath County Council, Louth County Council and Drogheda Borough Council. The increasing growth and development in the region has resulted in serious deficiencies in the available water sources of the study area in the short term and is leading to poor levels of service in some areas. Meath County Council is the lead authority acting on behalf of Drogheda Borough Council and Louth County Council for the East Meath, South Louth and Drogheda Water Improvement Scheme.

Meath County Council commissioned McCarthy Tobin JV (joint venture of McCarthy Consulting Engineers and TOBIN Consulting Engineers), to prepare a Preliminary Engineering Report to evaluate the existing water supply and make proposals for a future supply scheme, up to a design horizon of 2023.
The Preliminary Engineering Report was structured to address the following aspects:

- Demand assessment, based on existing and projected population growth and development areas;
- Assessment of existing water sources;
- Assessment of existing water supply infrastructure;
- Network analysis and design;
- Development options and recommendations for improvement of the overall scheme.

EXISTING AND FUTURE WATER RESOURCE PROJECTIONS

The current water requirements for East Meath, South Louth and Drogheda are almost totally provided by surface water abstraction from the River Boyne at Roughgrange. Approximately 29,500m^3/day of surface water is abstracted at Roughgrange and pumped to Staleen Water Treatment Works (WTW).

Staleen WTW is operating near its capacity, with limited reservoir capacity. Further constraints in the distribution system capacity between Staleen WTW and Donore Reservoirs also restrict the volume of water transmitted from Staleen and impact on security of supply.

Supply to the south of the East Meath region (Curragha and Dunshaughlin) is supplemented from groundwater production wells. Supply to Drogheda is supplemented from a collection of mountain streams in south County Louth, which is treated at Rosehall WTW.

The Preliminary Report for the East Meath, South Louth and Drogheda Water Improvement Scheme proposes a total water requirement of 83,000m^3/day to year 2023. Therefore, the existing supply is required to be augmented by approximately 53,000m^3/day.

A phased hydrogeological assessment was conducted in parallel to hydrological studies to assess the potential of groundwater and surface water to augment the supply.

PLANNING LEGISLATION COVERING LARGE GROUNDWATER ABSTRACTION SCHEMES

Development of groundwater sources for the purpose of water supplies is addressed in the Planning and Development Act 2000. An understanding of this legislation is important to ensure that all potential groundwater supply schemes are compliant with Irish Law.

A groundwater abstraction scheme, where abstraction exceeds the threshold of 5,476m^3/day, will fall under a class of development under Part 10 of the Planning and Development Regulations and will require the preparation of an EIS.

Where abstraction from the scheme is less than the threshold of 5,476m^3/day and proposed by a Local Authority, such a scheme will fall under a class of development under Part 8 of the Planning and Development Regulations.

Groundwater abstraction schemes are also covered under the Water Framework Directive, which promotes sustainable water use, by ensuring a balance is maintained between abstraction and recharge and there is no damage to terrestrial eco-systems. The WFD sets a framework for comprehensive management of water resources in the European Community, within a common approach and with common objectives, principles and basic measures.

Some references are provided below with respect to development of groundwater abstraction schemes relating to the Planning and Development Act and Regulations (2000 & 2001 respectively).

Drilling of wells for the purpose of water supplies is covered in Part 8 of the Planning and Development Regulations (2001), which deals with requirements in respect to development on behalf of Local Authorities. The exact wording from the Regulations are detailed below:
Part 8 Clause 80 (1)

Subject to sub-article (2) and sub-section (6) of section 179 of the Act, the following classes of development, hereafter in the Part referred to as "proposed development" are hereby prescribed for the purposes of section 179 of the Act –
(f) – 'drilling for water supplies'

Section 179 of the Planning and Development Act 2000 addresses "proposed developments" planned by the Local Authority itself.

Sub-article 2 of the Act details:
- Consultations, notifications and particulars to be submitted to prescribed bodies;
- Documents, particulars, plans or other information to be made available to members of the public; and
- The requirement to make submission of observation to local authority with respect to the proposed development.

Sub-article 6 of the Act indicates proposed developments under which Section 179 will not apply, which includes:
is development in respect of which an environmental impact statement is required under Section 175 or under any other enactment.

Section 176, sub-article 3 indicates the following:
Any reference to an enactment to development of a class specified under Article 24 of the European Communities (Environmental Impact Assessment) Regulations, 1989 (S.I. No. 349 of 1989). SI 349 of 1989 has been subsequently amended by (S.I. No. 93 of 1999, *European Communities (Environmental Impact Assessment) Regulations (Amended, 1999).*

Schedule 5 of the Planning and Development Regulations 2001 lists developments that require preparation of Environmental Impact Assessments.

Paragraph 10(L) of Part 2 of Schedule 5 states that an EIS is required in respect of "*Groundwater abstraction and artificial groundwater recharge schemes not included in Part 1 of this schedule where the average annual volume of water abstracted or recharged exceeds 2 million cubic metres*". An average annual abstraction of 2 million cubic metres equates to 5,476m^3/day.

PHASING OF HYDROGEOLOGICAL INVESTIGATION

The objective of the hydrogeological assessment was to determine the potential of groundwater to significantly, and in a sustainable manner (bearing in mind the requirements of the WFD), contribute to the future water requirements of the East Meath, South Louth and Drogheda catchment area to the year 2023.

The hydrogeological investigations were undertaken in a phased approach, ranging from initial desk studies through to final intrusive investigations and testing, with various intermediary stages.

As part of the Preliminary Engineering Report, a Hydrogeological Assessment Report (Phase 1) was prepared. This report was essentially a desk based review of existing information and an examination of the existing groundwater usage in the East Meath, South Louth and Drogheda Region.

An extensive area of East Meath, South Louth and Drogheda (approximately 153km^2) is underlain by bedrock (Dinantian Pure Bedded Limestone) classified as a regionally important aquifer, with high groundwater potential. To the south of the regionally important clean limestone, i.e. in south County Meath, the bedrock geology is dominated by the Calp Limestone (Dinantian Upper Impure Limestone). This unit is classified as a Locally Important Aquifer, however existing data suggests a higher than average groundwater potential from this unit in south County Meath and north County Dublin.

The Hydrogeological Assessment Report (Phase 1) in the initial Preliminary Engineering Report recommended further investigation of the true groundwater potential of both Dinantian Units.

Meath County Council retained McCarthy Tobin JV to undertake a more detailed Hydrogeological Assessment Report (Phase 2). To maximise the return on the financial investment, a strategic plan and methodology was developed to identify potentially suitable areas for investigation and also to highlight constraints that could potentially preclude long term groundwater abstractions (i.e. sensitive eco-systems). This site suitability assessment was collated and managed within a GIS (Geographic Information System) platform to enable rigorous data management and allow spatial analysis.

The output from the GIS was a set of individual graphic maps, however when this data was overlayed and interrogated as a whole, it allowed determination of physical and man-made constraints which could potentially impede future development of groundwater resources. The GIS platform, using the same datasets, also indicated potentially favourable regions where the groundwater development could positively impact the distribution of water supplies within the region.

The data inputs to GIS were as follows:

- Topographic elevation and regional drainage information;
- Regional soils classification;
- Quaternary (subsoil) geological data;
- Groundwater vulnerability classification;
- Structural and lithological bedrock geological data;
- Aquifer classification and historical hydrogeological well data;
- Hydrogeological records and data;
- Nature conservation designation information;
- Distribution of archaeological sites and potential archaeological sensitive areas;
- Residential/commercial distribution of man-made structures;
- Regional and local commercial and industrial risks;
- Public water supply distribution network (both existing and proposed).

Interrogation of the datasets provided a broad categorisation of the lands. The study focused on eliminating sections of the study area where particular constraints or multiple constraints existed that could preclude or place undue restrictions on groundwater abstraction. For this reason, sensitive terrestrial eco-systems were avoided and areas of contaminant risk. This information is included in the Site Selection Report issued in September 2005.

With the elimination of constrained areas, the next phase of the site selection process was to delineate suitable Candidate Areas. The candidate areas were largely determined from the available geological and hydrogeological information, where specific information was available to prove or suggest high groundwater potential. The potential for linking to existing major supply infrastructure was also prioritised. The Candidate Areas, comprising of landbanks varying in area from 42 to 214 hectares, were widely distributed throughout the study area. The wide distribution was considered warranted to allow a strategic location of abstraction points to suit the needs of the overall augmentation programme.

Following delineation and agreement of the candidate areas, visual assessments were undertaken. The objective of the visual assessments was to identify potentially suitable areas to allow accessibility for site investigation plant and equipment and requiring minimal site preparatory works. The secondary purpose of the visual assessments was to identify any local hazards, including farm storage facilities and small commercial enterprises, to refine the available data from the desk study.

The outcome of the visual assessments was to allow profiling and refinement of the candidate areas. The candidate areas were reassessed following the visual assessment, with a specific ranking (generally from 1 to 10) assigned to particular sites within the candidate areas, based on the most preferential areas for intrusive investigations in decreasing order. The ranking of the candidate areas was provided to the Meath County Council, showing the preferable areas for site investigation. Meath County Council undertook to seek landowner agreements to permit investigations within their landholding.

Upon securing landowner agreements, the focus of the hydrogeological assessment (Phase 2) turned to the exploratory phase. The initial stage of the exploration phase comprised remote sensing of 31 No. nominated sites, using geophysical (2-D resistivity) surveying techniques. The geophysical surveys were conducted by Minerex Geophysics Ltd. in May/June 2005.

The objective of the geophysical surveys were as follows:

- Determine the vertical stratification of the geological units, including subsoil and bedrock media;
- Identify geophysical anomalies which are characteristic of highly permeable, water bearing features;
- Highlight preferential drill targets, where possible, within individual field boundaries;
- Rank sites based on interpreted data for favourable ground conditions; and

A secondary advantage of the geophysics survey was to provide some details of envisaged ground conditions to drilling contractors for subsequent intrusive drilling works.

Based on the surveys undertaken, resistivity values of the geological materials to a penetration depth of approximately 30m were recorded. Minerex Geophysics interpreted the surveyed resistivity values as compared with known resistivities for various geological media and typical physical parameters for subsurface features. Interpreted geological cross sections (pseudo-sections) of ground conditions were constructed for each of the surveys, which delineated the lateral and vertical extent of geological material.

The results of the geophysical survey lead to the characterisation of the 31 No. surveyed sites into 4 No. broad categories, based on ground conditions and potential for encountering water bearing strata in the upper 30m.

The categorisation of the nominated drill sites was very useful in determining the thickness of overburden material. However, owing to the limited depth penetration, this information was not used exclusively for determining potential borehole locations as fissure and fracture zones have been recorded to a depth of 100m below ground level in the study area.

The final stage of the Hydrogeological Assessment Report (Phase 2) involved the drilling and hydraulic testing of boreholes within the study area. In total, 42 No. trial boreholes and 1 No. production borehole were drilled throughout the study area as part of this project.

The drilling works were awarded in two separate contracts. Contract No. 1 was awarded to Dunnes Drilling Services Ltd. for 13 No. trial boreholes and 1 No. production borehole. Contract No. 2 was awarded to Tom Briody and Son Ltd. for 29 No. trial boreholes.

SUMMARY OF FINDINGS FROM HYDROGEOLOGICAL INVESTIGATIONS

The following provides an overview of the findings of the intrusive hydrogeological investigation undertaken as part of the East Meath, South Louth and Drogheda Water Improvement Scheme. With respect to the Trial Borehole drilling technique, drilling in unconsolidated material was generally progressed using 250mm-300mm diameter rotary, down hole hammer, with air flush. Owing to natural variable geological conditions across the study area, the depth at which bedrock was encountered differed from site to site. Each of the trial boreholes was lined with 250mm and/or 200mm steel lining through the full depth of subsoil material and keyed into rock. The depth to which the lining was installed in each borehole varied depending on the competency of the rock, which could be highly weathered and unstable in the upper horizons. Drilling in bedrock was generally progressed at 200mm diameter. Where possible, each trial borehole was completed at 200mm diameter open hole. In some instances, where highly fractured bedrock occurred and where very high rate of groundwater inflow were encountered, 150mm diameter slotted steel casing was installed to trial holes and drilling progressed further at 150mm diameter.

Following completion of the trial boreholes, the drillers were requested to provide an estimate of the potential yield. This estimate was made by gauging water expelled from the borehole standpipe during development works. The estimation of potential yield was important as a minimum threshold of $250m^3$/day was imposed for advancement to pump testing. The minimum threshold of $250m^3$/day was considered appropriate for the purposes of this project, as development of strategic groundwater sources at yields below $250m^3$/day is not considered cost effective or of significant augmentation potential.

The hydraulic testing programme generally entailed initial testing of individual boreholes for relatively short duration (i.e. over a 24 hour period). During these early stages of the initial tests the abstraction rates were varied to ascertain the impact on water levels (i.e. multiple step tests of 100 minutes duration). Following completion of the step tests pumping continued at an approved constant yield to determine if equilibrium conditions were achieved.

Following completion of the individual pump tests on the trial boreholes, a more extensive testing programme was undertaken. Trial boreholes were grouped into discrete wellfields, comprising of up to 6 No. trial boreholes. Simultaneous pump tests were conducted on trial boreholes within each wellfield, at a constant abstraction rate for 7 days duration (168 hours continuous pumping). The purpose of the simultaneous testing was to examine the cumulative impact of multiple abstractions and reduce the risk of over-estimating the potential the aquifer. In general, equilibrium condition (or very close to equilibrium conditions) were achieved by the end of the 7 day pump tests for each wellfield. Summary data of the hydraulic testing regime are provided in Tables 1- 3, below.

Table 1 Summary findings of Pump Tests from Contract No. 1

Borehole	Test Duration	Abstraction Rate m^3/day	Final Drawdown m	Specific Capacity m^3/day/m	GSI Productivity Class
TW1 C1	Estimated yield below 250m3/day. Not sufficient potential for further development				
TW2 C1	24 hour	1970	17.12	115	Class I
TW3 C1	24 hour	1980	5.1	388	Class I
TW4 C1	24 hour	2045	7.14	286	Class I
TW5 C1	24 hour	1860	15.91	117	Class I
TW6 C1	26 hour	300	28.18	11	Class III
TW7 C1	Estimated yield below 250m3/day. Not sufficient groundwater potential for further development				
TW8 C1	Estimated yield below 250m3/day. Not sufficient groundwater potential for further development				
TW9 C1	Estimated yield below 250m3/day. Not sufficient groundwater potential for further development				
TW10 C1	Estimated yield below 250m3/day. Not sufficient groundwater potential for further development				
TW11 C1	24 hour	1690	29.61	57	Class II
TW12 C1	24 hour	926	33.11	28	Class II
TW13 C1	168 hour	1310	9.75	134	Class I

Table 2 Summary Findings from Pump Tests from Contract 2

Borehole	Test Duration	Abstraction Rate m^3/day	Final Drawdown m	Specific Capacity $m^3/day/m$	GSI Productivity Class
TW1 C2	24 hour	322	41.69	7.71	Class III
TW2 C2	24 hour	1896	9.59	197.7	Class I
TW3 C2	24 hour	1836	20.36	90.18	Class I
TW6 C2	Estimated yield below 250m3/day. Not sufficient groundwater potential for further development				
TW7 C2	Estimated yield below 250m3/day. Not sufficient groundwater potential for further development				
TW8 C2	24 hour	977	7.52	129.9	Class I
TW9 C2	24 hour	938	13.17	71.25	Class II
TW10 C2	24 hour	82	4.71	17.32	Class III
TW11 C2	Estimated yield below 250m3/day. Not sufficient groundwater potential for further development				
TW12 C2	24 hour	986	14.57	67.7	Class II
TW13 C2	Estimated yield below 250m3/day. Not sufficient groundwater potential for further development				
TW15 C2	24 hour	533	24.08	22.13	Class II
TW16 C2	24 hour	650	1.35	481.78	Class I
TW17 C2	Estimated yield below 250m3/day. Not sufficient groundwater potential for further development				
TW18 C2	24 hour	847	22.73	37.27	Class II
TW19 C2	24 hour	271	19.06	14.23	Class III
TW20 C2	24 hour	583	25.82	22.59	Class II
TW21 C2	24 hour	2078	11.34	183.28	Class I
TW22 C2	24 hour	1814	17.59	103.15	Class I
TW23 C2	Estimated yield below 250m3/day. Not sufficient groundwater potential for further development				
TW24 C2	24 hour	312	24.66	12.65	Class III
TW25 C2	Estimated yield below 250m3/day. Not sufficient groundwater potential for further development				
TW26 C2	24 hour	1985	6.25	317.6	Class I
TW27 C2	24 hour	410	48.69	8.43	Class III
TW28 C2	Estimated yield below 250m3/day. Not sufficient groundwater potential for further development				
TW30 C2	72 hour	1381	14.14	97.67	Class I
TW31 C2	72 hour	337	4.46	75.56	Class II
TW32 C2	24 hour	645	0.76	849.5	Class I
TW33 C2	24 hour	595	1.57	379.11	Class I

Table 3 Summary findings from 7-day, multiple borehole tests

	Test Duration (hrs)	Abstraction Rate (m3/day)	Final Drawdown (metres)	Specific Capacity (m3/d/m)	GSI Productivity Class
Scheme 1 - Curragha					
TW 21 C2	168	1903	13.83	137.61	Class I
TW22 C2	168	1420	20.12	70.62	Class II
TW27 C2	168	278.4	22.78	12.22	Class III
Scheme 2 - Rath					
PW1 C1	168	598	41.69	14.34	Class IV
Scheme 3 - Rathfeigh					
TW15 C2	168	470	20.81	22.6	Class II
TW16 C2	168	1512	8.68	174.2	Class I
TW18 C2	168	850	26.2	32.43	Class II
TW19 C2	168	194	17.65	11.01	Class III
TW20 C2	168	365	24.2	15.07	Class III
TW31 C2	72				
Scheme 6 River Nanny					
TW8 C2	168	888	8.07	110	Class I
TW9 C2	168	1205	21.32	56.5	Class II
TW12 C2	168	919	18.5	49.7	Class II
Scheme 7 - Kiltrough					
TW1 C2	168	197	26.18	7.53	Class III
TW2 C2	168	1478	12.86	114.96	Class I
TW3 C2	168	1527	21.5	71.04	Class I
TW4 C1	168	1547	11.07	139.77	Class I
TW5 C1	168	1507	18.27	82.48	Class I
Scheme 8 - Byranstown					
TW2 C1	168	1525	14.22	107.21	Class I
TW3 C1	168	1592	5.48	290.58	Class I
TW6 C1	168	258	25.24	10.23	Class III
Scheme 9 - Ballymakenny					
TW11 (C1)	168	1400	32.76	42.74	Class II
TW12 (C1)	168	600	30.08	19.95	Class II
Scheme 10 - Mosney					
TW24 C2					
TW26 C2					
Scheme 11 - Battle of Boyne					
TW32 C2	168	646	0.84	768.57	Class I
TW33 C2	168	595	1.61	369.69	Class I
Scheme 13 - Staleen					
TW13 C1	168	1313.5	9.75	134	Class I

DISCUSSION OF RESULTS

INDIVIDUAL PUMP TEST (24 HOUR DURATION) OF TRIAL BOREHOLES

- 12 No. boreholes (29 % of boreholes drilled) were found to be below the development threshold of 250m3/day.
- 15 No. boreholes (36%) were rated as Class I Productivity.
- 8 No. boreholes (19%) were rated as Class II Productivity
- 7 No. boreholes (14%) were rated as Class III Productivity.

MULTIPLE PUMP TESTS (168 HOUR DURATION) OF WELLFIELDS

- The productivity rating of the boreholes did not change significantly with extended pumping from multiple abstraction boreholes.
- The hydraulic efficiency of the trial boreholes dropped, however this was expected.
- The hydraulic efficiency fell within the range of 2% to a maximum of 51%.
- The extended wellfield pump tests have proven that good groundwater potential exists for development of discrete and strategically located wellfields

FURTHER PROGRESSION OF PROJECT

A Hydrogeological Assessment Report (Phase 2) is currently being finalised and will be submitted to Meath County Council. Following completion of this report and in association with the detailed hydrological studies undertaken on the River Boyne and the engineering reports on the current sources (and related infrastructure), McCarthy Tobin JV will review the Preliminary Engineering Report. The purpose of the PR Review is to provide details of development strategies on how to augment the public supply into the future. While no finalised options have been agreed, it is likely that the augmentation scheme will involve increased abstraction form the River Boyne, together with development of discrete and strategically located groundwater wellfields.

In the longer term, higher integrity production boreholes will need to be drilled at the location of the approved wellfields. These subsequent production boreholes will require screen and casing to ensure long-term stability of the borehole and increase the protection of the groundwater resource.

Session III

CRYPTOSPORIDIUM RISK ASSESSMENT – SQUARE PEGS & ROUND HOLES

Karen-Lee Ibbotson, White Young Green

ABSTRACT

Cryptosporidium parvum is a protozoan parasite found in humans, many animals, birds and fish. Cryptosporidiosis is a severe diarrhoeal disease caused by ingesting Cryptosporidium oocysts. The main symptoms include nausea, abdominal pain, diarrhoea, fever and weight loss. The disease can be very dangerous to the very young and old and to people who are immunocompromised.

On 1st January 2004, cryptosporidiosis became a notifiable disease and the Environmental Protection Agency (EPA) has subsequently requested all Local Authorities to develop an action plan to manage the risk of Cryptosporidium within their supply systems. The recommended framework for assessing the risk is a modified version of the Scottish Executive Directions. While this methodology has merits for surface water sources, it has significant failings when applied to groundwater sources. The risk of contamination occurring based on the presence of a pathway into the aquifer is not considered, and as a result, aquifers with no real risk can potentially be designated as High Risk. Two case studies will be presented in which the outcome of the risk assessment did not reflect the hydrogeological conditions known to be present in their respective catchment. The consequence of this has implications for Local Authorities trying to assess their public supplies in a meaningful way. The case for using professional judgment to compensate for the shortcomings of the recommended quantitative approach is discussed.

INTRODUCTION

Cryptosporidium parvum is a protozoan parasite found in humans, many animals, birds and fish. The parasite was first discovered in the early 20th century but its significance only became known in the 1970's when its link to a diarrhoeal disease was established. The life cycle of the parasite is completed within a single host. It multiplies in the gastrointestinal tract of the host, which then excretes the oocysts of the parasite in its faeces. These oocysts are incredibly small, 4 – 6 microns in diameter, and are excreted in large numbers. The oocysts are robust and resilient and can survive for long periods in a cool, wet environment.

Cryptosporidiosis is a severe diarrhoeal disease caused by ingesting *Cryptosporidium* oocysts. It is transmitted by the faecal-oral route, which includes person-to-person, animal-to-person, waterborne, food borne and possibly airborne transmission. The disease normally affects immunocompetent patients for up to two weeks following an incubation period of 1 – 12 days. The main symptoms include nausea, abdominal pain, diarrhoea, fever and weight loss. The disease can be very dangerous to the very young and old and to people who are immunocompromised.

Following designation of cryptosporidiosis as a notifiable disease on the 1st January 2004, the Environmental Protection Agency (EPA) requested all Local Authorities to develop an action plan to manage the risk of *Cryptosporidium* within their supply systems.

While a framework for assessing this risk does exist, the methodology is considered flawed when applied to groundwater sources. There is no provision for assessing the hydrogeological vulnerability of the aquifer from which the supply is abstracting which is main influencing factor on whether oocysts, if they are present, will find their way into the aquifer and ultimately into the water distribution network.

WATERBORNE *CRYPTOSPORIDIUM*

Cryptosporidium can be transmitted by water that is contaminated with human or animal faeces. *Cryptosporidium* oocysts from human waste can enter surface or groundwater through wastewater, leaky septic tanks or recreational activities (paddling, swimming etc) while oocysts from animal waste can enter water bodies either directly or through runoff. The water transmission route also has implications for food production as food items can be directly affected if washed and prepared with contaminated water.

There is no internationally recognised threshold level of *Cryptosporidium* contamination of water that indicates human illness will develop. The probability of an outbreak of illness occurring following the detection of *Cryptosporidium* oocysts in a water supply is not known. Therefore the risk to human health from *Cryptosporidium* in water supplies is not fully understood but it is believed to be related to the parasite characteristics, the dose and the immunity of those exposed. The UK *Cryptosporidium* Regulations (DETR 1999) gives an action limit of 1 oocyst per 10 litres of water.

The oocysts are resistant to treatment – standard water treatment tends to involve a pre-treatment phase, coagulation/flocculation/sedimentation, filtration and disinfection. Some oocysts are eliminated at pre-treatment but no major reduction occurs at this stage. Most oocysts are caught by the floc and removed by settlement although if the floc is weak then oocysts may continue to pass through the treatment process. If the filtration system is operating efficiently then the majority of oocysts will be removed, although ineffective removal of backwash water can lead to oocysts passing into the distribution system. Oocysts are resistant to chlorination but ozone and ultraviolet treatment at some wavelengths is effective at oocyst removal.

Where treatment can not be relied upon to remove the risk of contamination, then consideration must be given to assessing the likelihood of *Cryptosporidium* oocysts getting into a water supply in the first instance.

OUTBREAKS OF *CRYPTOSPORIDIUM* LINKED TO WATER SUPPLIES

The first recorded outbreak of cryptosporidiosis in humans associated with a water supply occurred in Texas in July 1984 and this has been followed by numerous other cases. An unquantifiable number of these cases occur throughout the developing world. Cases have been recorded that have been linked to both surface water and groundwater used for consumption. It is reported that 250 – 500 million infections occur each year in Asia, Africa and Latin America alone (Hanly 2003).

INTERNATIONAL

The first recorded outbreak of cryptosporidiosis in humans (Texas 1984) associated with groundwater occurred when a well supplying the area with drinking water was contaminated by sewage. The groundwater was chlorinated but not filtered. Although no oocysts were recorded in the chlorinated water, contamination by sewage was indicated when faecal coliforms were detected. Studies indicated a strong link between drinking tap water and occurrence of diarrhea, with a higher attack rate associated with a high intake of tap water (D'Antonio et al, 1985 in NDSC 2004).

To date the UK has recorded multiple outbreaks associated with both surface water, groundwater and recreational settings. The first outbreak was recorded in Ayrshire in 1988 when runoff from agricultural land entered a public water supply holding tank through a broken pipe. Oocysts were found in the filter backwash, in the sludge and in the mains supply in concentrations ranging from 0.13 – 1000 per litre.

In all these incidents it is highly likely that the actual number of cases of illness exceeds the numbers reported and investigated.

NATIONAL

Several small outbreaks have been reported in Ireland prior to 2002, however, the first case of cryptosporidiosis associated with a public water supply occurred in Co. Westmeath in April 2002. The water supply for Mullingar town and central Westmeath is sourced from Lough Owel, to the north of the town. Westmeath County Council (WCC) appointed a firm of hydrogeological consultants (O'Callaghan Moran and Associates (OCM)) to assess the significance of the groundwater pathway for the entry of the parasite into the lake. The information in this section is sourced from OCM's findings.

Lough Owel covers around 3000 acres and has a catchment of some 24.5km^2. The local surface water drainage network is poor and areas of bogland exist within the catchment. The potential sources of *Cryptosporidium* within the catchment were identified as farmyards, slurry/dung stores, grazing land, landspreading of animal and wastewater treatment plant slurries and domestic wastewater treatment systems. All dwellings within the catchment are serviced by on-site treatment systems due to a lack of municipal sewage system. The lake is underlain by Carboniferous bedrock, namely the Lucan Formation and the Derravaragh Cherts. Published geological information does not indicate any significant faulting in the area of the lake. Glacial tills overlie the bedrock. Gravels are considered to extend under the lake in the south-western area. The low drainage density in the catchment was interpreted as indicating a high portion of rainfall is recharging the aquifer. The lake is spring-fed through karst features in the underlying limestone bedrock. Treatment of the water source included chlorination but not filtration. Groundwater was identified as a potential pathway for the entry of *Cryptosporidium* into the lake. In addition, overland flow from farm yards was also considered to be a source of the contamination.

In recent weeks, an outbreak of cryptosporidiosis in Galway has been linked with the public water supply. To date, over 100 cases of illness have been confirmed with additional information emerging daily.

LEGISLATION AND REGULATIONS - *CRYPTOSPORIDIUM* IN WATER SUPPLIES

The Department of the Environment and Local Government (1998) requested every Local Authority to review their action plans and training programmes to cover potential risks associated with *Cryptosporidium* (Circular Letter L7/98, 3rd July 1998). This document states that routine sampling for *Cryptosporidium* is not feasible and that actions plans should be formulated to account for source specific risks. Where a risk of *Cryptosporidium* infection is identified it is recommended that the Local Authority samples for the presence of *Clostridium perfringens*, an anaerobic spore forming bacterium that is an indicator organism for *Cryptosporidium.* If *Clostridium perfringens* is detected it is recommended a sufficient risk exists to merit sampling directly for the presence of *Cryptosporidium.*

The revised EU Drinking Water Directive (98/83/EC) came into effect in Irish Law through Statutory Instrument No. 439 of 2000 (effective from 1st January 2004). This revised directive does not specifically include for *Cryptosporidium* sampling but does include *Clostridium perfringens.* The directive indicates the parametric value of *Clostridium perfringens* shall be less than 0 counts per 100ml for water fit for human consumption. In the event of a non-compliance with this limit the supply should be investigated to ensure that there is no potential danger to human health arising from the presence of pathogenic micro-organisms such as *Cryptosporidium.* There is an established relationship between elevated turbidity levels and the presence of *Cryptosporidium.* The revised EU Directive therefore lists turbidity as an indicator parameter.

RISK ASSESSMENT METHODOLOGY

A Risk Assessment is simply a formal procedure based on a detailed assessment of all the factors that contribute to the potential risk associated with a particular event. The main function of a Risk Assessment is to identify and prioritise measures for reducing the risk.

The increased awareness in recent years of the risk posed by *Cryptosporidium* has lead to the development of a number of Risk Assessment Models. A European Commission Research Project (2000 – 2003) on "A risk assessment of *Cryptosporidium parvum,* an emerging pathogen in the food and water chain in Europe", developed a quantitative risk assessment (EU Commission Report, 2003, QLK1 1999 007750). The UK Drinking Water Inspectorate (DWI) issued a document entitled "Guidance on Assessing Risk for *Cryptosporidium* oocysts in Treated Water Supplies to satisfy The Water Supply (Water Quality) (Amendment) Regulations 1999, SI 1524" for England and Wales. This is a qualitative model that does not include a scoring system to quantify the risk and is not considered suitable for the Irish context (EPA 2004).

The Scottish Executive (2000) published a methodology for carrying out *Cryptosporidium* Risk Assessment and the EPA in Ireland has modified this model for the Irish context. The methodology sets out a quantitative scoring system for each of the factors that contribute to the risk. The output of the risk assessment model is an indication of whether the source is at Very High, High, Medium or Low risk. The Directions were reviewed in 2003 and are entitled "The *Cryptosporidium* (Scottish Water) Directions 2003". The EPA Office of Environmental Enforcement document "EU (Drinking Water) Regulations, 2000 (SI. No. 439 of 2000) Handbook on Implementation for Sanitary Authorities" recommends that this is the preferred methodology for implementation in Ireland.

This thinking is based on a preference for adopting a quantitative approach rather than relying simply on professional judgment. While this approach has its merits, in practice the methodology has severe shortcomings when applied to groundwater sources in particular. The pathway by which oocysts may enter surface water are much clearer and easier to assess than those pathways that render groundwater sources at risk, and oocysts are much more likely to be present in large numbers in surface water rather than groundwater. The existing methodology fails because it does not provide for any assessment of the ease at which oocysts may impact on an aquifer i.e. the aquifer vulnerability. While catchment factors, such as land use activities, are taken into account, it can be demonstrated that the real risk to a source is hugely influenced if the aquifer vulnerability is considered. This methodology places much emphasis on the likelihood that treatment will remove any *Cryptosporidium* oocysts present in the water supply – not on the likelihood of oocysts being present in the first instance. For example, the presence of turbidity meters significantly lowers the risk even without proper treatment to actually remove *Cryptosporidium*, if it was present.

The following (Table No. 1) provides a summary overview of the risk assessment and the steps involved in obtaining a risk assessment score for a water supply.

Table No. 1 Overview of Risk Assessment Methodology (for Groundwater)

THE CATCHMENT RISK SCORE		
Item	**Risk Factor**	**Score Range**
Animals within catchment	Cattle/calves, sheep/lamb, deer, pigs per hectare of forage area, animals with direct access to watercourses, high no. of birds	Min score = 5 Max score = 35
Agricultural practices within catchment	Slurry/dung storage/spraying, sheep pens or cattle briars, lambing in catchment	Min score = 0 Max score = 26
Discharges to catchment/water source	Population served by septic tanks, sewage mains, storm sewer overflows, livestock marts	Min score = 14 Max score = 23
Geology/Hydrogeology	Sand and gravel aquifer with free or impeded drainage, sandstone and conglomerate aquifer with free or impeded draining soils, limestone aquifer, igneous or metamorphic aquifer	Min score = 4 Max score = 12
Rapid By-Pass of unsaturated zone	Speed of transmission from surface water to groundwater	Min score = -20 Max score = 20
Induced recharge from surface water bodies	Proportion, if any, of groundwater derived from induced recharge from SW, infiltration into spring pipework system	Min score = -20 Max score = 20
Groundwater Site Drainage	Site drainage conditions, slope of ground surface towards or away from well head, well head above or below ground level, in secure chamber or not,	Min score = -4 Max score = 24
Borehole Construction and Integrity	Condition of casing integrity	Min score = -8 Max score = 12
Catchment Risk Score = sum of above score		**Min score = -29** **Max score = 172**
THE GROUNDWATER TREATMENT AND SUPPLY RISK SCORE		
Treatment work performance and monitoring	Presence of turbidity meters at each abstraction point or not, changes in turbidity detected or not, automatic shutdown if increase in turbidity detected	Min score = -9 Max score = 16
Treatment works operation	Use of process control manuals and action plans, record of actions, audit trails, use of variable speed drive, works run above design capacity	Min score = -6 Max score = 13
Groundwater Treatment and Supply Risk Score = sum of above score		**Min score = -15** **Max score = 29**
FINAL WEIGHTED GROUNDWATER RISK ASSESSMENT SCORE		
Final Groundwater Risk Score = Catchment Risk Score + GW Treatment and Supply Risk Score		Min score = -44 Max score = 201
Final Groundwater Risk Score must be weighted for accordingly to the population served by the supply – Weighting Factor = 0.4 x $\log_{10}$ (population served by the supply).		
Final Weighted Groundwater Risk Score = **GW Risk Assessment Score x Pop. Weighting factor**		

WATER SUPPLY RISK CLASSIFICATION	
Water Supply Risk Classification	**Final Risk Assessment Score**
Very High Risk	>100
High Risk	76 – 100
Moderate Risk	50 – 75
Low Risk	<50

RISK ASSESSMENT APPLIED TO TWO IRISH PUBLIC SUPPLIES SOURCED FROM GROUNDWATER

The two case studies discussed in this paper are the Roscommon Town Public Supply[1] sourced from Ballinagard Spring and the proposed Dunshaughlin Well Field[2] in Co. Meath. Roscommon County Council engaged consultants for the Four Roscommon Regional Water Supply Schemes. One aspect of this project was to undertaken a risk assessment of the Roscommon town public supply source (Ballinagard Spring) following contamination by *Cryptosporidium* in 2005. Meath County Council engaged consultants to complete a risk assessment as part of the detailed design stage for the proposed Dunshaughlin Well Field in 2006.

Ballinagard Spring is located approximately 2.4km south of Roscommon Town in a relatively low lying and marshy area. The River Hind, into which the spring discharges, flows some 75m to the south of the spring.

The general topography in the Dunshaughlin area is low lying and flat. The general elevations of the wells are around 100m AOD Malin Head. PW1 and PW7 are located within the urban area of Dunshaughlin village and the remaining wells are located on the outskirts of the village in rural land. The main land uses outside the village are agricultural and residential.

OUTCOME OF RISK ASSESSMENT FOR BOTH BALLINAGARD SPRING AND DUNSHAUGHLIN WELL FIELD (SQUARE PEGS AND ROUND HOLES!)

The risk assessment for the Dunshaughlin Well Field was undertaken for two scenarios – optimum treatment and minimum treatment – as the treatment plant had not been commissioned at the time of the study. The final risk assessment score for the optimum treatment scenario resulted in the HIGH RISK category. The final risk assessment score for the minimum treatment scenario resulted in the VERY HIGH RISK category. The risk assessment result for the Roscommon Town supply was VERY HIGH.

COMMON SENSE APPROACH (AVOID SQUARE PEGS AND ROUND HOLES!)

When professional judgment or ‘hydrogeological common sense’ is applied to these two public supplies the following observations can be made:

The HIGH risk score for Ballinagard Spring is considered valid for a number of reasons:

- Source is a spring into which agricultural runoff can enter through overland flow
- A swallow hole at Fuerty into which agricultural runoff discharges is hydraulically connected to Ballinagard Spring
- A turlough in townland of Stonepark has a pipe discharging into it directly from a farm yard
- Throughout the catchment, livestock have unrestricted access to watercourses that discharge into swallow holes and to springs themselves
- No known restriction on landspreading of organic wastes immediately adjacent to watercourses or various karst features (turloughs, springs, swallow holes etc)
- Large number of farms within catchment, with variable practices
- High density of septic tanks and soak pits within catchment
- A *Cryptosporidium* outbreak has occurred in this water source
- In summary, a valid pathway exists for *Cryptosporidium* to enter this public supply source. In fact, the spring nature of the source means it is considered as surface water for the

[1] Jennings O’Donovan (Lead Consultant) and JB Barry Consulting Engineers are the engineers involved in this project. WYG provide hydrogeological consultancy services.

[2] PH McCarty Consulting Engineers are Project Managers and Consulting Engineers for the Dunshaughlin Water Supply Scheme, with WYG providing hydrogeological consultancy services.

purposes of the risk assessment, indicating an inherently higher risk. In addition to the pathway, potential sources of *Cryptosporidium* are present within the catchment

Table No. 2 – Summary Catchment Characteristics

	Roscommon Town Supply - Ballinagard Spring	**Dunshaughlin Well Field**
Land Use	Agricultural, grazing, forestry	Agricultural, residential
Population served	4,165	22,000 (projected)
Details	Spring source	Well Field – 7 Production Wells (PW1 – PW7)
Yield	3,272 m^3/d	7,600 m^3/d
Quaternary Geology	Thin clay layer overlying peat overlying gravel	Clay with some gravel
Bedrock Geology	Undiff. Visean Limestones Upper 30m dolomitised = increased permeability	Loughshinny Formation Major southwest northeast fault in area of well field
Hydraulic Continuity	Rapid throughflow of GW between gravels and fractured limestones	Low permeability overburden restricting downward movement
Aquifer Classification	Regionally Important Karstified Aquifer (Rk)	Locally Important Aquifer that is generally moderately productive (Lm)
Vulnerability	Extreme in region of karst features, High to Moderate rating elsewhere	Majority of well field catchment High, but some areas of Extreme to Low
Karst	Direct connection with swallow hole in Fuerty and various other swallow holes and turloughs	None
GW Flow	Solutionally enlarged bedding plane partings, joint, fractures, fissures and conduits. GW flow velocity 25m/hr	Predominately fissure flow, with fault zone acting as major pathway
Transmissivity	60 – 180m^2/d	Huge variations associated with fault zone
Hydrochemical analysis	During outbreak, counts of *Cryptosporidium* between 0.01 - 1.3 per 10 litres	High turbidity seasonally but no visual deterioration in water quality in the existing production wells following heavy rainfall. No history of *Clostridium perfringens*
Risk Assessment Score	VERY HIGH	VERY HIGH TO HIGH

The HIGH to VERY HIGH risk score for the Dunshaughlin Well Field is considered invalid for the following reasons:

- PW1 – PW7 are deep boreholes abstracting groundwater predominantly from fissures and fractures at depth within the aquifer profile
- PW1 – PW7 designed and constructed with source protection in mind; casing grouted into competent bedrock to prevent ingress of contaminated surface runoff and well head protection incorporated into design
- Majority of catchment underlain by low permeability overburden in excess of 3m thick. One borehole (PW6) recorded thinner soil.
- Land use restrictions around production wells to be put in place (cordon sanitaire)
- No history of *Clostridium perfringens* within wells based on 28 sampling rounds between January 2004 – May 2006
- Absence of karst features or exposed bedrock within catchment
- No major problems of faecal contamination within groundwater in the catchment
- No history of elevated turbidity or suspended solids in existing public supply following heavy rainfall
- Low intensity agriculture in catchment with good standard of agricultural practices
- In summary, a significant pathway does not exist in the case of this public supply. In addition, land use practices within the catchment indicate the risk of *Cryptosporidium* being present is not considerable.

CONCLUSIONS

While it is reasonable to favour a quantitative approach over professional judgment, the existing quantitative method is fundamentally flawed because it does not provide for any assessment of the ease at which *Cryptosporidium* oocysts get into a groundwater supply.

When professional judgment is applied to both sources, it is clear that the spring at Ballinagard is at much higher risk of *Cryptosporidium* contamination than the Dunshaughlin Well Field. A question must therefore be asked: *how can the risk assessment model classify these two public supplies with the same risk score when common sense indicates otherwise?*

The hazard-pathway-target approach to risk assessment is a fundamental concept. Risk is defined as the likelihood or expected frequency of a specified adverse consequence. In this context it is dealing with the likelihood of a specific water source becoming contaminated by *Cryptosporidium.*

The risk of contamination of groundwater depends on 3 things:

- the hazard afforded by a potentially polluting activity
- the pathway via which this hazard may impact on the groundwater
- the potential consequences of a contamination event

The existing risk assessment methodology sufficiently explores the hazard. The ultimate consequence is a contamination incident involving an outbreak of cryptosporidiosis within the supply network. Where a hazard, and therefore a risk, is known to exist, the actual vulnerability of the water source to contamination (i.e. *Cryptosporidium*) will determine how likely a contamination event is. The Scottish Model, as adapted by the EPA for the Irish context, fails to take account of some very important factors in determining the real risk to a water supply. These include:

- the hydrogeological vulnerability of the aquifer
- the attenuation capacity within the aquifer
- existing chemical analysis of the source
- specifics of the treatment process

In the absence of a more robust methodology, the assessment of the risk of *Cryptosporidium* contaminating our public water supplies will become much more meaningful and legitimate if professional judgment is used to compensate for the shortcomings of the recommended risk assessment methodology.

RECOMMENDATIONS

Treatment to remove *Cryptosporidium* is very costly. Therefore if design engineers and Local Authorities are to decide on installing *Cryptosporidium* treatment for new public supplies sourced from groundwater in the future, there must be a robust method with which the likelihood of *Cryptosporidium* being present can be established.

Consideration should be given to implementing a phased approach for *Cryptosporidium* risk assessments:

- a primary assessment phase considering the geological and hydrogeological facts to establish if a pathway exists. Review of all catchment characteristics, historical sampling data for *Clostridium perfringens* and turbidity especially. This stage will establish the risk of *Cryptosporidium* entering the aquifer and passing through it.
- a secondary assessment phase to be implemented if the primary assessment deems it necessary. This secondary phase would be based on the recommended modified Scottish Executive risk assessment methodology. This stage will establish the risk of *Cryptosporidium* entering and passing through the treatment operation and distribution network.

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MICROBIAL CONTAMINATION OF AQUIFERS IN IRELAND: IDENTIFICATION OF VULNERABILITY FACTORS AND DEVELOPMENT OF DETECTION PROTOCOLS FOR KEY PATHOGENS

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1.0 INTRODUCTION

Of the 200,000 private drinking water supplies currently estimated in Ireland, 36% (EPA, 2006) are frequently contaminated with faecal microorganisms from human and animal sources. The rapid infiltration of microbial contaminants through thin, free draining overlying soils and karst/fractured bedrock (50% of Ireland) into aquifers is a major contributing factor to groundwater contamination. This infiltration is further amplified following heavy rainfall, thus highlighting aquifer vulnerability.

This study investigated the dynamics of microbial contamination of karst aquifer systems in response to rainfall. A groundwater susceptibility matrix was developed and applied to identify and rank the vulnerability of aquifers to microbial contaminants while also incorporating pressure magnitudes and pathway characteristics. From this matrix, two extremely vulnerable karst aquifers were sampled over a 24 month period. The occurrence and breakthrough of faecal bacteria in these supplies were monitored in untreated water on an hourly basis following significant rainfall events and periodically during seasonal cycles, when land spreading of manure, livestock grazing, etc. occurred on surrounding lands. In addition, a protocol was designed for nucleic acids-based detection of key viral, bacterial and protozoan pathogens. Two-phase tangential flow filtration was applied to water samples from these supplies to concentrate bacterial cells, *Cryptosporidium* oocysts and virus particles. Concentrates were subjected to three phases of analysis: (a) cell counts; (b) Colilert®-18 growth-based tests for detection of total coliforms and *E. coli*; and (c) extraction of total bacterial and viral nucleic acids coupled to PCR-based assays. The occurrence of pathogens was correlated with rainfall events at the sites tested.

Following intense rainfall events, a rapid breakthrough of faecal microbes occurred at the sites tested. These characteristic breakthrough curves were observed for each supply over an 18-24 h period following rainfall.

2.0 GROUNDWATER PROTECTION IN IRELAND

Agricultural, industrial and other human activities are posing increasing risks to Irish groundwater quality with runoff from these activities travelling through soils to the groundwater beneath. This poses significant risk to human health as drinking water derived from groundwater is generally not routinely treated prior to supply (Wright, 2000). To begin to address this issue, groundwater protection schemes are being established on in Ireland on a county basis (Fig. 1b). These schemes are based on vulnerability or the ease of a contaminant moving through the unsaturated zone to groundwater and define source protection zones, with restricted access for animals etc.

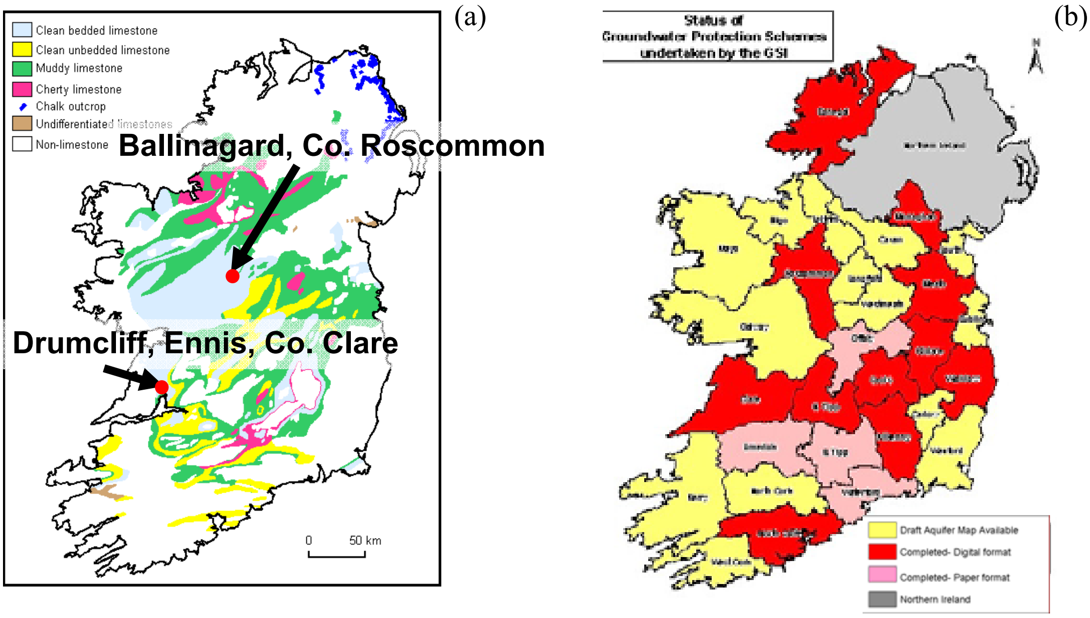


Figure 1.

(a) Geographical Map of Karst in Irleand with detailed study sites highlighted. Ireland is approx. 50% Karst. (Daly *et al*., 2005).

(b) The Status of Groundwater Protection Schemes in Ireland (GSI, 2003). Yellow areas denote those counties where Draft Aquifer Maps are available, Red: completed Digital format maps, Pink: completed paper format maps and Grey: Northern Irealnd.

3.0 MATERIALS & METHODS

3.1 SITE SELECTION & MATIX DEVELOPMENT:

All geological and hydrogeological factors influencing groundwater sources were identified and an aquifer vulnerability matrix was developed (Table 1).

Table 1 The Susceptibility Matrix

Pathway susceptibility	**Ranking**
Rkc: Karst **with** point recharge	1 (VE)
Rkd: Karst **with no** point recharge **(<1m)**	2a (E)
Rkd: Karst with no point recharge **(1-3m)**	2b
Rf & Lm: Fissured aquifer **(<1m)**	2c
Ll, Pl & Pu: Low flow fissured **(<1m)**	2d
Karst with **no swallowholes (3-5m)**	3a (H)
Rf & Lm: Fissured aquifers **(1-3m)**	3b
Ll, Pl & Pu: Low flow fissured **(1-3m)**	3c
Lg & Rg: Sand/ gravel aquifers **(<1m)**	3d
Lg & Rg: Sand/ gravel **(1-3m)**	4a (M)
Rf & Lm: Fissured aquifers **(3-5m)**	4b
Ll, Pl & Pu: Low flow fissured **(3-5m)**	4c
Remaining areas	5 (L)

This incorporates all geological and hydrogeological factors influencing a water supply and ranks them from 1-5 based on their vulnerability (1 being extremely vulnerable, 5 being the least vulnerable). VE: Very Extreme, E: Extreme, H: High, M: Moderate & L: Low vulnerability.

3.2 CELL COUNTS

Epifluorescent microscopy using Sybr-Gold^{TM} nucleic acid stain was performed to obtain total micorbial counts for each water sample.

3.3 HOURLY & SEASONAL MONITORING:

Two extremely vulnerable karst aquifers (VE (Drumcliff) & E (Ballinagard), Table 1) (Fig. 1a) were sampled during a 24 month trial. The occurrence and breakthrough of faecal bacteria in these supplies were monitored in untreated water as follows:

(a) an hourly basis following rainfall events using Sigma 900MAX Autosampler, Fig. 2b)
and
(b) periodically during seasonal cycles when land spreading of manure, livestock grazing, etc. occurred on surrounding lands.

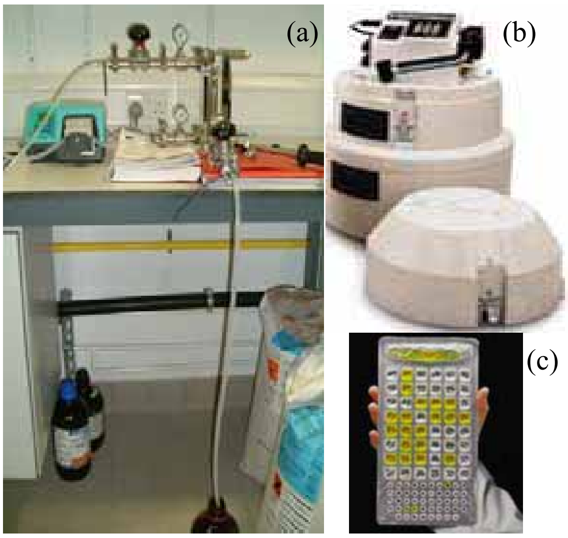


Fig. 2. (a) Tangential Flow Filtration Unit (b) Sigma 900MAX Autosampler
(c) IDEXX Quanti-Tray®/2000

3.4 SAMPLE PREPARATION:

5-10 litre groundwater samples (Seasonal Monitoring) & (24 x 1) litre groundwater samples (Hourly Monitoring) were filtered using a tangential flow filtration unit (Sartorius) (Fig. 2a). Two phases of filtration concentrate (a) bacterial cells & *Cryptosporidium* oocysts using a 0.22 µm filter cartridge (Sartorius) and (b) virus particles using a 100 kDa filter (Sartorius).

3.5 CULTURE-BASED DETECTION OF TOTAL COLIFORMS & *E.coli:*

Coliforms and *E. coli* were detected in raw water samples using the Colilert®-18 Quanti-Tray®/2000 system (APHA, 1998) (Fig. 2c). Duplicate 100 ml samples of unfiltered groundwater were processed, according to the standard protocol, and results were read using most probable number (MPN) tables.

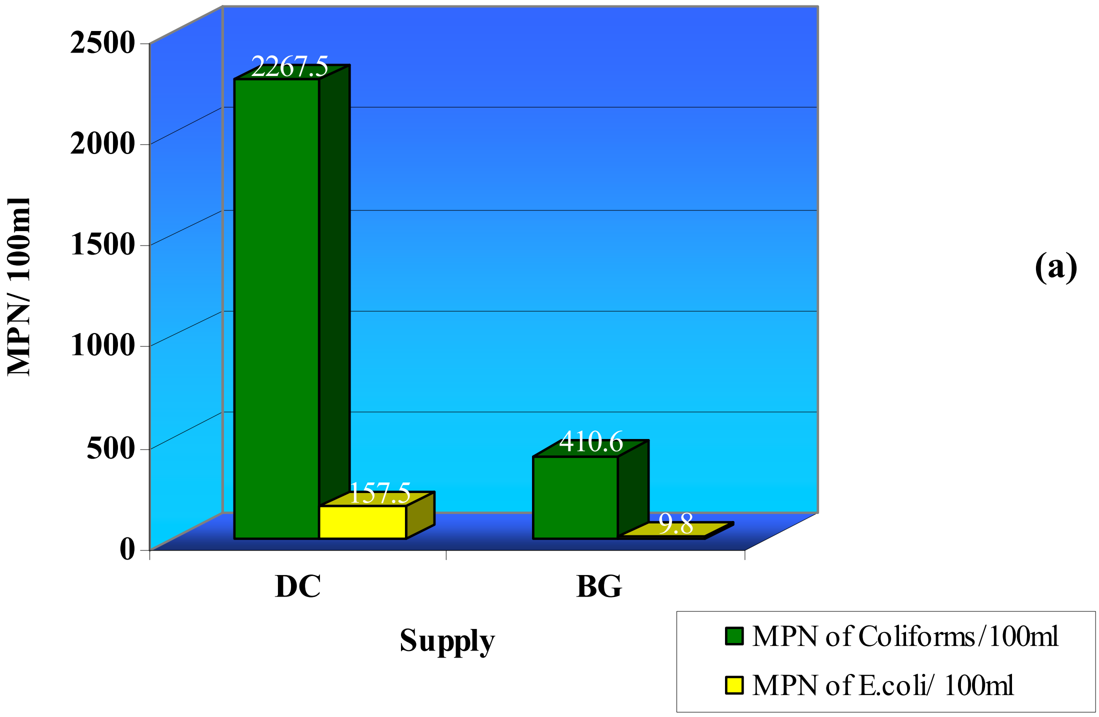
4.0 RESULTS

4.1 CELL COUNTS & TOTAL MICROBIAL OCCURRENCE

Average total microbial occurrence in supplies varied from 8.9×10^4 per 2ml sample in Drumcliff to 6.6×10^3 per 2ml sample in Ballinagar, which highlights the differences in vulnerability rating between the two supplies (Table 1) and reinforces the vulnerability rating methodology. Drumcliff is classified as VE and Ballinagar as E

4.2 SEASONAL MONITORING

During Spring/ Summer season (Fig. 3a), Coliform & *E. coli* occurrences in both supplies were higher than during the Autumn/ Winter season (Fig. 3b)



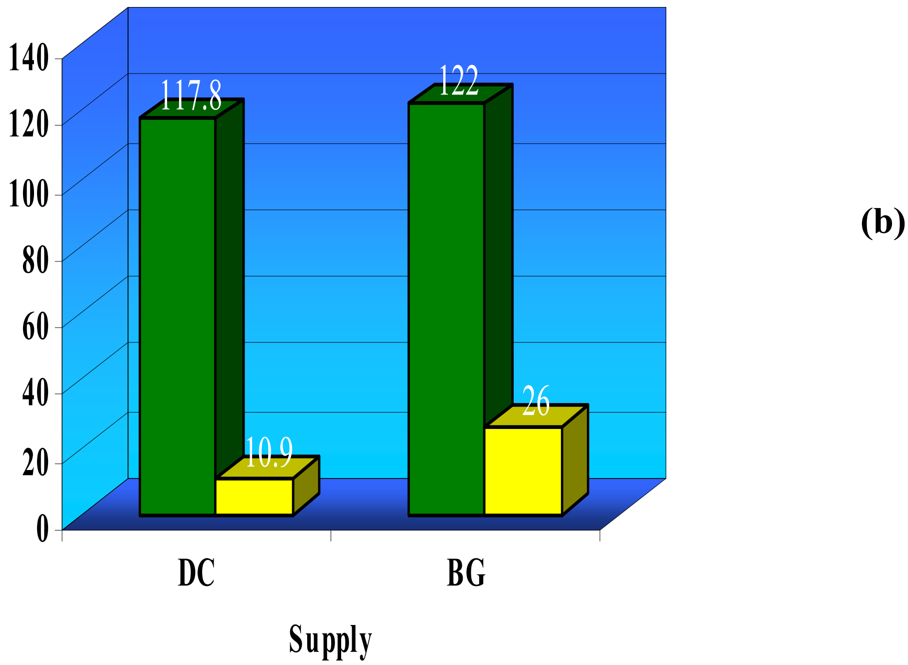


Fig. 3. Coliform & *E. coli* (MPN/ 100ml) in Drumcliff (DC) & Ballinagard (BG) Springs 2005-2006 (a) Spring/ Summer season (b) Autumn/ Winter season.

4.3 HOURLY MONITORING

Following intense rainfall events, a rapid & corresponding breakthrough of faecal microbes occurred (Fig. 4). These characteristic breakthrough curves were observed for each supply over an 18-24 h period following rainfall.

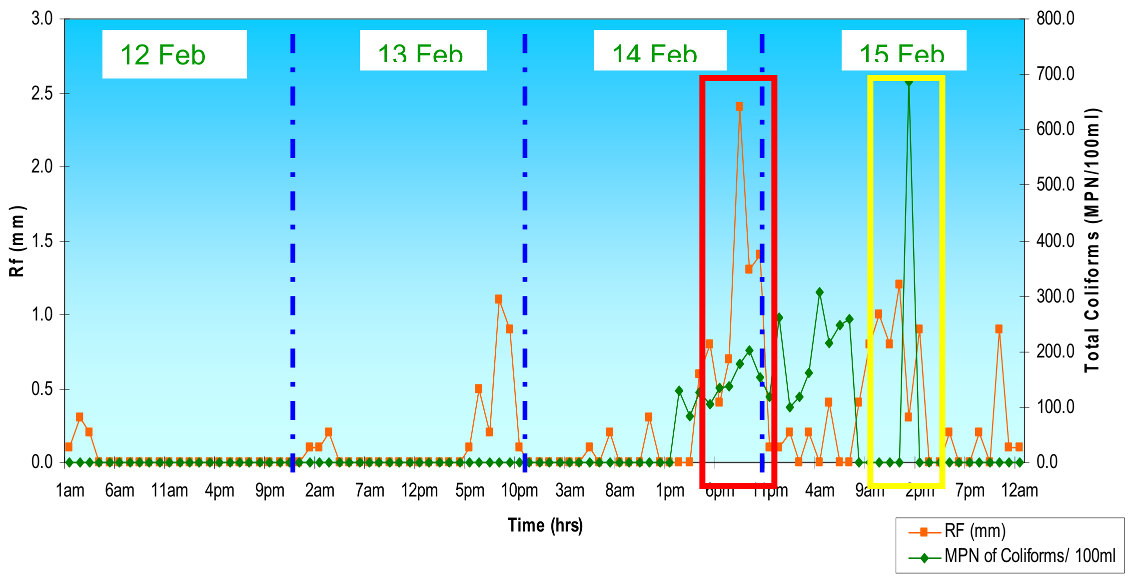


Fig. 4. Total Coliform & Rainfall Results from Drumcliff Spring 12-15th February 2006. Heavy rainfall (red box) leads to corresponding rapid spike in Total Coliforms (yellow box).

5.0 CONCLUSIONS

In Ireland, the difficulty involved in tracing groundwater flow means there is a lack of awareness of the risks of microbial groundwater contamination. A key factor in this management approach is an understanding of the nature and extent of microbial contamination of groundwater, and the relationship between contamination and climatic and seasonal factors, particularly in response to heavy rainfall events. As shown above, the microbial contamination of karst aquifers is a dynamic process driven by rainfall and pathogen loading. The rapid breakthrough and occurrence of these pathogens in extremely vulnerable supplies i.e. karst aquifers etc, could lead to potential risks human health. Therefore improved monitoring and treatment approaches are required for the protection of public health.

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QUANTITATIVE RISK ASSESSMENT: THE IMPORTANCE OF KNOWING YOUR SITE

Rob Glavin, RPS

ABSTRACT

Quantitative Risk Assessment (QRA) can be used to determine whether remediation is required, and if so, its extent and nature. Whilst there are a number of risk assessment tools available, regardless of the modelling software it is all too easy to simply enter values without fully considering the "conceptual model". The conceptual model is arguably the most important part of any risk assessment. It may not be possible to exactly replicate the site conditions within the model; but a robust conceptual model will should provide an understanding of the model limitations.

Case studies are used to illustrate the importance of the conceptual model. In both of the examples the site investigation data was used to characterise the groundwater environment and fully define the conceptual model. This understanding enabled the QRA process to be properly designed, the appropriate receptors to be identified and the most cost effective remedial solution determined. Whilst neither scenario could be completely replicated by the modelling software, adjustments were made to compensate for the model limitations.

In the first example a series of sandy lenses were identified beneath the site, with groundwater flow resulting form rainfall filling the uppermost lenses causing them to "spill" into the lower lenses. The clay appeared to be restricting infiltration directly into the deeper lenses. This effect was replicated in the QRA model by reducing the groundwater gradient and, as a result, increasing the travel time. In the second example, a dip in the underlying low permeability Boulder Clay Formation appeared to be restricting the lateral migration of contamination; as a result vertical migration was considered to represent a greater risk to controlled waters.

In both case studies, understanding the groundwater environment enabled substantial remediation cost savings to be made. Clear communication, supported by a robust conceptual model and fully justified input parameters enabled regulator understanding and agreement.

In many instances the delay in gaining regulatory agreement can significantly impact upon a project. However, by engaging the regulators and demonstrating a clear understanding of the environment, the degree of contamination, the likely impacts and most effective solution, speedy resolution can be achieved. Above all, the QRA must be defensible and the input parameters be fully justified. Without an appropriate conceptual model this justification will be incomplete and the QRA inadequate.

INTRODUCTION

Quantitative Risk Assessment (QRA) can be used to determine whether the degree and nature of contamination present at a site require remediation, and if so, the extent and likely cost of any works. There are a number of risk assessment tools available, both for the assessment of Human Health and Groundwater. However, regardless of the modelling software, it is all too easy to simply enter values without fully considering the site setting, the impacts of the underlying geology, the nature of any contamination or the proposed development. In CLR11 [1] this is defined as the "conceptual model". CLR11 notes that there is a degree of uncertainty inherent in any QRA and requires that this uncertainty is reduced through the collection of additional data, the use of risk conservative input parameters, or sensitivity analysis.

Any QRA is simply a representation of the real world, confined by the limitations of the modelling software. As a result the conceptual model is arguably the most important part of any risk assessment. It may not be possible to exactly replicate the site conditions within the model; a robust conceptual model will therefore enable an understanding of the model limitations. Furthermore, CLR11

recommends a transparent approach, allowing regulators and third parties to clearly understand the modelling process. Above all the QRA model must be both accessible and defensible; to achieve this, a robust conceptual model is essential.
A series of examples are used to illustrate the importance of understanding a site, and the resultant implications on remedial works. For reasons of confidentiality the sites are not named and their location is not provided.

Example 1

The first example relates to a site situated in the Midlands to be re-developed to a commercial unit with associated hard standing and only very limited soft landscaping. The site formerly comprised a dairy and petrol filling station with residual underground fuel storage tanks. A previous site investigation had been undertaken by a third party and identified contamination of soils and groundwater by petroleum hydrocarbons.

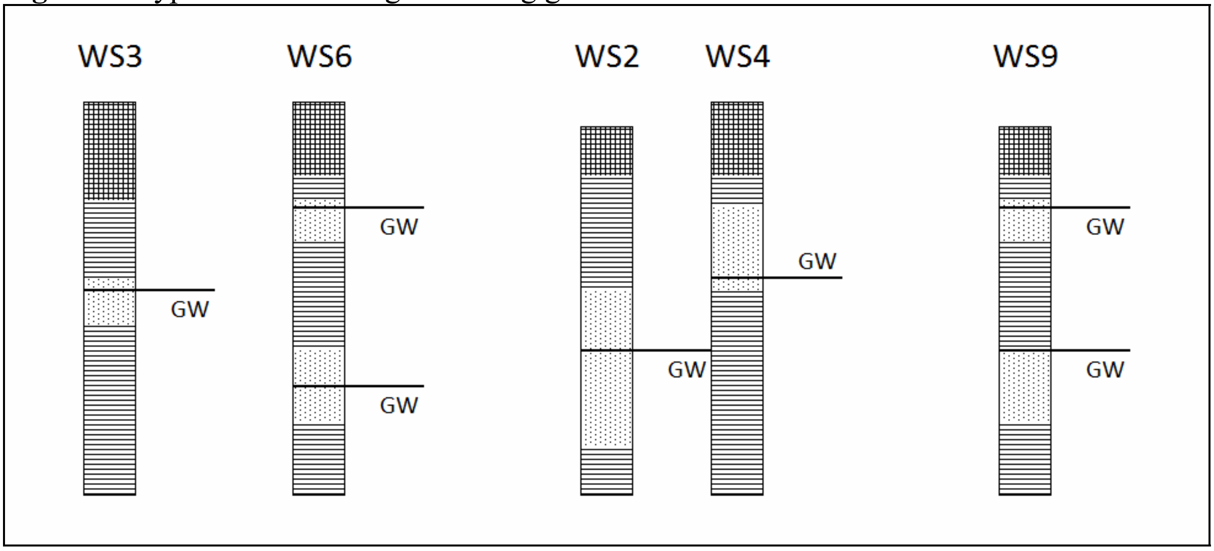
The underlying geology reportedly comprised made ground, overlying glacial clay with locally sandy horizons, overlying the Sherwood Sandstone. The Sherwood Sandstone in the vicinity of the site was classed as a Major Aquifer and the site was situated within a groundwater Source Protection Zone. The closest surface water feature was a small stream, located approximately 200 m to the southwest of the site.

The sandy horizons in the vicinity of the underground storage tanks were noted to be contaminated, and it was considered likely that these would have acted as a preferential migration pathway, facilitating more widespread contamination across the site. The proposed remedial strategy comprised the wholesale excavation of any potentially contaminated soils and large-scale groundwater treatment, with remedial costs estimated to be in the region of £150,000. The Environment Agency had rejected this initial proposal on the grounds that a QRA was required to assess the potential risks to controlled waters.

RPS undertook a further site investigation comprising a number of window sample probeholes. The probeholes were installed to facilitate groundwater and ground gas monitoring. The data was interpreted in conjunction with the information from the previous site investigation. Soil data indicated that contamination appeared to be limited to the vicinity of the tanks. Three rounds of groundwater monitoring were undertaken. These indicated locally elevated concentrations of total petroleum hydrocarbons within perched groundwater contained in the sandy elements of the glacial clay. No impact was recorded on the deeper groundwater within the Sherwood Sandstone aquifer. In addition, elevated ground gas concentrations were found in association with contamination of both soils and groundwater by petroleum hydrocarbons.

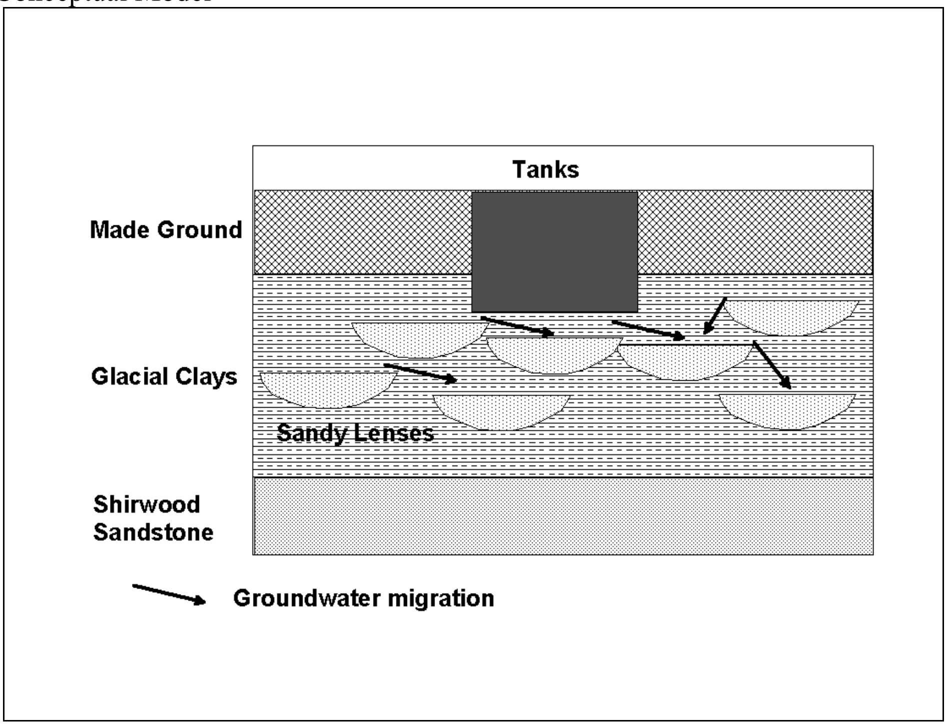
The borehole locations were surveyed to enable calculation of the groundwater flow direction and the hydraulic gradient. However, groundwater levels across the site varied greatly; furthermore, the sandy inclusions within the glacial clay appeared laterally discontinuous, both at different levels and of varying thickness, as indicated by Figure 1. Not only did groundwater levels vary laterally, but also temporally, with changes in height ranging from 0.3m to 0.75m. The greatest increases in groundwater levels were recorded in the boreholes with the thickest sand lenses. This information was assessed against rainfall data obtained from the Met Office [2] and indicated that increases in groundwater were directly related to rainfall events.

Figure 1: Typical borehole log indicating groundwater levels and sand thickness



The following interpretation was made: the sand within the glacial clay, previously interpreted as a continuous sandy horizon, was in fact a series of lenses within the clay, with a limited degree of hydraulic conductivity. Rainfall would fill the upper most lenses, which would then spill into the deeper lenses, as indicated by Figure 2. This "fill to spill" principle was used to determine the overall groundwater flow direction; this was towards the southwest, in the direction of the closest surface water feature. Groundwater data also indicated that contamination was restricted to the uppermost lenses and had not "spilt" to any great degree into the deeper lenses. The risk to groundwater in the underlying Sherwood Sandstone was therefore considered negligible.

Figure 2: Conceptual Model



The conceptual model was used to inform a QRA constructed in the Environment Agency's R&D P20 spreadsheets [3]. However, it was not possible to replicate the exact groundwater environment beneath the site. This was accounted for by adjusting the hydraulic gradient, thus reducing the flow velocity and increasing the travel time to the receptor. The elevated concentrations of methane found in association with hydrocarbon contamination of soil and groundwater, combined with the assessment of attenuation parameters, indicated that biodegradation was likely to be occurring. Therefore, reducing the hydraulic gradient and the resultant increase in travel time increased the potential for contaminants to break down prior to reaching the stream.

The model indicated that the contaminants in groundwater did not have the potential to impact upon controlled waters. However, the model did indicate that the grossly contaminated soils, found in association with the tanks, represented a potential risk. In addition, it was considered likely that the tanks themselves were acting as an ongoing source of contamination. The remedial strategy therefore involved the removal of the tanks and any associated grossly contaminated soils. Excavations were validated against the remedial criteria derived through the modelling process. The strategy was approved by the Environment Agency and the conceptual model commended. In total two loads of contaminated soil (36 tonnes) were excavated, combined with the removal of the tanks themselves. The overall remediation costs were in the region of £15,000, compared to the £150,000 previously recommended by a third party consultancy.

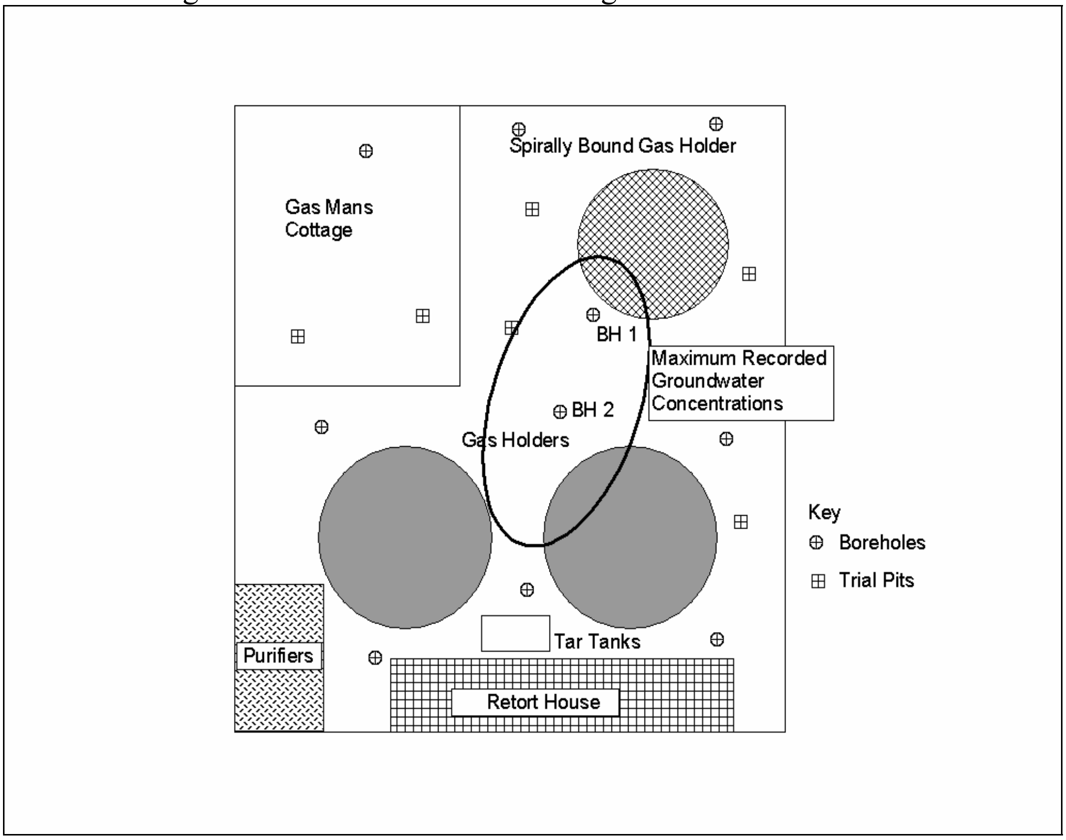
Example 2

The second example relates to a former gasworks comprising two in-ground gasholder bases, one spirally bound gasholder, a retort house, purifiers and tar tanks. The underlying geology comprised made ground overlying glacial gravels, over the Boulder Clay Formation (reported likely to be in the region of 20m thick in the vicinity of the site), with the Chalk at depth. The glacial gravels were classed as a minor aquifer, whilst the Chalk was a Major Aquifer. The closest surface water feature was a stream located approximately 190m to the north of the site. The proposed redevelopment consisted of residential properties with private gardens.

A site investigation, comprising the excavation of a number of boreholes and trial pits was undertaken. This identified widespread contamination of the made ground by cyanide (generally found in association with Blue Billy), as well as more localised contamination by total petroleum hydrocarbons, BTEX, poly aromatic hydrocarbons and phenols, associated with the former in-ground gas-holder bases, retort house, purifiers and tar tanks. The glacial gravels had also been significantly impacted by contamination.

Groundwater samples collected from the glacial sands and gravels indicated that the Minor Aquifer had also been impacted. However, the greatest concentrations were located in boreholes BH1 and BH2, the locations of which are illustrated in Figure 3. Figure 3 also shows the location of the key components of the former gasworks infrastructure. It was observed that the greatest impact on groundwater was in the central portion of the site, with rapid decreases in concentrations in the surrounding boreholes.

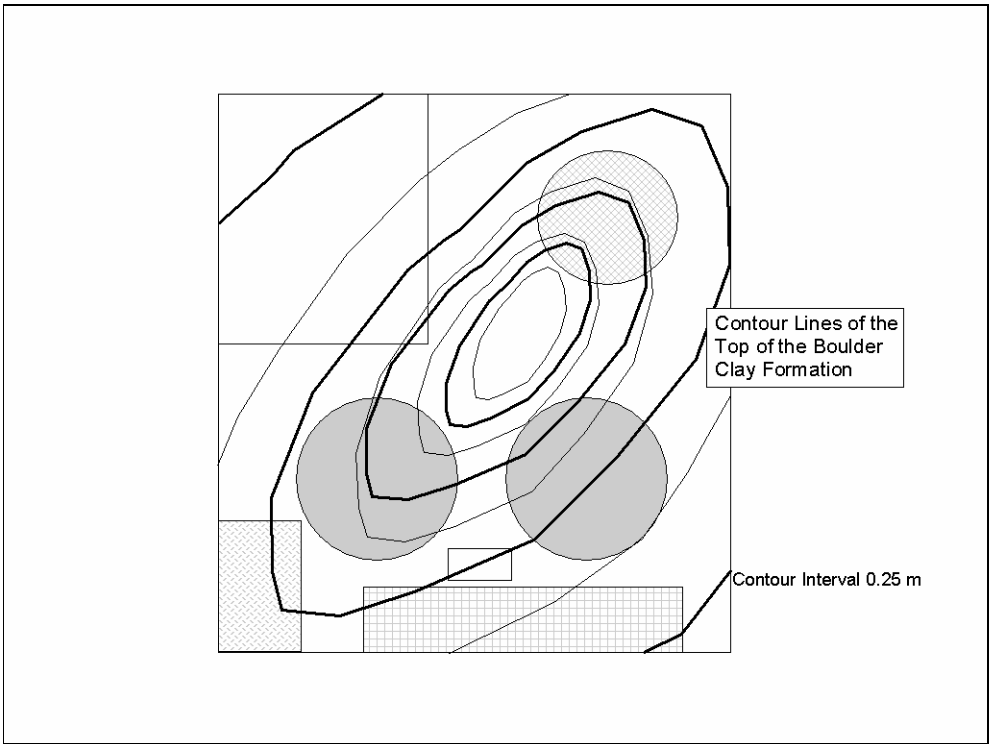
Figure 3: Elevated groundwater concentrations and gasworks infrastructure



The borehole locations were surveyed to enable calculation of the groundwater flow direction and hydraulic gradient. Contouring the groundwater elevations from five rounds of monitoring provided contradictory information. In three of the plots the groundwater flow direction radiated out from the centre of the site, with an overall flow direction to the north. This flow pattern was effectively reversed on the remaining plots. As for the first example, this was compared to rainfall data, which indicated that groundwater flow in a northerly direction occurred after rainfall events. In general, the highest contaminant concentrations in groundwater in boreholes BH1 and BH2 were recorded by the monitoring rounds undertaken following the rainfall events. Much less variation was observed in the surrounding boreholes.

To understand the variations in groundwater flow direction and contaminant concentrations, the depth to the top of the Boulder Clay Formation was contoured using data from both the trial pits and boreholes. This information indicated a significant dip in the surface of the Boulder Clay Formation in the centre of the site; illustrated on Figure 4. The maximum-recorded contaminant concentrations (boreholes BH1 and BH2) were coincident with the centre of this dip. Given the reductions in the downstream concentrations it was considered likely that the dip was in fact restricting lateral contaminant migration.

Figure 4: Plan indicating the location of the dip in the Boulder Clay Formation



Since the lateral migration of groundwater appeared to be restricted, the conceptual model focused on the potential for the vertical migration of contamination. CONSIM [4] was used to model the migration of contaminants in the gravel aquifer, through the Boulder Clay Formation to the underlying Chalk. This model indicated that there was only very limited potential to impact upon the deeper aquifer.

The Environment Agency agreed with the interpretation and, as a result, only very limited remedial works were required. To facilitate the redevelopment of the site, the former gasworks structures were removed, this process also captured the most significantly contaminated soils, and a clean cover system introduced to mitigate the potential risks to human health. The base of the most easterly gasholder was coincidental with the dip in the Boulder Clay Formation, and extended into this stratum. The removal of the gasholder base therefore required the dewatering of the excavation and hence pumping of the most significantly impacted groundwater. It was previously noted that contaminant concentrations in groundwater greatly increased following periods of heavy rainfall. Therefore an infiltration barrier was introduced to restrict further contamination of groundwater.
Remedial excavations confirmed the dip at the top of the Boulder Clay Formation and post remediation monitoring indicated a significant and sustained improvement in groundwater quality (monitoring continued for a period of nine months during and following construction works). The alternative solution was the widespread excavation and treatment or disposal of contaminated soils. The potential cost savings were estimated to have been in the region of £250,000.

CONCLUSIONS

In both examples the site investigation data was used to characterise the groundwater environment and fully define the conceptual model. This understanding enabled the QRA process to be properly designed, the appropriate receptors identified and the most cost effective remedial solution determined. Whilst neither scenario could be completely replicated by the modelling software, adjustments were made to compensate for the model limitations. In the first example the hydraulic gradient was reduced, reflecting the influence of the sandy lenses on groundwater migration; in the second example vertical migration was considered more significant than lateral migration.

In many instances the delay in gaining regulatory agreement can significantly impact upon a project. However, by engaging the regulators and demonstrating a clear understanding of the environment, the degree of contamination, the likely impacts and most effective solution, speedy resolution can be achieved. Above all, the QRA must be defensible and the input parameters fully justified. Without an appropriate conceptual model the justification of input parameters will be incomplete. It may even be possible to argue that a full QRA is, in fact, not required. In both of the examples it would have been possible to assess the potential risks to controlled waters based on the conceptual model and available data. However, the requirement for values against which to validate the remedial works made an element of QRA necessary.

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Session IV

GEOTHERMAL RESOURCES IN IRELAND – APPLICATIONS FOR HYDROGEOLOGY

Roisin Goodman
CSA Group

ABSTRACT

The goals of recent studies of geothermal potential in Ireland included:

1. *Identifying potential resources of geothermal energy in Ireland;*
2. *Gathering the necessary thermal, geological, structural and hydrodynamic data to facilitate modeling of the geothermal potential and*
3. *The production of a GIS-linked geothermal database and the creation of a series of geothermal maps of Ireland.*

A review of the current status and utilisation of geothermal energy resources in Ireland was also included and recommendations were presented on the future potential exploitation of the geothermal resource in Ireland in the context of International Best Practice.

The results of the review indicate that Ireland is particularly well suited for the utilisation of shallow resources by ground source heat pumps due to its temperate climate and rainfall levels that ensure good conductivity and year round rain-fall recharge. Warm spring and deeper geothermal temperature survey data were added to the existing temperature data compiled for earlier studies. Modelling of the data available resulted in updated geothermal resource maps of Ireland confirming that at 2,500m temperatures range from 28°C – 45°C to the south to 64°C – 97°C to the north.

Shallow geothermal potential in the Irish context is primarily a groundwater resource issue. As with hydrological resources, regional aquifers can be generally assessed and modelled. Before development can take place a site specific assessment is required, to establish water temperature, water flow rate, environmental impact etc. Once the resource at the site has been profiled the appropriate utilisation technology can be chosen. The emphasis here is on the design of a system which maximizes the potential of the resource while ensuring its future integrity. Geothermal systems can be designed for a whole range of utilisation scenarios, for example Single Buildings using single borehole systems, Multiple Buildings using multiple borehole heat exchangers, high yield single boreholes or industrial-using borehole heat exchangers, borehole re-injection systems.

This study was funded by Sustainable Energy Ireland (SEI) in 2004 and was performed by the CSA Group in co-operation with Conodate Geology, Cork Institute of Technology and the Geological Survey of Ireland. This was updated again in 2005 to include a more detailed analysis of the geothermal potential in Northern Ireland as funded by the EU INTERREG programme. A later study to look in more detail at the shallow geothermal resource in NI was funded by Action Renewables of DETINI.

SELECTED SUMMARY

Extract from SEI Report – see References for url link to report

The results of reviews during 2004-2006 indicate that Ireland is particularly well suited for the utilisation of ground source heat pumps, due to its temperate climate and rainfall levels that ensure good conductivity and year round rain-fall recharge. The current installation rate is increasing rapidly and requires immediate attention to set and maintain high standards of equipment installation and operation. There are abundant marine and surface water geothermal resources which could be exploited in Ireland, but they need some encouragement for their development. There are two main areas of warm spring development in Ireland, in north Leinster and the Mallow area. They are undeveloped, except for the heat-pump in the Mallow swimming pool, and there is currently available exploitation potential, especially in the light of the recent discovery at Glanworth, Co. Cork.

This study has added new data from 39 boreholes including newly monitored boreholes. Considering the Republic of Ireland and Northern Ireland together, this review has indicated a regional increase in temperatures ranging from 17ºC – 19ºC in the south to 25ºC – 27ºC in the north at 500m depth. At 2,500m, temperatures range from 28ºC – 45ºC in the south to 64ºC – 97ºC in Northern Ireland. This indicates a significant economic resource with potential for commercial development.

Major Recommendations - Nine Action Areas

1. Select a short list of deep borehole sites – choose one for a major demonstration project – provide support.
2. Support a medium depth pilot borehole e.g. on the Blackrock – Rathcoole Fault in an area with many potential users.
3. Maintain monitoring of borehole temperatures across the country as they become available.
4. Delineate Urban Heat Island Shallow Aquifers beneath major towns and cities across the country and encourage exploitation – use UCC Arts Museum building as example.
5. Investigate continuation of the warm spring development along the Killarney – Mallow line, where there is considerable exploitation potential.
6. Encourage warm spring exploitation, e.g. Hotwell House, Enfield, Co. Meath – use Mallow swimming baths as example.
7. Examine exploitation of Surface Water Source Heat Pumps – especially the marine environment, but also in rivers and lakes.
8. Encourage utilization of Ground Source Heat Pumps in office / apartment block developments– use Tramore Civic office and Tralee Tax office as good examples.
9. Encourage countrywide usage of single-dwelling Ground Source Heat Pumps with particular attention to Quality - equipment certification, installer accreditation, and technician training and follow-up.

The statutory perspective

It is crucial that local and national government take a composite approach to geothermal developments so that projects are effective and sustainable. Initial support for geothermal systems is important as has been demonstrated in Sweden, Switzerland and other countries. Although some incentive (financial and technical) may be required to stimulate the take-up of geothermal systems, the primary requirement is that projects are economically viable in their own right.

Since the reports were published the Government has announced significant grants for the installation of Ground Source Heat Pumps. Also, training schemes have been put in place in CREDIT in Dundalk IT for Heat pumps, GT Skills for installer training under Skillsnet funding and also 2 other courses under Skillsnet funding for renewable energy. It should be noted that most if not all heat pumps installed in Ireland have a European quality mark.

Integration of geothermal systems with other renewable options is considered one of the best ways to encourage the uptake of this technology.

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THERMOGEOLOGICAL ASSESSMENT OF OPEN LOOP WELL DOUBLET SCHEMES – AN ANALYTICAL APPROACH

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ABSTRACT

The origins of modern groundwater flow theory in heat conduction theory were recognised by Charles Theis in 1935. So strong is the analogy between groundwater flow and subsurface heat transport that we can construct a new scientific substructure of thermogeology *to support the rapidly expanding ground source heat pump industry in Ireland, Britain and many other European nations. Although the word may be novel, the science is not: much of the theoretical work on subsurface heat conduction and convection was performed in the mid-late 20th Century by workers such as the Ingersolls, Zobel and Alain Gringarten.*

The sciences of thermogeology and hydrogeology overlap strongly in the case of "open loop doublet" systems, where groundwater is abstracted from a well and used as either a source of heat (to a heat pump) or a sink for waste heat from a building or industry. The thermally "spent" (i.e. heated or cooled) water is then re-injected to the aquifer via the second well of the doublet. Contrary to popular belief, such systems may not be indefinitely sustainable and may have a finite life, due to the phenomenon of thermal feedback of warm (or cold) water to the abstraction well. Although numerical models such as HST3D or SHEMAT can be used to simulate open loop doublet performance, relatively simple analytical techniques may also be used as a "first level" screening tool. These techniques are summarised in this paper.

1.0 WHAT ON EARTH IS THERMOGEOLOGY?

The term "thermogeology" is guaranteed to rile many scientists, particularly those who work in the field of geothermal energy. I will, in this paper, try to defend the term, however. When we talk about geothermal energy, we typically think of medium-high enthalpy resources that occur either at great depths below the earth's surface or at specific geological locations where geothermal heat fluxes and temperature gradients are significantly higher than average (e.g. along tectonic plate boundaries or above mantle plumes) or both. In thermogeology, I am thinking of the ubiquitous low-grade "ground source heat" that is locked up in all groundwaters, sediments and rocks – even chilly Irish and British rocks at around 10°C. In practice, in thermogeology, we're usually talking about temperatures of <30°C and depths of less than 200 m. Let me offer the following definition of thermogeology (Banks 2007):

"The study of the occurrence, movement and exploitation of low enthalpy heat in the relatively shallow geosphere."

Irish-born William Thomson, later Lord Kelvin (who can lay claim to being the world's first thermogeologist for his calculation of the age of the earth from the current geothermal heat flux – Thomson 1864) was among the first to figure out how humans could use this very low temperature heat. Around 1852, he alleged (Thomson 1852) that a so-called "heat multiplier" (heat pump - running on a compression-expansion cycle) could transfer heat from one place to another *at a rate greater than the supply of mechanical work to the system.* This concept was, at that time, being used to provide artificial refrigeration (for the fridge is a form of heat pump), but it was another 100 years before large-scale heat pumps were constructed to extract low-temperature heat from wells, from rivers and from the ground, in order to provide space heating. Among the early pioneers was John Sumner who, in 1945, constructed a heat pump (comprising a room full of bits and pieces of salvaged gear!) in order to extract heat from the chilly waters of the River Wensum in Norwich and use that heat for space-heating a riverside building (Sumner 1948).

Still, there was relatively little interest in the potential of heat pumps to extract heat from the geological environment, until the oil crisis of the 1970s, which focussed the attention of fossil-fuel-poor nations, such as Sweden and Switzerland, on means of utilising electricity as cheaply as possible to provide space heating. Since that time, the Swedes and the USA have led the way in developing the theoretical framework and the practical exploitation of ground source heat, using electrically powered "ground source heat pumps" (GSHPs). Other nations on the outskirts of Europe, including Britain and Ireland, have only recently rediscovered the true potential of heat pump technology to extract heat from the geosphere. In Britain, the GSHP market took off in the period 2002-2003, and is currently growing at over 100% (Bouma 2002), to the extent that regulators are struggling to keep up. The ultimate driving forces behind the market's growth have been:

(i) The Kyoto Protocol, committing signatory nations to control emissions of carbon dioxide and other greenhouse gases in an attempt to limit anthropogenic climate change.
(ii) Decreased security of supply and increased market competition for oil and gas resources, resulting in increased prices of fossil-fuel-based energy supplies.

The effects of these "drivers" have been:

- Ever stricter Buildings Regulations, requiring developers to look closely at a building's heating / cooling efficiency and carbon footprint (EU Directive 2002/91/EC on the Energy Performance of Buildings). GSHPs are very carbon-efficient.
- Conditions being attached to planning consents, requiring a certain percentage of the development's energy requirements to be renewably sourced (GSHPs fall into this category).
- Subsidies becoming available for carbon-friendly technologies via the Irish "Greener Homes" scheme and the UK's "Low Carbon Buildings Programme".
- Developers looking for alternative space heating and cooling solutions that can compete economically with conventional fossil-fuel-based systems. In fact, GSHPs can compete effectively – even without subsidies – when considering a large enough development.

The science of thermogeology is the theoretical substructure that underpins the practical exploitation of ground source heat, in much the same way that hydrogeology underpins the practical exploitation of groundwater.

1.1 THE RELEVANCE FOR HYDROGEOLOGISTS

This is all very interesting – but what does it have to do with hydrogeologists? Another reason that I use the term "thermogeology" is because it invites comparison with hydrogeology. The similarity is not merely fortuitous – there are a whole set of pleasing mathematical analogies between:

- groundwater flow and heat conduction in the subsurface,
- contaminant transport and heat convection with groundwater flow.

You may not be aware that modern quantitative hydrogeology grew out of thermal conduction theory. The sainted Charles V. Theis recognised, from his practical experience of groundwater resources assessment in New Mexico, that the conventional Thiem equation was not wholly adequate to describe the evolution of drawdown around an abstraction well. Theis's maths was not, however, up to the job of developing a better solution. Instead, he was humble enough to go and ask his chum, the physicist Clarence Lubin, for advice. Lubin was able to tell Theis that the problem of groundwater flow to a well was *exactly* analogous to radial heat conduction towards a heat sink, and had already been solved some years before. Thus, our Theis equation should, by rights, be called the Theis/Lubin equation, and it is derived directly from thermal conduction theory! If you don't believe me, check out Theis's (1935) paper, where our hero places great emphasis on the analogies between groundwater flow and heat flow.

Thermogeology had a sound theoretical footing before Theis and Lubin, of course. In the 1860s, William Thomson, J.D. Everett and Anders Jonas Ångström had started making determinations of the thermal diffusivity/conductivity of sediments and soils (Everett 1860, Thomson 1868, Rambaut 1900). In 1862, William Thomson had used a consideration of geothermal gradient and thermal conductivity to deduce the age of the earth (Thomson 1864). My predecessors at the University of Newcastle, Professors A.S. Herschel and G.A. Lebour were, in 1879, able to present a series of determinations of thermal conductivities of rocks, and even to comment on their thermal anisotropy (Herschel *et al.* 1879, Prestwich 1885, 1886, Barratt 1914). By the 1940s, the Ingersolls and Zobel had begun to formulate the theoretical heat flow fields for a variety of ground heat exchangers (Ingersoll *et al.* 1948, 1954). A particularly concise collection of papers concerning heat conduction towards heat extraction boreholes was published by Per Eskilson and Johannes Claesson in Sweden (Eskilson 1987).

In fact, the theory behind thermogeology is already well established. The reason it is very poorly known in Ireland and the UK is due to the fact that much of it was done in the period 1920-1980 and is hence poorly available in digital form (and, of course, we don't use dusty old books any more!) and some of the important work is "foreign" (i.e. Swedish!).

Most of the parameters that we are familiar with from hydrogeology have exact analogues in thermogeology, as do most of our favourite equations (Table 1).

	Hydrogeology	**Thermogeology**
What are we studying?	Groundwater flow	Subsurface heat flow
Key physical law	Darcy's Law $Q = -KA\frac{dh}{dx}$	Fourier's Law (conduction only) $Q = -\lambda A\frac{d\theta}{dx}$
Flow	Q = groundwater flow (m^3/s)	Q = heat flow = (J/s or W)
Intrinsic property of conduction	K = hydraulic conductivity (m/s)	λ = thermal conductivity (W/m/K)
Measure of potential energy	h = groundwater head (m)	θ = temperature (°C or K)
Measure of storage	S = groundwater storage (related to porosity)	S_{VC} = volumetric heat capacity (J/m^3/K)
Exploitable unit of rock	Aquifer (Lat: *aqua* : water)	Aestifer (Lat. *aestus*: heat)
Tool of exploitation	Well and pump	Borehole or trench and heat pump
Energy loss at borehole	CQ^2	QR_b
Measure of well/borehole efficiency	Well loss coefficient (C)	Borehole thermal resistance (R_b)
Advective transport	Contaminant transport with sorptive retardation on mineral surfaces, hydrodynamic dispersion and degradation.	Convective heat transport with retardation due to absorption in matrix, hydrodynamic/thermal dispersion.

Table 1. The key analogies between the sciences of hydrogeology and thermogeology (modified after Banks 2007)

Thus, if you know hydrogeological theory, you are also very well placed to work within the rapidly growing sector of thermogeology and the practical exploitation of ground source heat.

2.0 OPEN LOOP WELL-DOUBLET SCHEMES

2.1 OPEN LOOP GROUND SOURCE HEATING AND COOLING

Another reason for hydrogeologists to be aware of thermogeology is because one means of utilising ground source heat is the so-called "open loop" system. Here, groundwater at, say, 10°C is abstracted from a well at a rate Q and passed through a heat pump (Figure 1). The heat pump extracts an amount of heat H from the water and delivers it to a building as space heating. The groundwater that exits the heat pump is now cooler – maybe 5°C. The amount of heat extracted from the water can be calculated by:

$$H = Q.S_{VCwat}.(\theta_{in} - \theta_{out}) \quad (1)$$

Where

- H is in J/s or W,
- Q is in L/s
- S_{VCwat} is the volumetric heat capacity of water ≈ 4180 J/L/°C
- $(\theta_{in} - \theta_{out})$ is the temperature difference between water entering and leaving the heat pump.

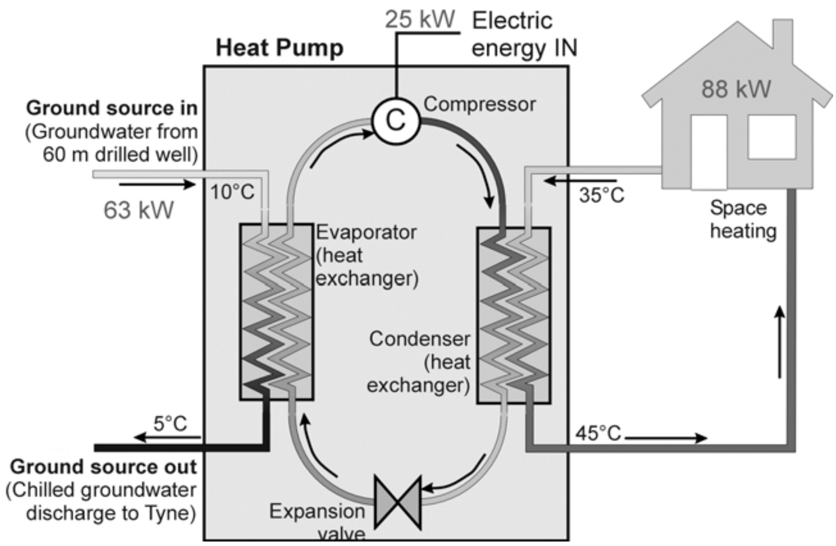

Figure 1. An open loop ground source heat pump scheme, based on the design for the Eco-Centre building at Hebburn, near Jarrow, south Tyneside, UK (after Banks 2007).

Many heat pumps can be switched into reverse, such that they provide active chilling / space cooling. They extract heat from the building and dump the waste heat to the stream of groundwater. In this case, the "waste" groundwater is several °C hotter than it originally was.

In fact, we don't even need to use a heat pump at all in order to perform space cooling. In "free" cooling or "passive" cooling, our groundwater at, say, 10°C is simply circulated around the building through a series of heat exchange elements (chilled beams, chilled panels, fan-coil units) and heat is absorbed from the building (at say 20°C) to the groundwater (at 10°C). Again, we are left with an effluent stream of groundwater that is a few °C warmer than it was (Figure 2). Note that, in some cases, it may not be desirable to circulate a groundwater directly through a heat pump or heat exchanger, due to the risk of biofilm growth or mineral precipitation (e.g. calcite, iron oxyhydroxide). In these cases, it is common to insert a "prophylactic heat exchanger" between the groundwater and the building. This transfers heat between the groundwater and a "carrier fluid" of controlled composition.

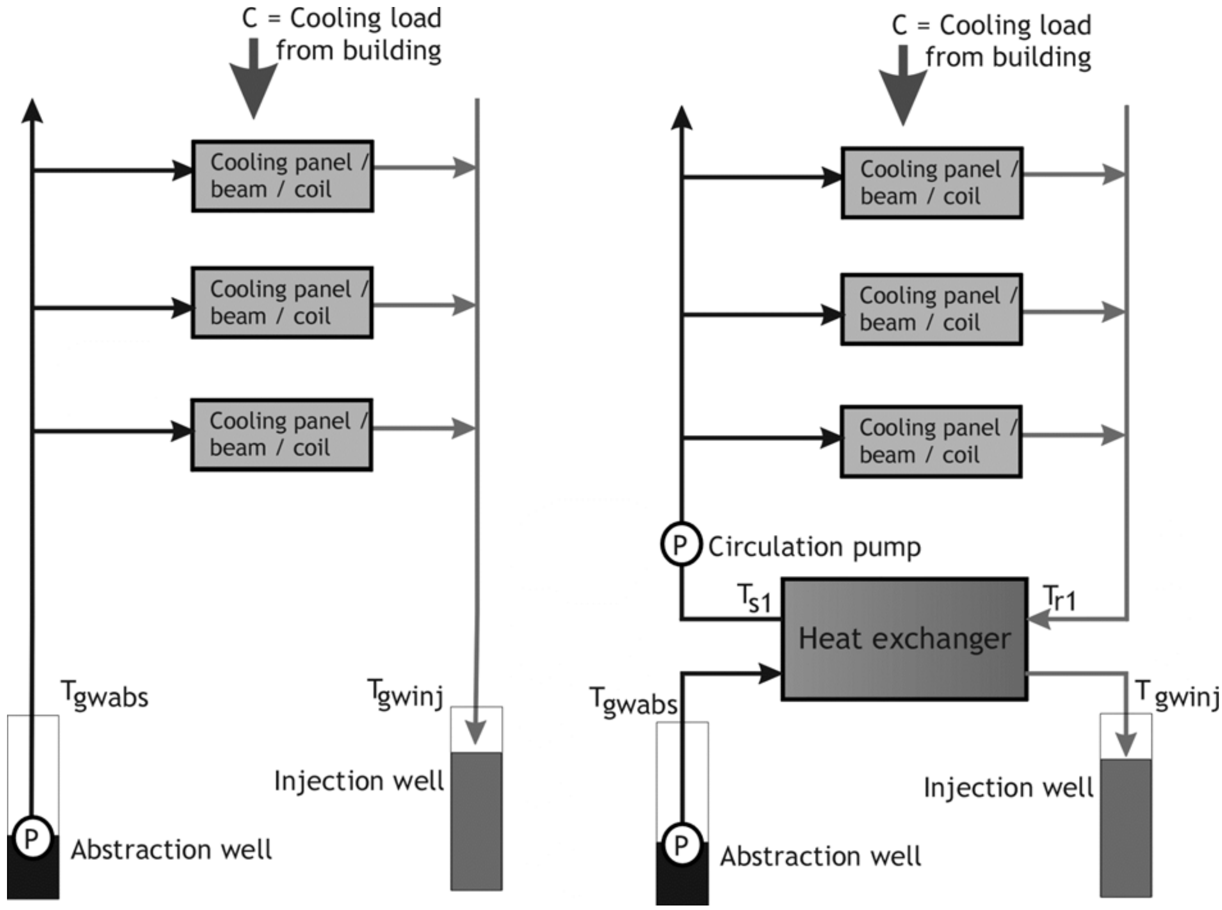

Figure 2. Performing passive cooling using groundwater. In the right-hand diagram, a prophylactic heat exchanger has been inserted in the system to protect the building loop from incrustation and biofilm formation in groundwater (modified after ©Banks 2006 and Banks 2007).

Kazmann and Whitehead (1980) tell us that use of groundwater for cooling was relatively popular in the 1920-30s in Brooklyn and Long Island, USA. So popular, in fact, that there began to be fears that the large scale abstraction of groundwater would deplete the aquifer resource. Authorities then began to insist that the warmer waste water should be somehow re-injected to the aquifer. This, of course led to new fears over the regional heating of the aquifer! Kazmann and Whitehead do not tell us whether this regional heating was in fact observed, but the whole episode is very similar to discussions taking place regarding the use of the London Chalk aquifer today.

Of course, open loop systems can be elegant and hydrogeologically unproblematic, and a good example can be seen at the Eco-Centre, on the south bank of the Tyne near Jarrow, north-east England (Figure 1). Here, 3 L/s saline groundwater is abstracted from a 60 m deep borehole in the Carboniferous Coal Measures and sent through a marine-grade heat pump, which heats the Eco-Centre via underfloor heating. The cold effluent groundwater is simply discharged to the Tyne Estuary (Banks 2007). The Environment Agency does not, in this case have any objection to the operation: the saline aquifer has no water resources value and the discharge is unlikely to have any significant impact on the Tyne Estuary.

In London, however, the demand for ground source heating and (predominantly) cooling has been huge, thanks largely to the local authority's insistence on a certain percentage of renewable energy to be incorporated into any new development. Initially, given the perceived surplus of groundwater in the London Chalk aquifer (the groundwater levels had been regionally rising for some decades, due to declining abstraction), most such schemes proposed discharging the abstracted water directly to the River Thames (Ampofo *et al.* 2004).

More recently, the Environment Agency have noted that groundwater levels beneath London have tended to stabilise, or even decline, in some areas. They have thus begun to restrict new consumptive groundwater abstraction licenses in some parts of London (EA 2006). The implication of this is that new open loop ground source heating and cooling schemes are having to consider re-injecting their spent cooler or (usually, given the predominance of space-cooling demand) warmer water back to the aquifer via another re-injection borehole.

A typical open loop well doublet scheme thus comprises three elements:

1) an abstraction well, from which water is abstracted at a rate Q and a temperature θ_{gwabst},
2) a heat-transfer system (the details of which need not concern us), which either extracts heat from, or rejects heat to, the groundwater flux,
3) a re-injection well, at a distance L from the abstraction well, where water is re-injected at a rate Q and temperature θ_{gwinj}. For space-cooling schemes, $\theta_{gwinj} > \theta_{gwabs}$.

2.2 RISK OF FAILURE OF OPEN LOOP WELL DOUBLET SYSTEMS

Let us consider an open loop well doublet cooling scheme, where naturally cold water is abstracted and where warm water is re-injected to the aquifer.

Ideally (Figure 3), we would situate our injection well down the hydraulic gradient from the abstraction well, in the hope that natural groundwater flow would carry our rejected warm water away from our scheme in a "thermal" plume, to become "somebody else's problem". The risk to "somebody else" (other aquifer users and environmentally sensitive features) can be considered an "external" risk and will not be considered in detail here.

However, there is also a potential "internal" risk to the sustainability of the system. It can be shown theoretically (Lippmann & Tsang 1980, Clyde 1983, Banks 2007) that our neat scenario in Figure 3 will only happen if L (the well separation) is relatively large and if Q is relatively small. In fact, our thermal plume will only disappear away down-gradient if:

$$L > \frac{2Q}{T.\pi.i} \tag{2}$$

Where T = aquifer transmissivity and i = regional natural hydraulic gradient.

If the above relation is not true, there is a risk that a proportion of the discharged warm water will flow back (against the regional hydraulic gradient) to the abstraction well. The temperature of the abstracted water will thereafter rise over time (Figure 4). At best, this compromises the efficiency of the cooling scheme and at worst it can result in system failure or environmental non-compliance. In other words – far from being a "renewable" energy source – the system can become unsustainable over a relatively short period. Ferguson and Woodbury (2005) document a case from Winnipeg, Canada, where an open loop well doublet scheme in a carbonate aquifer almost immediately experienced significant thermal "feedback" following commissioning and rapid rises in the temperature of the abstracted water.

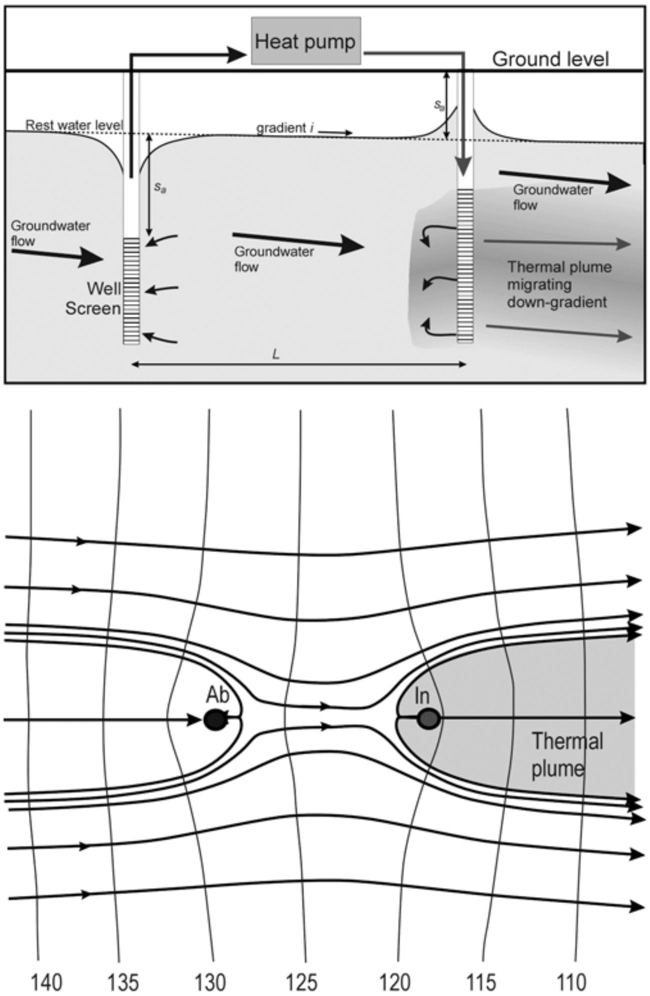

Figure 3. (left) An open loop well doublet system where no hydraulic feedback occurs (after Banks 2007). Arrows show groundwater flow lines and numbered contours are equipotentials.

In practice, the value of *L* required to ensure that there is no risk of thermal feedback is usually unrealistically large (try it! Values of T = 100 m^2/d, i = 0.01, Q = 900 m^3/d require a well separation of 570 m for risk to become negligible!). Thus, we need to carry out a risk assessment of the likely timing and magnitude of thermal feedback before we commission an open loop well doublet scheme.

2.3 RISK OF HYDRAULIC FEEDBACK

Firstly, we can consider the risk of hydraulic feedback between the re-injection and abstraction wells. The maths behind this is well known. For the case where the natural hydraulic gradient (i) = 0, the time (t_{hyd}) taken for groundwater flow along the shortest flow path between the injection and abstraction well (neglecting dispersion) is (Grove 1971, Güven *et al.* 1986, Himmelsbach *et al.* 1993):

$$t_{hyd} = \pi n_e D \frac{L^2}{3Q} \qquad (3)$$

Where n_e = effective porosity and D = effective aquifer thickness.

If i is non-zero and the re-injection well is situated perpendicularly down-gradient from the abstraction well, Lippmann & Tsang (1980) and Clyde (1983) contend, from geometric considerations:

$$t_{hyd} = \frac{L.n_e}{K.i}\left[1 + \frac{4\alpha}{\sqrt{-1-4\alpha}}\tan^{-1}\left(\frac{1}{\sqrt{-1-4\alpha}}\right)\right] \quad (4)$$

where:

$\alpha == \frac{Q}{2\pi.K.D.i.L} = \frac{Q}{2\pi.T.i.L}$ and K = hydraulic conductivity.

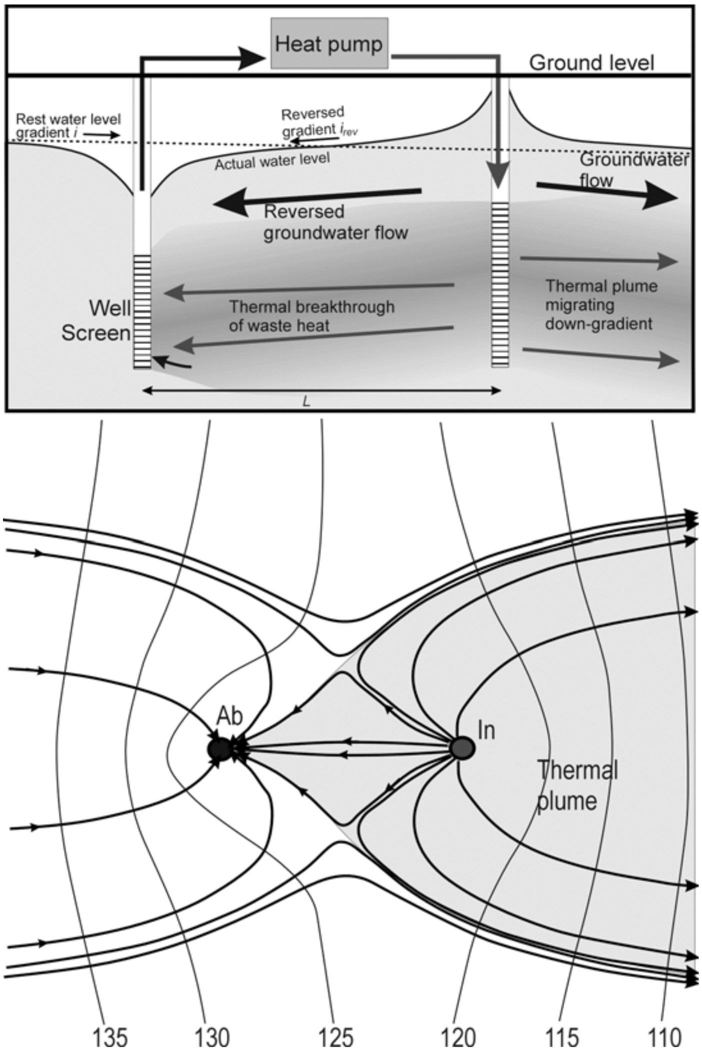

Figure 4. An open loop well doublet system where flow rate (Q) is large enough and the well separation (L) small enough for feedback to occur (modified after Banks 2007). Arrows show groundwater flow lines and numbered contours are equipotentials.

2.4 RISK OF THERMAL FEEDBACK

We might think that, once we have calculated the hydraulic travel time from the injection to abstraction well, we have also calculated the thermal travel time. This is not the case, however: as warm groundwater flows through a cool aquifer matrix, heat is absorbed from the water into the matrix until a thermal equilibrium is attained. This has the effect of retarding the heat travel front (in the same way that sorbed contaminants are retarded – see Table 1). In fact, it can be shown (de Marsily 1986) that, if the groundwater flows through a porous medium and contact between water and mineral grains is so intimate that thermal equilibrium is attained effectively instantaneously:

$$R = \frac{v_{the}}{v_{hyd}} = \frac{n_e S_{VCwat}}{S_{VCaq}} \quad (5)$$

Here, R is a retardation factor, v_{the} is the velocity of a thermal front, v_{hyd} is the hydraulic velocity (of a water molecule) and S_{VCaq} is the volumetric heat capacity of the saturated aquifer.

Thus, we can rewrite Equations (3) and (4) in terms of thermal breakthrough time (Gringarten 1978, Clyde 1983, Banks 2007):

$$t_{the} = \pi D \frac{S_{VCaq} L^2}{3 S_{VCwat} Z} \quad \text{for } i = 0 \tag{6}$$

$$t_{the} = \frac{S_{VCaq}.L}{S_{VCwat}.K.i} \left[1 + \frac{4\alpha}{\sqrt{-1-4\alpha}} \tan^{-1}\left(\frac{1}{\sqrt{-1-4\alpha}} \right) \right] \quad \text{for } i > 0 \tag{7}$$

2.5 CAVEATS

These seem a straightforward set of equations that can be programmed into an Excel™ spreadsheet. We must, however, be aware of the assumptions that underlie them in order to judge the reliability of our risk assessment. The main assumptions are (Banks 2007):

1) That groundwater flow is laminar and Darcian and can adequately be simulated using homogeneous, saturated porous medium assumptions.
2) The equations do not account for dispersion effects, neither hydrodynamic dispersion nor molecular thermal diffusion. In reality, some thermal breakthrough will inevitably occur ahead of the calculated mean travel time.
3) That thermal equilibration between groundwater and aquifer matrix is instantaneous.
4) That conductive heat losses into overlying or underlying strata are negligible.
5) That the recharge well is located immediately down-gradient of the abstraction well.

We should be able to judge that the equations are likely to work best for granular, porous medium aquifers such as alluvial sands and gravels or, at a push, the Sherwood Sandstone. If flow is via fractures, then macro-scale dispersion along fracture pathways of greatly differing transmissivity is likely to be significant, leading to earlier than expected thermal breakthrough. If flow is through a few widely spaced fractures, separated by large chunks of matrix, thermal equilibration between water and matrix is unlikely to be instantaneous. This, too, will lead to overestimation of travel times. In both cases, the equations are likely to be less applicable in fissured and fractured aquifers such as the Chalk, many limestones and crystalline bedrock.

We may be able to get around assumptions (2) and (4) by more sophisticated numerical or analytical models, that explicitly consider dispersion and conductive losses.

2.6 THAT'S GROUND SOURCE COOLING SORTED, THEN! WHAT ABOUT GROUND SOURCE HEATING SCHEMES?

2.7

The maths outlined above also works in exactly the same way if we are re-injecting chilled water from a heating scheme instead of warm water from a cooling scheme!

3.0 CAN OPEN LOOP WELL DOUBLET SCHEMES EVER BE SUSTAINABLE?

Having performed our thermogeological risk assessment, we may find that our open loop well doublet system has a finite operational life before thermal breakthrough becomes too large. However, in an aquifer with a high porosity and a well separation of several hundred metres, the time to thermal breakthrough may be decades. This alone may be enough to render our ground source heating or cooling scheme economically viable. But we should remember that, even after thermal breakthrough has occurred, temperatures may not rise so quickly as to render our scheme unworkable immediately. We may still have several years or even decades before our abstracted water becomes unfeasibly warm. Indeed, Clyde (1983) worked out a formula for how the temperature of the abstracted water increases with time following thermal breakthrough, assuming that $i = 0$.

$$\frac{\theta_{gwabs} - \theta_{gwinj}}{\theta_o - \theta_{gwinj}} = 0.34\exp\left(-0.0023\frac{t}{t_{the}}\right) + 0.34\exp\left(-0.109\frac{t}{t_{the}}\right) + 1.37\exp\left(-1.33\frac{t}{t_{the}}\right) \qquad (8)$$

Where t = time since scheme started, θ_o = initial temperature of aquifer water, θ_{gwinj} = re-injection temperature (assumed to be constant) and θ_{gwabs} = temperature of abstracted water (which changes with time following thermal breakthrough at time $t = t_{the}$). An example of the use of this formula is shown in Figure 5.

Thus, although an open loop well doublet scheme may not be indefinitely sustainable and may have a finite lifetime, this life may be long enough to be economically worthwhile. Gringarten (1978) summarises various strategies for prolonging the life of such abstraction/re-injection schemes and notes that a chequerboard arrangement of a number of alternating abstraction and injection wells is amongst the most efficient ways of exploiting the heat resource of a given volume of aquifer.

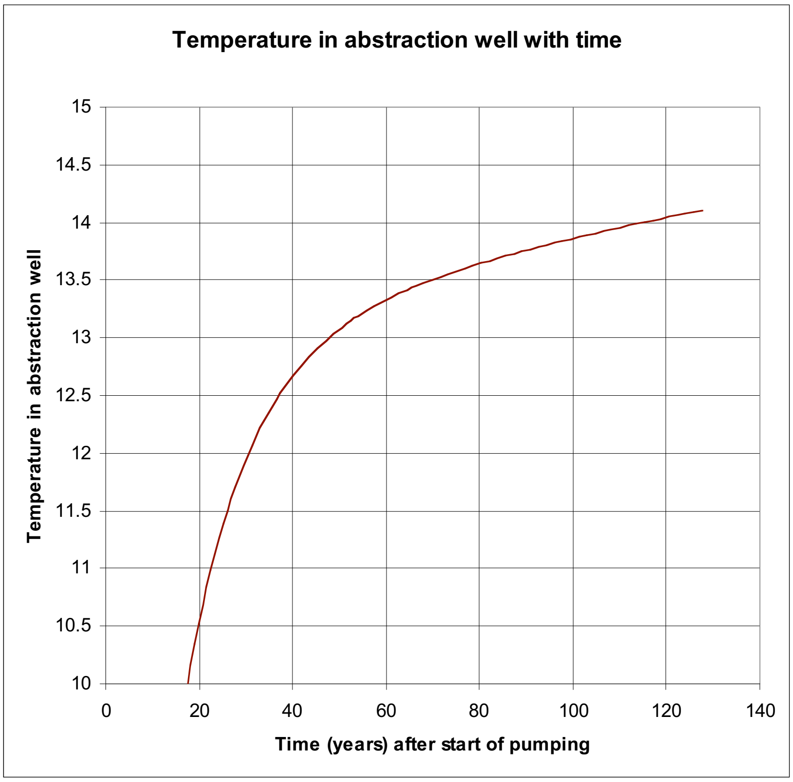

Figure 5. The predicted temperature evolution in an abstraction well of an open loop well doublet system, where the breakthrough time is calculated at 17.5 years, the initial groundwater temperature is 10°C and the constant injection temperature is 18°C. i = 0. Figure © D Banks

3.1 SEASONALLY REVSERSIBLE SCHEMES

Probably the best strategy for the sustainable operation of an open loop well doublet scheme is to use it (via reversible heat pump system) alternately for heating in the winter and cooling in the summer. Thus, given a well doublet comprising wells A and B, we could envisage two modes of reversible operation:

Mode 1.

- Winter: Well A used for abstraction. Heat extracted from water. Well B used for recharge of chilled water.
- Summer: Well A used for abstraction. Heat rejected to water from cooling system. Well B used for recharge of warm water.

In this case, if the heating and cooling loads are well balanced and t_{the} is several years, then by the time breakthrough occurs, the annual heat signals should have largely evened themselves out and little net change in the temperature of the abstracted water would be expected.

Mode 2.

- Winter: Well A used for abstraction. Heat extracted from water. Well B used for recharge of chilled water.
- Summer: Well B used for re-abstraction of cold water previously injected during winter. Heat rejected to cold water from cooling system. Well A used for recharge of warm water.
- Next Winter: Well A used for abstraction of previous summer's warm water. Heat extracted from water. Well B used for recharge of chilled water.
- And so on...

Mode 2 has two advantages. Firstly, we are using the cold/warm water re-injected during the previous heating/cooling season. Thus, in the heating season, we are recovering waste heat from the summer: the abstracted water is effectively "pre-heated" and the heat pump will operate more efficiently. In the cooling season, we are abstracting "pre-chilled" water and the cooling system operates more efficiently. Furthermore, provided that the seasonal water fluxes and seasonal heating and cooling loads are approximately balanced, all we really need to ensure sustainable operation is a well separation that corresponds to a value of t_{the} greater than a single heating or cooling season (i.e. greater than around 6 months).

The disadvantage of Mode 2 is that the roles of the wells are seasonally reversed. In aquifers such as the Chalk, where open holes can be used, this *may* not be such a problem. In porous medium aquifers, requiring well screens and gravel packs, the construction of recharge and abstraction wells may be very different to each other and their roles may not be automatically reversible.

4.0 MORE COMPLEX THAN ANALYTICAL MODELS CAN HANDLE?

Clearly, it is possible that we may reach a stage of complexity that the simple analytical models outlined in this paper cannot handle. For example:

- our recharge well may not be directly down-gradient from our abstraction well,
- heating/cooling loads and re-injection temperatures may vary in a complex manner through the year,
- we may be using more than just a single abstraction and re-injection well,
- the aquifer may be heterogeneous or may have complex boundary conditions,
- the abstraction may occur at a different elevation from re-injection (i.e. 3-dimensionality).

In such cases, we may have to send an emergency call to a groundwater modeller. Several models are available that simulate groundwater flow, solute transport and heat transport. In order of increasing expense, these are:

- SHEMAT (Simulator for HEat and MAss Transport) described by Clauser (2003). It comes packaged with a graphical user interface.
- HST3D (Heat and Solute Transport in 3-Dimensional Ground-Water Flow Systems). This is actually a public domain (free) finite difference code produced by the United States Geological Survey (Kipp 1997). In practice, it requires expenditure on a graphical user interface.
- FEFLOW (Finite Element subsurface FLOW system) – commercial finite element programme.

5.0 CONCLUSIONS

The involvement of hydrogeologists in thermogeological problems is likely to increase, due to the rapid uptake of ground source heat pump and passive cooling technologies. A common type of problem to be tackled is a risk assessment of the open loop well doublet system. It is common belief amongst engineers and environmental activists that, because such schemes may represent low-carbon heating / cooling alternatives, they are automatically “sustainable”. In fact, this is not necessarily the case, the phenomenon of hydraulic / thermal feedback may place a limit on the usable lifetime of the scheme, ranging from (in the worst case) several years to (in the best case) many decades. A risk assessment can be performed of several tiers, of increasing complexity:

<u>Tier 1:</u> Assessment of well separation in relation to hydraulic gradient, discharge rate and transmissivity (Equation 1). Is there a risk of thermal feedback?

<u>Tier 2:</u> Calculation of likely thermal breakthrough times and evolution of temperature of abstracted water following breakthrough. Is “lifetime” adequately long for scheme to be viable?

<u>Tier 3:</u> Numerical modelling of heat transport coupled to groundwater flow.

This type of risk assessment can be performed with most confidence in porous medium-type aquifers (sands, gravels, some sandstones). A significantly lower degree of confidence can be placed in the methodology for fissured and fractured aquifers (such as many limestones and crystalline rocks).

In order to improve sustainability (scheme lifetime), the following steps can be taken:

(i) increase well separation (L)
(ii) decrease pumping rate (Q)
(iii) reconsider scheme layout (e.g. chequerboard arrangement of several wells – Gringarten 1978), or re-injection to and abstraction from different horizons in the aquifer.
(iv) consider the viability of a balanced, seasonally reversible scheme.

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UNDERGROUND THERMAL ENERGY STORAGE IN THE NETHERLANDS

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ABSTRACT

In order to reduce the emission of greenhouse gases and the use of fossil fuels, and thus meeting the Kyoto Millennium Goals in fighting global warming, thermal energy storage is increasingly used in The Netherlands. Over the last 20 years various developments have led to an efficient implementation of this sustainable energy technology in Dutch aquifers and 600 systems are already in operation.

Energy storage in aquifers is used for cooling and heating in office buildings, hospitals, residences and greenhouses. With the use of groundwater, the surplus of heat in summer or cold in winter is stored in the underground and used in the following season. The groundwater temperatures around the up to 200 m deep wells, vary between 5 and 30 °C. For the exchange of energy between the building and the groundwater, a heat exchanger is used.

The potential of energy storage in the Netherlands is much higher than currently used: good aquifers are practically found everywhere. Especially in areas with a strong urban or agricultural development, the number of energy storage systems is increasing rapidly. Geothermal modelling is an important tool to guarantee the long term efficiency of the system and in order to get an abstraction licence. According to the Dutch Groundwater Act, energy storage is only permitted if the hydrogeological and geothermal impacts have been studied carefully and are acceptable. The results of geothermal modelling are also used by governmental institutions and developers for area planning to optimize the storage potential.

INTRODUCTION

One of the central problems with energy supply systems for buildings is that supply and demand are not simultaneous. In principle the sun, wind and outdoor climate provide enough energy, but not in the right place and time. If heat from the sun in summer could be stored, it would be useful for heating in winter. On the opposite, winter cold could be very handy for cooling in summer. Long term energy storage in aquifers offers a solution to bridge the gap between supply and demand.

Hydrogeologists in the Netherlands work together with consultants for energy supply systems, to create an optimal design of the energy storage systems. Drilling and technical installation companies subsequently take care of the implementation of the systems. This article briefly describes the Dutch practice and developments of energy storage in the Netherlands in the last twenty years and shows the opportunities and pressures to be dealt with in future.

HISTORY OF DEVELOPMENT

20 YEARS OF ENERGY STORAGE IN THE NETHERLANDS

In the late seventies and early eighties of the last century, a strong rise in prices for fossil fuels created attention in the Netherlands to find possibilities to realise energy savings and cost reductions. In this period the first demonstration projects for energy storage were carried out. The concept started with the storage of solar energy for space heating in buildings. The first energy storage system for cooling was implemented in 1987, for a printing office in Amsterdam. In the meantime approximately 600 projects are realised.

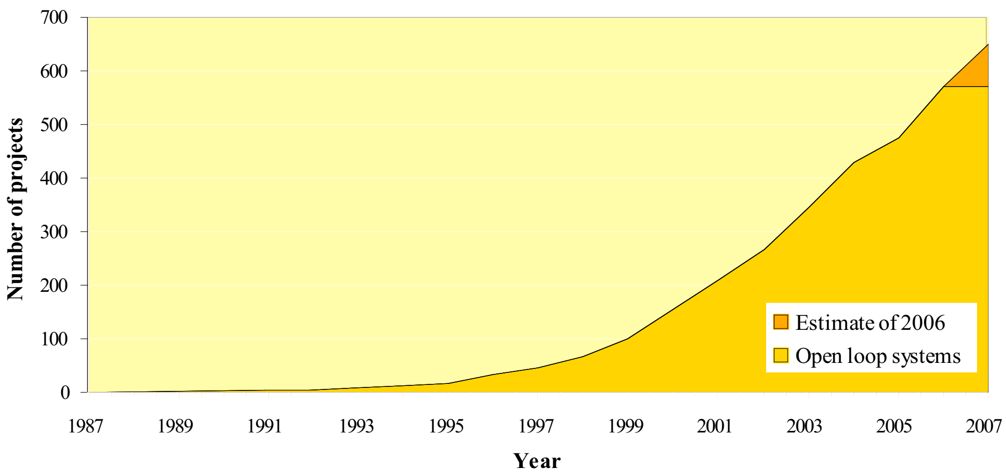

Figure 1: Increase of open loop groundwater source systems in the Netherlands 1987 - 2007

The first projects of underground thermal energy storage (UTES) concerned mainly direct cooling of large office buildings. According to this concept, in summer groundwater is abstracted from the aquifer. With the help of a heat exchanger energy is transferred from the groundwater to the building energy supply system and used for cooling. The groundwater is reinjected back into the aquifer by a second well. In winter the pumping direction of the system turns and with means of air handling units, dry coolers or cooling towers, cold is stored in the aquifer. After the successful introduction of the heat pump in the nineties, the systems could also be used for heating. With low temperature heat from the groundwater, a heat pump efficiently raises the temperature to the level needed. Providing both heating and cooling, increased the profitability of UTES systems.

In contrast to office buildings, in residential areas not the cooling but the heating dominates. The introduction of the heat pump broadened the market for UTES and at the end of the nineties UTES made its appearance in the residential sector. An advantage of UTES is that residences now also can have the luxury of cooling. That's why in the residential sector one often speaks about "adding comfort" in stead of providing heating and cooling.

In the new century, the broadening of the market and the exchange of experiences and knowledge between the different sectors, started standardisation of the technology. Standardisation resulted in cost reductions and made UTES also profitable for smaller office buildings.

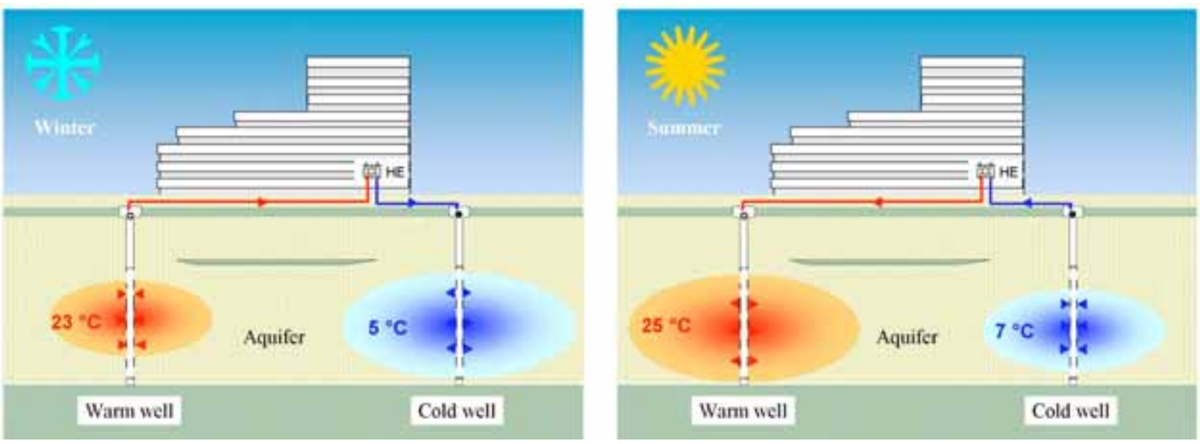

Figure 2: Most common system concept of UTES "cold and low temperature heat storage"

PRESENT STATUS

Area development

In the last couple of years energy storage is applied in large-scale projects. Several buildings in new urban or industrial areas make use of an individual system, or are connected to a collective groundwater source system. The discharge volume is based on the energy demand in the buildings. One of the largest collective systems realised, has a capacity of 2000 m^3/hour (20 MW). Collective systems have the advantage that energy can be exchanged between buildings and that they have a higher reliability. The result: lower costs and an efficient use of energy. Large-scale projects give developers and power companies possibilities to contract end-users or owners for 15 years or longer. This could result in a further enlargement of the financial feasibility of UTES projects in the Netherlands, especially in cases where projects would not be profitable for individual users or owners.

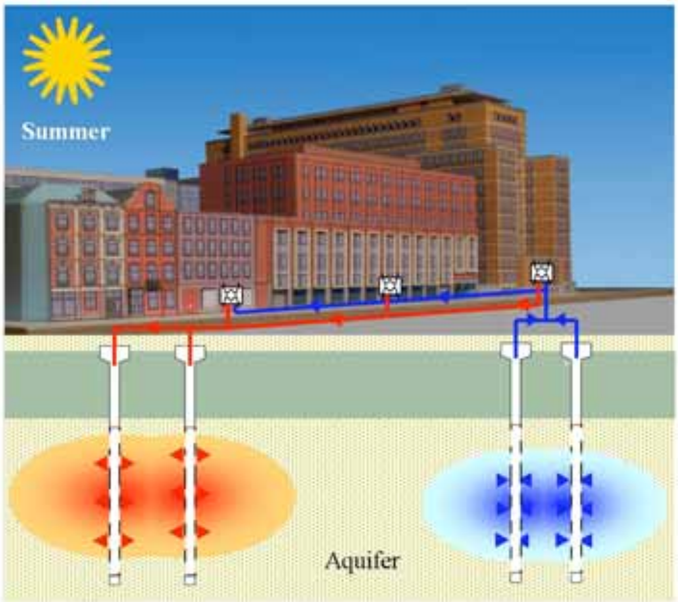

Figure 3: System concept of a collective groundwater source system

Commercial greenhouses

Greenhouses in the Netherlands are well known for their immense energy consumptions. The ongoing increase of gas prices and regulations from the government, which more and more restrict the use of fossil fuels, force growers to change their energy management and make optimal use of new technological developments. Energy storage is a good option to realize energy savings and is therefore often used and integrated with the specialized energy supply systems from greenhouses.

The system concept is strongly dependent on the type of cultivation. So is UTES used in combination with a heat pump when also cooling is needed. For the floriculture, a cogeneration unit in combination with a cooling tower could economically be more attractive than a heat pump. A cogenerator produces also electricity, beside heat. This electricity can be used for artificial lighting or can be sold to the local electricity network. Furthermore the production of CO_2 raises the crop yield.

Recently a rose-grower in Nieuwveen (NL), who already had a cogenerator, started a new energy demonstration project. For cooling, the rose-grower used to open its roof windows in summer. Now the greenhouse will close its roof windows in summer. A new type of heat exchanger (Fiwihex) is hanged above the roses. The heat exchangers are able to cool the greenhouse and store the summer heat in the aquifer for use in winter. In future the greenhouse will also provide district heating to a nearby residential area.

OPPORTUNITIES

POTENTIAL OF ENERGY STORAGE IN THE NETHERLANDS

Environmental and operational savings

Nowadays energy storage is considered to be a standard technology in the Netherlands for energy supply systems in buildings, residences or greenhouses. The investment is a little bit higher but the operational energy savings can amount to 50 or 80 %. Generally speaking, UTES is economically profitable with cooling demands starting from 200 kW.

Energy storage avoids the use of fossil fuels for both cooling and heating. The production of heat from natural gas, or cold from electricity (generated by the combustion of fossil fuels), causes a permanent damage to our environment. The burning of fossil fuels is the largest source of emissions of carbon dioxide, which is one of the greenhouse gases that contribute to global warming. In addition other air pollutants are produced, such as nitrogen oxides or sulphur dioxide, which are responsible for acid rain. Besides that fossil fuel supplies will run out on the long term.

The energy saving for the cooling part of UTES is expressed as electricity saving. The energy saving for the heating part of UTES is expressed as natural gas saving. The avoided primary energy is the sum of the contribution of both the cooling and heating part. For 2005 the avoided primary energy by UTES is estimated at 1 PJ (CBS, 2006). This amount of energy is sufficient for the heating of approximately 15.000 households. The total capacity of the systems in 2005 amounts 500 MWh.

The target of the Dutch government for 2020 is that 10 % of the consumed energy in the Netherlands is sustainable. They indicate that approximately 5% of this sustainable energy could be realised with UTES systems. This energy amount of 15 PJ corresponds with the consumption of natural gas of 230.000 households. Presumably this is only half of the technical potential of UTES, which is feasible with a payback period of 10 years or less.

The government promotes energy storage for organisations and companies through a few tax incentives and subsidies for bigger projects. Furthermore, provinces sometimes give financial support for local projects. For house owners, who make use of a collective UTES system in combination with an individual heat pump, a special “green-mortgage” exists. This mortgage has a low interest for the sustainable part (heat pump) of the house.

Figure 4: Presence of aquifers in the Netherlands (< 100 m)

Hydrogeology

The Dutch underground is extremely suited for energy storage through the presence and lithology of unconsolidated sediments, deposited in a subsiding basin. The axis of the basin dips to the north-west, resulting in the largest thicknesses (> 300 m) of aquifer systems in the north-western part of the Netherlands. Aquifer thicknesses are smaller at the margins of the basin. Especially on the eastern border, there are in some areas no exploitable aquifers at all.

For energy storage projects this means that in 90 % of the cases, one or more aquifers are present. But the depth and hydrogeological characteristics vary and determine the feasibility of the project. The deeper the wells or the lower the groundwater volume, the more expensive the system will be.

Figure 5: Drilling works and final injection well from a UTES system for a hospital

To make a rough estimate of the feasibility of a UTES project, information from hydrogeological databases is used. Together with information from the energy specialist regarding the energy demand in the building, a preliminary well design is made. Usually groundwater volumes of UTES systems vary from 20 to 250 m^3/hour. If the prospects are good and the client decides to go on, more detailed information about the often complex systems of sand and clay layers is needed. If nearby borehole-data or groundwater data are absent, often a pilot borehole needs to be drilled.

A pilot borehole gives information about the permeability of the aquifer. In combination with the expected operating hours of the well an optimal well design can be made. Groundwater samples are taken from different depths, which give relevant information about the existence of water quality changes within the aquifer. These data are very useful to reduce the risks of well clogging by mixing of different water types. Groundwater samples are also used for material selection of the different components in the energy storage system (salt water).

Special equipment, like the Geoflo™ instrument, is used to measure the direction and speed of the groundwater flow in a horizontal slotted borehole screen. This information is used to predict the amount of energy losses around the wells by natural groundwater flow. If the energy storage is not feasible, the system concept has to be changed to “abstraction and injection”. This means that the injected energy will not be used in the following season because the flow direction in the system is one way: from the abstraction to the reinjection well. The energy supply system of the building, uses always the natural groundwater temperature from 11 °C, for both cooling and heating. The advantage of this system is that it is cheaper, but with the same flow volume and smaller temperature differences between the wells, the heating or cooling capacity of the system is lower (box 1).

Box 1: How much groundwater is needed to meet the energy demand ?

For calculating the needed groundwater discharge to meet the energy demand in the building, the following rule of thumb is used in the Netherlands:

$$Q = P / (\Delta T \times 1.16)$$

Q : total discharge volume of wells (m^3/h);
P : cooling /heating capacity (kW)
ΔT : difference of groundwater temperatures between wells (K).

PRESSURES

ENVIRONMENTAL REGULATIONS

In the Netherlands groundwater is a protected resource by law (Groundwater Act, 1981) and is therefore monitored by the provincial government to ensure the sustainability of quality and flow volume. All abstractions of more than 10 m^3/hour or 12.000 m^3 a year, usually require a permission. This holds also for thermal energy storage in aquifers.

Due to the fact that UTES is in principle a sustainable technology and will create energy savings, provinces are positive regarding its implementation. Nevertheless regulators only grant abstraction licenses if is demonstrated that environmental impacts from the abstraction and injection of groundwater are acceptable. Because groundwater interests differ in each province, also the regulations for energy storage differ strongly. But in the last few years provinces have reached more uniformity in their policy towards energy storage (box 2).

If the abstraction license is granted, the owner of the system in obliged to register the maximum groundwater flow rates, the annual volume and injection temperatures. Furthermore right before operation a water quality analysis has to be carried out.

Box 2: Most common requirements of provinces regarding UTES

- The energy storage has to be energetically balanced, at least over a period of 5 years. This means that the total amount of stored and extracted energy (heat and cold) should be equal. Net the system is not allowed to warm up or cool down the groundwater environment;
- Permitted infiltration temperatures are generally not cooler then 5 °C and not warmer than 25 °C. Some provinces do not allow a mean annual infiltration temperature in the warm well above 20 °C, with a maximum of 25 °C. Others allow temperatures of 30 °C;
- Energy storage is not allowed in protected areas for drinking water supplies;
- In a few provinces certain aquifers are reserved for the purpose of drinking water only;
- The use of the aquifer for energy storage should not cause changes in the depth of the transition from fresh to brackish and saline groundwater;
- The energy storage should not have negative effects on the efficiency of nearby energy storage systems or other groundwater abstractions for which the use of groundwater is already permitted;
- The abstraction of groundwater should not cause damage to foundations of buildings or infrastructure, as a result of the lowering of the groundwater table.

Because all groundwater is reinjected back into the aquifer, the use of groundwater for energy storage is exempted from paying groundwater taxes.

To prevent clients to become disillusioned because abstraction licences are not granted, in UTES projects the hydrogeologist has to inform the client or energy specialist about the following:

- In the design of the energy supply system of the building one has to take into account that the UTES system has to be energetically balanced. This is not a problem if the heating and cooling demand in the building is equal. Otherwise measures has to be taken so that the user is able to correct the balance, for example by loading additional cold in winter;
- The user has to remain within the limits set in the abstraction license concerning the maximal and annual groundwater volumes and temperatures. This means that in the design process one has to take into account extreme climatic years, and the control and monitoring system has to be developed so that these limits will not be exceeded;
- Start a project with an investigation of possible bottle- necks concerning local hydrogeological conditions and obstacles for license granting.

GEOTHERMAL MODELLING

According to the Dutch Groundwater Act energy storage is only permitted if the hydrogeological and geothermal impacts have been studied carefully and are acceptable. This involves the development of a numerical groundwater and heat transport model to help predict changes in groundwater levels and temperatures in the aquifer, as a result of the operation of the UTES system.

Geothermal modelling is also an important tool to guarantee the long term efficiency of the system. Clients may become disillusioned if the long term system efficiencies are not as great as in theory. Therefore the hydrogeologist needs to ensure that predictive modelling of the long term and seasonal changes from the extracted groundwater temperatures in the wells, is integrated in the design process.

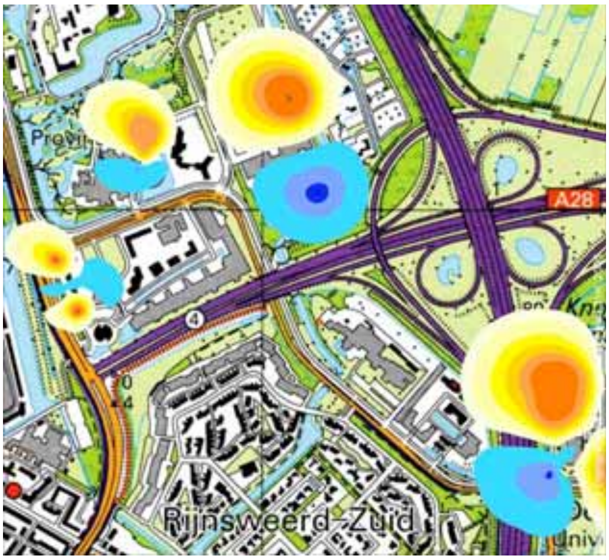

Figure 6: Heat and cold loads in the underground at four UTES locations in Utrecht, NL (FEFLOW)

For the modelling of energy storage systems Fugro uses the software program FEFLOW. With this program a three dimensional numerical groundwater and heat transport model of the area is built. In the model the seasonal change form abstraction to reinjection of groundwater between the warm and cold water wells is simulated for a period of twenty years. With the modelling results the minimal well distance can be determined, for which the heat and cold loads do not influence each other. The period of time needed to create an optimal loaded system, can also be estimated. The calculated abstraction temperatures in the well at the beginning and end of the cooling or heating period, give an indication of the efficiency of the system. If the system is not used between the cooling or heating period and natural groundwater flow causes energy losses around the wells, the modelling results will show temperature changes around the wells.

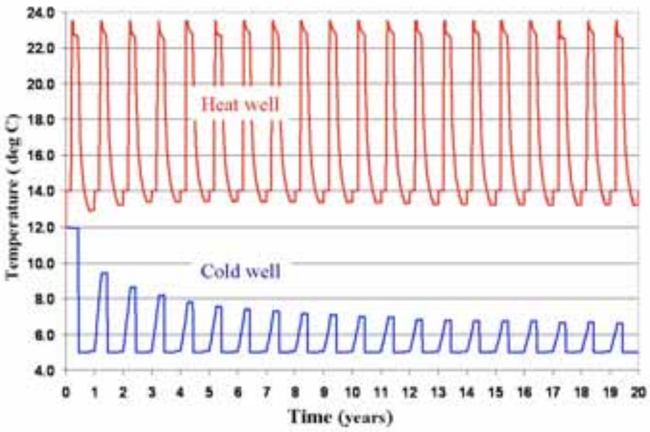

Figure 7: Prediction of long term efficiency of the system: calculated temperatures in wells.

Because the total amount of abstracted groundwater is reinjected back into the aquifer, the hydrogeological effects of the systems are usually limited to a few hundred metres from the well locations. The transport of heat or cold in the aquifer has a retardation towards groundwater flow. The area of influence concerning temperature changes, is therefore smaller then the area of influence in which groundwater level changes occur.

Although the effects of energy storage usually are limited, in some areas the rapid increase of energy storage systems causes pressures on the use of subsurface space. Abstraction licenses are traditionally granted conform the principle “first come, first served”. Informing about possible nearby energy storage systems is therefore more then earlier needed. If so, the well locations could be chosen in such a way, that the two systems will strengthen each other.

Governmental institutions and developers need the results of geothermal modelling nowadays more and more for area planning. By defining optimal locations of warm and cold water wells for the area, an optimal use of the storage potential of the aquifer can be reached.

CONCLUSION

In the last twenty years the use of Underground Thermal Energy Storage (UTES) systems in the Netherlands shows a continuous and strong increase. Energy storage has become a standard technology, fully integrated with the energy supply systems of buildings, greenhouses and residences. Stimulation of the development by governmental institutions, intensive cooperation between different sectors and consultancy firms and optimizing the technology to the aquifer characteristics, strongly underlie this increase. Standardisation, the broadening of the market and energy savings, ensure a further implementation of UTES in the future.

The latest trend in UTES is that developers and power companies are implementing the technology on a larger scale (collective systems) in urban areas. Here, and also in agricultural areas, the need of area planning to optimize the storage potential increases. The task of the hydrogeologist, as a consultant of all underground aspects of the UTES system, plays an important part in creating optimal efficiencies, in obtaining the required licenses and in optimizing the storage potential of an area. Geothermal modelling (groundwater flow and heat transport) is an indispensable part of the work.

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Session V

MINERAL WORKINGS – CONSIDERATION OF THE POTENTIAL FOR IMPACT ON THE WATER ENVIRONMENT

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ABSTRACT

The winning of minerals for use in a wide variety of engineering, manufacturing and building activities has a long history in the UK and Ireland and can contribute significantly to the economic prosperity of a region.

Whilst the importance of this industry is acknowledged, it is also recognised that mineral working has the potential to impact the environment in a variety of ways. In particular, there is potential for mineral workings to impact the local water environment by altering local surface water or underground groundwater flow regimes. Such impacts could manifest themselves as alteration of flow to nearby streams and rivers, reduction in yield at nearby boreholes and/or lowering of the water table at a sensitive ecosystem. Water quality may also be affected by pollution incidents at the quarry or where water containing high levels of suspended solids is discharged to surface water ecosystems.

New planning and environmental legislation increasingly requires developers to assess the potential for such impacts both for new mineral working sites and extensions and retrospectively for existing sites.

This paper presents an overview of the main issues that should be considered when investigating or reviewing the potential for impact on the water environment from mineral workings.

INTRODUCTION

The extraction of industrial minerals from shallow workings (quarries) has a long history in the UK and Ireland. As industrial development and urbanisation increased, the demand for minerals similarly increased. Development of mineral workings is essential to support national and regional development, generates direct and indirect employment and contributes to prosperity in the local economy.

The minerals extracted are used for a wide range of purposes including industrial processes such as cement manufacture and glass and ceramics production. They also provide the basic raw materials for construction and infrastructure developments including concrete production and road stone hardcore. The minerals are also used in the agricultural industry for soil improvement and as a constituent of animal feed and in processes associated with sewage treatment.

Minerals commonly extracted in Ireland include sand and gravel, limestone (including chalk in Northern Ireland) and gypsum along with aggregate stone from basalt, greywacke and schist quarries. The range of deposits available for extraction reflects the wide diversity of geological settings found across the island of Ireland.

Whilst extraction by quarrying represents a relatively straightforward industrial and engineering process, it has the potential to have a complex range of effects on the natural environment. Impacts can include visual or noise intrusion and deterioration of air or water quality. Some predicted impacts may be significant and in certain cases unacceptable in the context of the planning and environmental regulatory regime in operation at the time.

There is a particular risk of quarrying activities impacting the local water environment in the vicinity of the workings. Risks to both the surface water environment and groundwater principally arise from either:

i) Alteration of existing flow/drainage regimes or
ii) Introduction of pollutants from site activities.

New quarry developments fall within the current development & control planning regulation regimes and when making a planning application for new sites (or extensions to existing sites), developers are required in most cases to consider the full potential for impact on the local water environment. There are however many older sites where mineral winning permissions were issued under previous legislative frameworks. These "older" frameworks gave less priority to environmental protection and there is now scope for review and updating of these older mineral permissions.

LEGISLATION IN NORTHERN IRELAND

In Northern Ireland (NI) mineral workings falls within the Planning (NI) Order (1991). Applications for proposed new quarries and extensions to existing sites are generally determined to require an Environmental Statement as defined under The Planning (Environmental Impact Assessment) Regulations (Northern Ireland) 1999. The Environmental Statement should include some assessment of the local geology and the potential for the development to impact on the water environment.

The Planning Service NI recently introduced legislation to deal with the legacy of previous permissions. The Review of Old Mineral Permissions (ROMPS) [(1)] aims to ensure that historically permitted quarries will, in future, operate to a standard commensurate with present day environmental protection expectations. The new legislation will, amongst other things, apply revised and/or additional planning conditions to permissions in order to minimise or mitigate potential environmental impacts and ensure that operations meet the requirements of current European Directives on environmental impact.

The EC Water Framework Directive (2000/60/EC) is the most comprehensive piece of legislation introduced to date with the purpose of protecting the entire water environment. The Directive provides a holistic framework for the long-term sustainable management of water resources and water quality, including protection of associated water dependent ecosystems. Implementation of the WFD has required a comprehensive review of the risks that a wide range of activities, including quarrying, pose to water quality and water resources. Where activities are considered to represent a risk to water bodies or dependent ecosystems, further consideration must be given either in the form of monitoring, improved risk assessment or introduction of mitigation measures.

Similarly, the Habitats Directive (92/43/EEC) requires consideration of activities in the vicinity of designated sites such as wetlands and peat bogs with the aim of ensuring the sites achieve and retain their designation objectives.

MINERAL EXTRACTION TECHNIQUES

There are several common techniques used in shallow mineral workings, with the one selected determined principally by the geological and hydrogeological setting of a particular site and the degree and rate of development required at the site, generally based upon economic factors.

(1) – The Planning Reform (Northern Ireland) Order 2006 which incorporates the requirement to review old planning permissions (ROMPS)

Some of the main methods for unconsolidated deposits such as sands and gravels are:

- Dry working where mineral extraction is restricted to above the maximum seasonal water table.
- Dredging where minerals are extracted from below the surface water level or groundwater water table without direct management of the water.
- Dewatering and extraction where some form of control is applied to the natural water table to allow machinery and plant access to remove minerals from below the natural water table.

Quarrying in bedrock involves similar techniques with dry working above the water table and dewatering where extraction of minerals is desired below the water table. Extraction of minerals is facilitated in some cases by blasting with explosives or rock drilling to free rock for collection and transport.

POTENTIAL IMPACTS

As suggested above, the potential for impact on the water environment is significantly dependent upon the geological and hydrogeological setting as well as the intended method of working.

The location of a quarry or pit will partly determine impacts on surface water and existing drainage routes. Where minerals are to be removed immediately adjacent to or beneath existing waterways, the direct impact is obvious. The hydrogeological setting at a particular location however could also have an impact on surface watercourses and wetlands where the quarry intersects the established flow of groundwater and alters this natural flow either due to barrier effects, creation of new flow routes or due to alteration of groundwater gradients by pumping. Changes in natural groundwater levels can also impact other features such as springs and borehole supplies. Some of these potential impacts are illustrated in Figure 1 and are discussed further in the next section. There can also be effects on the quality of groundwater and surface water.

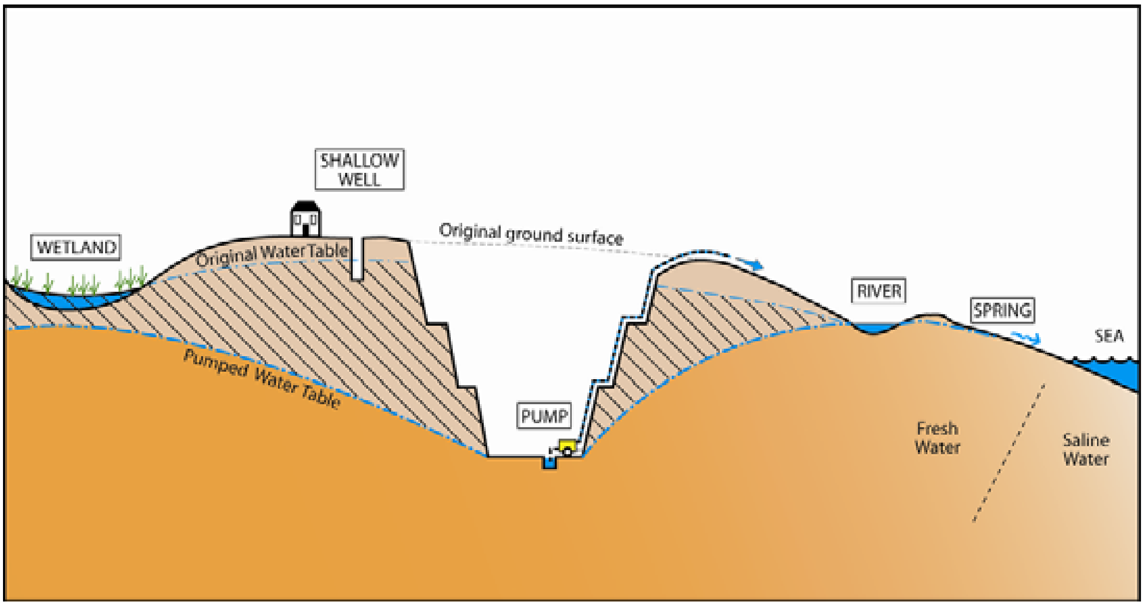

Figure 1 Schematic diagram showing effects of dewatering

DEWATERING

Where mineral extraction involves working strata below the natural level of water (the water table), some form of water control is usually required to allow and maintain access for plant machinery and personnel for the lifetime of the site. In Ireland, the most common dewatering methods involve suppressing the water table in and around the site either by direct abstraction or by gravity drainage from a low point (sump) within the site. The amount of water to be abstracted will strongly depend upon the nature of the geological deposit and more specifically it's associated hydrogeological properties.

Sub-water table working in sand and gravel deposits can require management of increasingly large volumes of water as the workings go deeper and intersect an increasing cross-section of the saturated zone of aquifer. In certain bedrock formations which are 'poorly productive' and where the most active flow horizons are in the upper zones, deeper working may not necessarily result in any significant increase in inflow due to the absence of open and connected fractures within the rock at depth. In karstic limestone settings, common in Ireland, groundwater movement is complex with discrete high flow zones, making prediction of possible inflow rates to quarries difficult. Further information on the implications for quarrying of different aquifer types is given in a report produced by the Environment Agency (2002).

Determination of the dewatering required to produce the required amount of drawdown of water levels around a quarry can be challenging. A range of approaches are taken and it is important to appreciate the limitations and assumptions made with each technique.

One approach is to use standard 'pump test' equations. Often however, these are applied with limited or no site-specific field data and using assumed aquifer parameters. Whilst the normal approximations are assumed regarding theoretical 'ideal' aquifer starting conditions, the additional influence of the nature of the abstraction point along with possible changes to local aquifer permeability as a result of rock blasting and working is not generally taken into account. In some instances less evolved equations, developed for estimation of water level drawdown around temporary open workings such as excavations for building foundations are used (e.g. CIRIA Report 113, 1986). At the other end of the range, it is possible, with adequate investigation and field data collation, to develop detailed and calibrated computer models which should offer a better representation of actual ground conditions.

In order to maximise confidence in whichever method is used to predict or determine alterations to water levels, around mineral workings it is essential to review the theory, approximations and assumptions used. This is particularly important for the majority of bedrock hydrogeological settings in Ireland where groundwater flow through fractures/fissure networks complicates the prediction of drawdown.

It is therefore clearly necessary to understand the local hydrological and hydrogeological regime in the general area of a proposed site before it is possible to determine the potential risks that a quarry development or working method poses to the water environment and dependent ecosystems.

IMPACT RISK ASSESSMENT

In Northern Ireland, most planning applications for new quarries or pits or extensions to existing quarries must undergo an Environmental Impact Assessment (EIA) or be accompanied by an Environmental Statement (ES). The assessment should include an appropriately detailed investigation and analysis of the hydrological and hydrogeological setting of the site and surrounding area. The process is deemed critical to determining the acceptability or otherwise of a quarrying activity at a particular locality

Some of the key aspects of this assessment considered necessary are:

DESKTOP REVIEW

The desktop review is a common first stage for many types of proposed developments. This involves collation of all readily available relevant information. Table 1 includes some of the information that can be obtained during this process and possible sources for such information.

Table 1. Information readily available for desktop review

Data	Information	Data Source (NI/RoI)
Ordnance Survey Maps	Watercourses, wetlands, lakes, wells, springs	OSNI/OSI
Aerial Photographs	Local setting including wetland habitats	
Geological Maps	Geological setting	GSNI/GSI
Aquifer Maps	Hydrogeological properties	
Vulnerability Maps	Potential for groundwater quality impact	
Borehole logs	Detailed geology/hydrogeology	
Groundwater Quality Data	Background conditions	EHS/EPA
Surface water quality data		
Groundwater level records	Background conditions and water balance	
River flows		EHS & Rivers Agency/EPA
Rainfall		Met. Office/Met Eireann
Habitat Listings	Potential sensitive receptors	GSNI/EHS/DWI/ GSI/EPA/ DoEHLG
Water abstraction locations		

SITE WALKOVER

Following the desktop review, it is recommended that a site visit and walk over survey is carried out by a suitably qualified person. This will allow a direct appreciation of the setting and confirmation or otherwise of data gathered previously. Where the proposal is for an extension to an existing quarry or located close to an existing quarry, direct observation of the site and discussions with experienced quarry workers can yield much useful additional information, for example regarding water pumping rates required to keep the workings dry or whether water management is only a problem at certain times of the year.

WATER FEATURES SURVEY INCLUDING MEASUREMENTS

A key element of assessment is the identification and investigation of water features such as wells, springs, wetlands and watercourses in and around the proposed development which could be impacted by surface water diversion or groundwater dewatering. The aerial extent of this survey should be based on the professional judgement of the hydrogeologist or engineer undertaking the survey and will be informed by information obtained during the desk-top review and site visit. For example the geological setting may be such that one area adjacent to the development may be in a different rock type to where the quarry is proposed with no hydraulic contact between the different units hence less consideration of water features in this area could potentially be justified. It is important to systematically document each feature identified including any measurements taken and when they were taken (e.g. springflow, water level in shallow well).

DRILLING

Once the above steps in the assessment process have been completed then the need to undertake more site-specific investigation can be assessed and planned. Normally this includes the installation of monitoring boreholes to measure water levels and water quality along with, where relevant, measurement of surface water flows, levels and water quality within nearby surface water features and/or wetlands. This phase of the investigation can be costly and hence the design of the monitoring network must be properly considered. Monitoring points should be located so that they allow confirmation or characterisation of the local hydrogeological setting, including relationships between groundwater and surface waters/ecosystems. The desk top review, site visit and water features survey will enable an initial conceptual model of the hydrogeological setting to be established which then informs the design and location of the monitoring points. If all available information indicates that the workings are likely to be above the seasonally high water table then the need to install monitoring boreholes may be minimised.

The drilling and monitoring phase of the assessment can be costly, however much useful information can be collected which can benefit the quarry developer. This includes a better assessment of the available mineral resource and potential problems that may be encountered during development (e.g. faulting), which in turn allows a more detailed and efficient, quarry design, working methodology, cost estimates and management system to be developed.

It has been common in the past to have environmental statements produced with one or more of the above steps absent or not properly completed. This has resulted in monitoring points being installed which are either too shallow, not in the correct location or insufficient in number (density). This can often result in the planners or their statutory consultees being unable to determine the potential impacts of the site, causing a delay in the planning permission process and potentially entailing avoidable, additional expenditure for the applicant.

Another common shortcoming in the drilling phase of the assessment is where inadequate time has been allowed for the investigation and monitoring programme. A very short (sometimes only a single value) data time series is collected for parameters such as water levels or flows which does little to enhance understanding of seasonal effects.

PREDICTING IMPACT

When all the phases of the site investigation have been completed, a more detailed conceptual model of the geological, hydrological and hydrogeological setting of the site and its immediate surrounds can be compiled. This model will aid the process of estimating impacts from the quarry development on the water environment. For example, if dewatering is required to control water inflow to the quarry then predictions of the resulting ‘drawdown’ effects on the local water table level can be made and this will in turn allow an assessment of the potential impacts on dependent water features such as springs or wells. The model will also identify the need or otherwise for other regulatory permissions such as an *abstraction licence* for dewatering or a *consent to discharge* to dispose of the water being pumped from the quarry. The model can also be used to help with site design; for example, to help locate settlement ponds required ensuring that any discharged water contains less suspended solids than the maximum permitted by the discharge consent

Further guidance on environmental assessment can be found in Symonds Travers Morgan, 1998.

WATER QUALITY IMPACTS

In addition to potentially impacting local surface water and/or groundwater flow, development of a mineral working site has the potential to detrimentally alter water quality. An obvious example arises where water collecting within the quarry is discharged from the site, commonly by gravity drainage or by pumping, to an adjacent surface watercourse. Quarry operations are such that water in the quarry area usually has a relatively high suspended solids content comprising soil, rock and dust particles. The discharge of water away from the site will generally be controlled by an authorisation issued by the water regulator who will specify a maximum suspended solids content for the water being discharged. To ensure that discharged water does not exceed this limit, settlement ponds/lagoons must be provided within the quarry. Careful planning of the location, nature and size of such features is necessary to ensure sufficient storage capacity to cope with the normal seasonal water as well as water generated during less frequent high rainfall events across the local catchment.

In addition to management of site drainage, provisions are required to prevent pollution from other normal site activities. These activities can include foul drainage associated with toilet and canteen facilities and storage of oils and fuel for vehicles and machinery. Standard pollution prevention measures associated with oil and fuel storage include provision of hard-standing and bunded areas with oil/water interceptors and are similar to those typically employed at many sites irrespective of their nature. However, the continually changing profile of a quarry environment often requires moving storage or refuelling areas, and this process can introduce additional risk factors which should be properly incorporated into site management practices. Removal of mineral deposits also reduces the natural protection available to the underlying groundwater; hence pollution events in such settings can result in a more immediate and significant impact. Consideration should also be given to the proposed restoration plan for the development. Abandoned mineral workings have commonly been used for waste disposal with the inherent risks to the water environment associated with this activity.

DEVELOPERS, PLANNERS AND CONSULTEES

Planning Authorities within Great Britain & Northern Ireland, do not generally have the in-house technical expertise required for assessing, in detail, Environmental Statements produced in support of planning applications. In Northern Ireland review of the assessment of impact on the water environment is usually undertaken by Environment and Heritage Service (EHS) as a consultee in the planning process.

The Planning Authorities may judge, usually on the advice of a statutory consultee such as EHS that inadequate environmental impact assessment has been carried out. In such situations the planning authority will request that additional environmental information be provided by the applicant to address the specific gaps identified by the consultee. This will result in an extension of the planning determination process and potentially involve additional unnecessary expenditure for the applicant (compared to a full and proper assessment being undertaken at the outset). It is therefore prudent that the applicant and the consultant employed by the applicant have a proper appreciation of the likely degree of assessment required by the statutory consultees. To assist with this, EHS, in conjunction with the Geological Survey of Northern Ireland, have produced a guidance document (EHS, 2004), which outlines the typical issues that require consideration when assessing potential impact on the water environment from such developments. Similar advice is contained in the Geology in Environmental Impact Statements publication (IGI, 2002).

Even though a review consultee may have determined that an environmental impact assessment has been adequate, the hydrogeological setting of a site may be such that uncertainty remains as to whether a predicted impact will be realised at a receptor. In such cases the preferred option may be to undertake precautionary monitoring with agreed measures to be implemented should adverse effects be detected. Addressing this element of uncertainty within planning permissions as specific conditions can present problems for certain planning authorities due to the legal and technical framework in which they operate and due to the increasing complexity of conditions and associated economic instruments required to ensure that protection of the environment is legally sound and enforceable. A mutual appreciation of the context in which both the planning officers and statutory scientific specialists operate can benefit the decision-making process.

MITIGATION MEASURES

Where assessment indicates the potential for impact on nearby water features, a range of mitigation measures can be considered which may address some or all of the concerns identified. A variety of mitigation measures case studies are reported in Wardrop et al. 2001.

SITE DEPTH/EXTENT

The planned site extent and/or depth of working may be modified to reduce an identified risk of impact. In particular, where dewatering would be required, reduction in depth of working will reduce the volume and duration of pumping necessary. This option can however have obvious consequences for the economic viability of a site.

PORTION WORKING

In some cases more careful planning of the extraction phases of the site can reduce the length of time that impacting activity is required. Rather than operating a large open floor space where increased water management is necessary, smaller working areas can be used and progressively restored reducing the area that needs to be kept dry and by implication reducing the volumes of water pumped.

WATER RECIRCULATION

In certain hydrogeological settings it may be possible to consider local recirculation of pumped water within the dewatered strata. This is a common practice in sand and gravel workings where recharge via boreholes or trenches outside of the area of working helps reduce the lowering of water levels in the aquifer outside the site. The intergranular porosity and unconsolidated nature of sands and gravels means that this is a relatively low cost mitigation measure in terms of installing and running a successful recharge system. Use of water recirculation schemes in bedrock aquifers is less common and generally a more complicated process in terms of returning water to the aquifer in sufficient quantities, to the right location.

FLOW/LEVEL SUPPORT

Where the minerals workings represent a risk to surface water features such as streams, rivers or wetland areas, careful consideration of where and how water abstracted from the quarry is discharged to can offer potential mitigation options. Where water can be discharged directly into the watercourse being affected by the dewatering, impacts over a short length of the watercourse may become acceptable where this is considered as a temporary situation for the lifetime of the site. Similarly, for wetland sites at risk of drying out, diversion of water to maintain ‘wetness’ may be an option. Such schemes do however require careful consideration of hydrogeological and ecological conditions. For example, is the natural chemistry of the water being discharged from the quarry sufficiently similar to the natural water chemistry of the wetland and will any difference be significant for the dependent ecology. In a study of two wetland sites adjacent to a limestone quarry in Northern England, hydrological and ecological monitoring revealed a disparity between the wetland site which received water from the quarry workings and an adjacent wetland area with no such inputs (Mayes et al, 2005). The less diverse habitat found in the wetland closer to the quarry and to where water was discharged was attributed to the wider range of water level fluctuations experienced, the chemistry (in particular pH) of the water input and higher sedimentation rates.

WATER SUPPLY OPTIONS

Options for obtaining alternative water supplies can be considered where existing water sources such as wells, boreholes or springs could potentially be impacted by falling water levels resulting from quarry dewatering. Solutions could include the deepening of existing wells or drilling new deeper wells, or provision of a supply from the local mains water system. Such alternatives would require negotiation between the developer and the owner of the water sources. Other issues to be considered include: the need for new pumps and plumbing, additional treatment costs and even potential future mains water supply charges.

MONITORING WITH CONTINGENCY

The exact requirement for mitigation measures can sometimes be difficult to predict and where these involve a significant cost to the developer, their implementation can potentially be linked to ‘trigger’ criteria. Such criteria could be set for example in association with monitoring of water levels or flow at designated locations such that where conditions exceed a determined trigger level, an agreed mitigating action would be implemented. The sensitivity and/or importance of the particular feature being protected will generally determine the depth of understanding and degree of monitoring required, to ensure suitable protection.

CASE STUDY

LIMESTONE QUARRY, COUNTY FERMANAGH

Blasting and stone removal from a quarry in limestone bedrock had been undertaken intermittently for number of years. Planning permission for the quarry had been granted with the condition that extraction below the water table should not occur but this ‘level’ had not been precisely defined and the hydrogeological assessment undertaken at the time was limited. The quarry is in close proximity to a series of turloughs (seasonally flooded lakes in karstic limestone terrain), the only examples of such features in Northern Ireland. The Environment & Heritage Service has designated these turloughs as “Special Areas of Conservation” under the EC Habitats Directive.

Concerns had been expressed both by local residents and by the environmental regulator regarding potential impacts that quarrying activities were having on the flow of water to the turlough sites with the general impression being that the duration of inundation with water was decreasing with time.

Following an initial investigation by EHS conservation officers, it was considered that there were legitimate concerns with respect to the potential for impact from the quarry workings. The local hydrogeological setting in and around the quarry and adjacent wetland areas is, as would be expected in a karstic setting, complex. Whilst the quarry did not actually routinely operate a dewatering scheme, groundwater (in the form of springs/seepages) was entering through the quarry faces on an intermittent basis. Specialist advice was sought regarding the hydrogeological setting and potential for impact and following an initial study it was determined that there was sufficient justification to apply a Discontinuance Notice under the Planning (NI) Order (1991) on the grounds that there was a possibility of impact at this important site. As a result, planning permission to extract rock was withdrawn by the Planning Service, and the quarry owner was required to submit a restoration plan. Compensation to the quarry owner is now under consideration. A more detailed investigation of the hydrogeological setting is underway to determine the need or otherwise for remedial action to minimise any impacts identified from the existing works. As part of this further study continuous monitoring of spring flows and water levels in the turloughs was initiated in addition to a series of water tracer experiments designed to better define local groundwater flow ‘catchments’. To support this work, a temporary meteorological station has been installed to facilitate accurate gauging of rainfall and evaporation and calculation of a local water balance.

SUMMARY

The quarrying of minerals for a wide range of uses is an intrinsic part of the economic and industrial ‘life’ of most societies. By their very nature, quarries involve disturbance of natural conditions and the potential exists for a range of impacts to occur.

To enable a balanced decision to be made as to whether mineral extraction is acceptable and sustainable in a particular locality, it is important to undertake a properly planned and targeted assessment of potential impacts. With respect to potential impacts on the water environment it is essential to develop a conceptual model for the hydrological/hydrogeological setting of a proposed site. The model should encompass all nearby receptors such as wells, springs and wetlands that could be impacted by alteration of existing flow, water level or water quality conditions.

Where a suitably comprehensive assessment is undertaken, options for working methods and/or requirements for specific mitigation measures can be considered with greater confidence. This leads to informed decision making regarding the acceptability of a proposed development. Where inadequate investigation and assessment have been carried out, much greater uncertainty surrounds the nature and degree of potential impact and this inevitably will result in delays in the planning process or refusal of a particular application.

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Environment and Heritage Service, 2004. Assessment of Environmental Impact (Water Resources) - mineral workings guidance note

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Mayes W M, Large A R G and Younger P L. 2005. The impact of pumped water from a de-watered Magnesium limestone quarry on an adjacent wetland: Thrislington, County Durham, UK. Environmental Pollution 443-454.

Symonds Travers Morgan 1998. Reducing the effects of surface mineral workings on the water environment. A guide to good practice. DETR

Wardrop D R, Leake C C, and Abra J. 2001. Practical techniques that minimise the impact of quarries on the water environment. *Trans. Instn Min. Metall. (sect. B: Appl. Earth sci.)*, 110

USEFUL RESOURCES

www.goodquarry.com - website administered by Mineral Industry Research Organisation. It contains useful overview for all environmental issues associated with quarrying along with a range of case studies looking at, amongst other topics, water impact issues.

www.gsi.ie – Geological Survey of Ireland

www.bgs.ac.uk\gsni - Geological Survey of Northern Ireland

www.imqs.ie – Irish Mining and Quarrying Association

www.qpa.org – Quarry Products Association (includes Northern Ireland)

The views expressed in this paper are those of the author and not necessarily those of the Geological Survey of Northern Ireland.

AGRICULTURAL PRESSURE – FARM AND NATIONAL SCALE CASE STUDIES & RISK ASSESSMENT

Pamela Bartley, Hydro-G
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ABSTRACT

In this paper, two distinct studies are presented. The focus of the detail is nitrate concentrations in groundwater. Firstly, a detailed farm scale study is presented whereby the hydrochemical response in groundwater to intensive dairy farming agriculture in a setting that is known to be hydrogeologically vulnerable is presented. The NO_3 concentrations found in the groundwater indicate that farming practices as conducted in 2001 and 2002 in vulnerable environments, such as Curtin's farm, need to be modified in order to ensure future compliance with the Nitrates Directive (EC, 1991). With respect to identification of the loadings that most significantly influenced groundwater NO_3-N concentrations – R_{eff}, or hydraulic loading, and the intensity of animal grazing were identified as the main drivers in the system. The organic N-loading rate is a crucial manageable factor in controlling N loss to groundwater. This finding supports the aim of the Nitrates Directive (EC, 1991a) to restrict grazing intensity in vulnerable areas. The importance of the N contributions and hydraulic loadings by grazing animals should not be ignored in future.

*Secondly, this paper describes the verification of the predictive risk assessment methodology for the impact of diffuse source mobile inorganics, such as nitrate, on the chemical status of various types of water body, including groundwater bodies. This risk assessment is part of 'initial characterisation' of the Water Framework Directive. Due to insufficient available water quality data, a predictive risk assessment approach was followed to enable a risk category for the water body to be determined, which was then adjusted if adequate representative monitoring data were available. The critical factors in determining the impact of nitrogen loadings on groundwater are **pathway susceptibility**, **pressure magnitude**, and the resulting **impact potential**, which is determined by combining the first two factors. The initial risk assessment for the groundwater bodies, which was undertaken at the end of 2004, categorised 78 groundwater bodies as being 'probably at significant risk', with the remaining 668 bodies falling into the 'probably not at significant risk' or 'not at risk' categories.*

It is important to note that although these projects ran concurrently, they were not designed to corroborate each other. However, results from both studies provide evidence that groundwater vulnerability concepts are valid in terms of nutrient response in groundwater. In addition, both studies found that livestock density is a valid indicator of pressure on a groundwater body, in hydrogeologically vulnerable areas. This validates the aim of the Nitrates Directive, which suggests that organic N loading (or animal density) is a key factor in groundwater nutrient concentrations.

1.0 FARM SCALE GROUNDWATER INVESTIGATION

Pamela Bartley *et al.*

1.1 INTRODUCTION

A three-year investigation undertook to measure nitrate concentrations in subsoil and groundwater under a grassland dairy farm managed at a stocking rate of 2.4 LU ha^{-1} (LU = livestock units). This stocking rate implies a nitrogen loading of 204 kg N/ha. The Nitrates Directive (EC, 1991) aims to restrict nitrogen loading to 170 kg N/ha. However, currently Ireland has a derogation to this limit and nitrogen loading of 210 kg N/ha is permitted. The hydrogeological regime is designated as 'extremely vulnerable' with soil cover less than 3m over karstic, fissured limestone aquifer. From borehole piezometers and ceramic suction cups in soil, average annual nitrate concentration in the subsoil was

31 mg l^{-1} NO_3 and in groundwater was 58 mg l^{-1} NO_3, exceeding specified target levels (50 mg l^{-1} NO_3). Although highly variable, nitrate concentrations were directly correlated with surface nitrogen loading, corresponding to different dairy farming agricultural management practices (grazing only, grazing with dirty water application, grazing with cutting for silage). Dual flow mechanisms (soil matrix and preferential/bypass flow) were found to occur resulting in minimum travel times to groundwater, at 25m depth, of 18 days. The principal driving mechanism for nitrate response was organic N loading at surface but coupled with relevant hydraulic loading (rainfall and dirty water). Results confirmed assessed contamination risk to groundwater under extremely vulnerable conditions.

1.2 BACKGROUND AND OBJECTIVES

A farm-scale hydrogeological investigation was established on a 50 ha dairy farm in north Cork, the south west of Ireland (national grid co-ordinates R813 008). This grassland farm is characterised by freely draining sandstone till, which forms the subsoil overlying a karstified-limestone bedrock aquifer. Groundwater flow in this limestone bedrock unit is characterised by fissure flow, that is, predominantly through interconnected, solutionally enlarged fracture zones. The average combined soil and subsoil thickness was 2.5 m, but it ranges from 0 to 4.5 m, conforming to the karst terrain. These characteristics of the subsoils in combination with the nature of the karstic aquifer create a groundwater environment vulnerable to potential contamination. The stocking density on the farm was ~2.4 LU ha^{-1}, which suggests an organic loading rate of 204 kg N ha^{-1} yr^{-1} in Ireland. All farm fields received 300 kg N ha^{-1} yr^{-1}, on average, as inorganic nitrogen fertiliser. The farm, in accordance with common Irish dairy farming practice, has dedicated management zones for grazing, grazing with dirty water application, grazing with one cut of silage and with two cuts of silage. Curtin's farm is an ideal study site because it is located on a plateau, close to a groundwater divide. Therefore, it was determined that nitrate concentrations in the underlying groundwater mainly reflected the influence of recharge percolating vertically through the subsoils of the farm – and are not influenced by the surrounding groundwater regime. The aim of the research was to define and measure subsoil and groundwater-nitrate response to meteorological and agronomic loadings, at the farm-scale.

1.3 MATERIALS AND METHODS

The investigative approach involved quantification of all loadings, both meteorological and agronomic, and monitoring of the response of the subsoil and groundwater system at numerous locations on the farm. Meteorological loadings were calculated using daily measured meteorological data, derived estimates of evapotranspiration using the Penman-Monteith approach (FAO, 1998) and soil moisture deficit accounting (Aslyng, 1965). All nitrogen loadings (inorganic fertiliser, grazing animal's depositions, applied slurries and dirty water) were recorded daily for each field in each management zone. Nine monitoring boreholes were drilled and monitored for water level and hydrochemical response to dairy farming practice. Boreholes were instrumented with piezometers to a depth of 27-30 m below ground level (bgl) and 5-10m below the water table. The groundwater sampling zone was isolated from direct contamination from the land surface by a cement and bentonite grout seals. Groundwater levels were recorded in each piezometer using a manual dip-meter each week and before all sampling events. Each piezometer was purged before sampling by removing three times the casing volume (i.e. the volume of standing water in the piezometer). Sampling frequency was twice monthly throughout the first year of the study but the summer sampling frequency was reduced in the second year, to once a month. Duplicate samples were collected from each piezometer and analysed in the laboratory. In addition to the suite of nutrients, a suite of ions was analysed for each sampling event in order to define the natural hydrochemical regime and the agricultural signal in the groundwater. The subsoil (at 1m depth) in each of the four management zones was instrumented with ceramic cups. The free-draining subsoil is never saturated; there is no perched water table within the subsoil. Three replicate fields in each management zone contained eight ceramic cups each, resulting in a total of 96 cups. Subsoil porewater samples were extracted, under a 50 kPa suction, each week for the duration of the 'drainage season', which was typically from October to April or May of each year. A bromide salt tracing experiment was conducted to investigate the rate of vertical migration of surface applied water and solutes through the unsaturated zone to groundwater.

1.4 RESULTS

Annual rainfall was 1071mm, on average, from which effective rainfall available for drainage, through the soil and subsoil, to groundwater was calculated to be 560mm, on average (Table 1).

Table 1. Meteorological loadings and average nitrate concentrations (mg l^{-1} NO_3)

Study Year	Rainfall (mm)	Effective Rainfall (mm)	Subsoil (mg l^{-1} NO_3)	Groundwater (mg $l^{-1}$$NO_3$)
2001-2002	1163	679	35	72
2002-2003	995	464	19	55
2003-2004	1055	537	40	48

Nitrogen loadings analysis showed that there was large spatial variation in organic nitrogen loading rates in the different dairy management zones (calculated range of 165 kg N ha^{-1} yr^{-1} in the grazing only zone and 471 kg N ha^{-1} yr^{-1} in the grazing with dirty water irrigation zone). The water table was 25 m bgl, on average, with a maximum annual range of 15 m, typical of karstic limestone. Measured groundwater nitrate concentrations in the groundwater ranged from 4 – 136 mg l^{-1} NO_3 over the entire study period and showed large variation both spatially and temporally. The 3-year mean groundwater nitrate concentration was 58 mg l^{-1} NO_3. The associated 3-year mean subsoil porewater concentration for all treatments was 31 mg l^{-1} NO_3. Annual average results are shown in Table 1. On an annual scale, groundwater nitrate concentrations were positively correlated (R^2 = 0.95) with grazing activity at the field scale (Figure 1). Results from the bromide tracing experiments in this freely draining soil, indicated that contaminant transport to groundwater was by a dual flow mechanism, i.e., by matrix as well as preferential flow. Bromide was transported to groundwater, by preferential flow, in 18 days under spring recharge of 50mm and a single dirty water irrigation rate of 16mm. Results suggest that delivery to groundwater, by matrix pulse, was in the following year's recharge season.

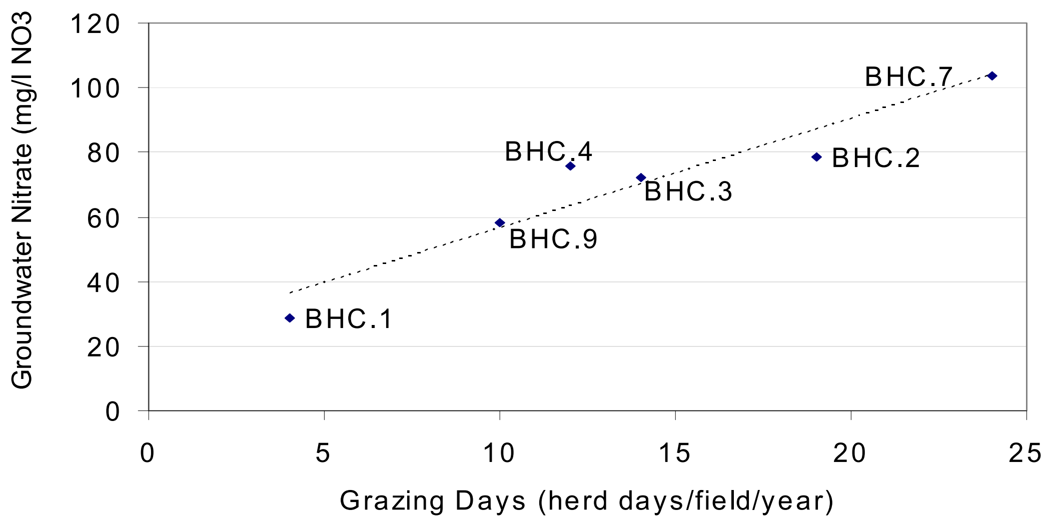

Figure 1. Relationship between grazing activity in 2001 and groundwater nitrate concentrations in the 2001-2002 'drainage season' (the trend line is indicated).

1.5 CONCLUSIONS

The results from this three-year study indicate that nitrate nitrogen concentrations in groundwater arising from current farming practices on an intensive dairy farm, located in an area zoned as 'extremely vulnerable' in North Cork, do not meet groundwater quality targets, as currently specified. It is noted that the nitrogen loading, rainfall and agricultural management practices that increase either the hydraulic or nitrogen loading, or both, were identified as important contributing factors. Hydraulic loading was shown to be a critical driver of nitrate responses. Spikes in groundwater concentrations of phosphorus, potassium, ammonium and nitrite were observed in response to certain recharge events, again suggesting a vulnerable hydrogeological setting and the influence of preferential flow. Nitrate concentrations recorded from both the subsoil ceramic cups and groundwater piezometers were positively correlated with the different management practices in zones at the surface. However, the ceramic cups, in the subsoil, generally underestimated the impact of agricultural practice on groundwater nitrate concentrations. This may be due to the ceramic cup sampling methodology under grazing conditions – where a direct hit of urine on a ceramic cup would be necessary to identify impact of grazing. The management practices that resulted in the highest nitrate concentrations in both subsoil and groundwater included dirty water irrigation and animal grazing intensity. Results suggested that the organic loading rate (animal intensity) dictated nitrate loss responses. The results indicate the potential for changes in management to achieve groundwater quality targets. The designated hydrogeological vulnerability category was shown to be a good indicator of risk and groundwater vulnerability.

2.0 NATIONAL SCALE

Monica Lee *et al*

2.1 INTRODUCTION

The key objective of the Water Framework Directive (WFD) is to maintain the 'high status' of waters where it exists and to achieve 'good status' of all other waters on a national scale by 2015. To work towards this, the present status of waters needs to be ascertained. However, in many instances there are few, if any, data available to highlight what the status, chemical or otherwise, is in different types of water body. This lack of monitoring data highlighted the need for a predictive risk assessment approach to identify likely water bodies that are potentially 'at risk' of having 'poor status', which can then enable an allocation of the limited monitoring resources to such bodies.

This part of the paper describes the verification of the predictive risk assessment methodology[1] for the impact of diffuse source mobile inorganics (such as nitrate) on the chemical status of the i) groundwater bodies (GWB), ii) groundwater dependent rivers, lakes and estuaries, and iii) drinking water protected areas (DWPA). Based on the verification results, the methodology was adopted by the Working Group on Groundwater in 2004 and formed the basis for running the risk assessments for the above water bodies. The risk assessment was part of 'initial characterisation' for the WFD and the results of the impact of diffuse source mobile inorganics on GWBs are also given.

2.2 BACKGROUND

In risk assessment (RA) sheets for GWB and DWPA, the threshold nitrate concentration above which a GWB is deemed to be 'at risk' is 8.5 mg/l NO_3-N (equivalent to 37.6 mg/l NO_3), as a weighted mean for the GWB; the corresponding threshold value in RA sheets for groundwater dependent rivers, lakes and estuaries is 5.65 mg/l NO_3-N (equivalent to 25 mg/l NO_3).

Due to insufficient water quality data a predictive risk assessment approach was followed to enable the risk category to be determined. The predicted risk category was then adjusted if adequate representative monitoring data were available. Where adequate data were not available, the results of the predictive assessment alone are used to determine the risk category, albeit that the level of uncertainty with the designation was greater.

Given that potential nitrates from other sources such as urban areas and waste water treatment systems are dealt with elsewhere (e.g. RA sheets GWRA5, GWRA7), the critical factors in determining the impact of nitrogen loadings on groundwater are as follows:

- **Pathway susceptibility**, as determined by soil, subsoil, vulnerability and aquifer information;
- **Pressure magnitude**, as determined by density of livestock and presence of tillage;

[1] The verification process is more fully described in Water Framework Directive Guidance Document No. GW10: **Verifying the Predictive Risk Assessment Methodology for Mobile Diffuse Inorganic Pollutants (NO_3)**, from which much of this part of the paper is taken (www.wfdireland.ie).

- The proportion of an area that has the combination of both relatively high pathway susceptibility and pressure magnitude, i.e. proportion of an area with relatively high **impact potential**.

In predicting the impact potential for a GWB, the main uncertainty relates to the proportion of that GWB with a relatively high impact potential that is needed to cause mean nitrate concentrations to be high enough to put the GWB 'at risk'. For instance, a small proportion (say <5%) of a GWB with intensive agriculture on free draining soils and subsoils may result in a high impact potential that is of local significance but that is unlikely to put the entire GWB 'at risk', as nitrate leached from this area will be diluted by groundwater from the remaining 95% of the area. In contrast, if the proportion is high, say 95%, then the likelihood that the GWB might be 'at risk' is high. Consequently, the aim of the verification process was to enable this percentage area to be determined. The process involved running the predictive RA approach for a number of GWBs with adequate nitrate data, and finding a relationship between the nitrate concentrations and the impact potential. The outcome was used to give the percentage area impact potential threshold that determined the risk category.

2.3 STUDY SITE SELECTION

The GWBs selected for this study (Figure 1) comprise approximately 5% of the national GWBs and meet the following criteria:

- The available nitrate data were considered sufficient to enable the mean nitrate concentration in the GWB to be determined.
- Each GWB was comprised of productive aquifers (Rk, Rf and Lm), as this helped ensure that monitoring data were representative and that denitrification would not be an issue.
- A range of vulnerability and soil types (i.e. susceptibility), and pressures was required to enable comparisons.

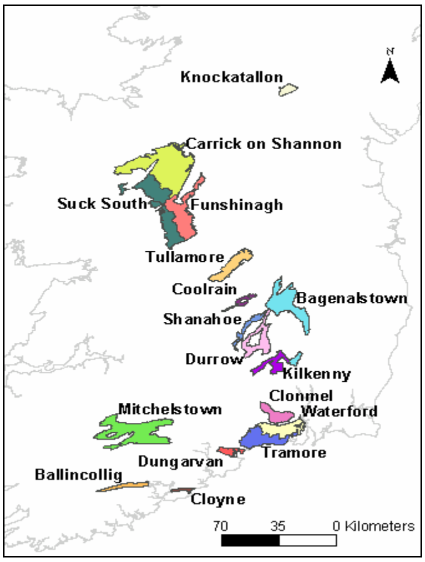

Figure 1. Location of Study GWBs

2.4 PATHWAY SUSCEPTIBILITY

The pathway susceptibility is derived by combining various layers of geological and hydrogeological information, as shown in Table 1.

Table 1. Pathway Susceptibility

PATHWAY SUSCEPTIBILITY			Flow Regime (Horizontal pathway)			
			Karst aquifers	*Fissured aquifers*	*Inter-granular aquifers*	*Poorly productive aquifers*
Vertical pathway***	Soil & subsoil	'Wet' soil	L	L	L	L
		Low permeability subsoil	L	L	L	L
	Vulnerability	Extreme	E	E	H	M*
		High	H	H	H	M*
		Moderate	M	M	M	L*
		Low	L	L	L	L
		High to Low**	H	H	H	M

*** In poorly productive aquifers where de-nitrification is not considered likely to occur, these categories should be the same as the karst and fissured aquifers categories.**

**** For areas where complete vulnerability map is not available from GSI.**

***** The 'wet' soil and low permeability subsoil layers take precedence over the vulnerability layers.**

For the study sites, all of the individual pathway layers were combined in ArcGIS. A susceptibility category was given to each polygon depending on the combination of pathway parameters outlined in Table 1. The pathway factors for the Dungarvan GWB are illustrated and described below:

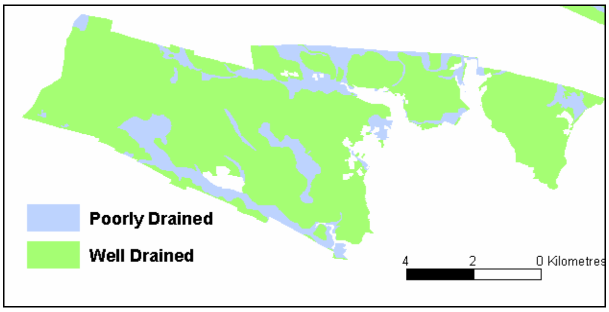

Figure 2a. Soil Drainage

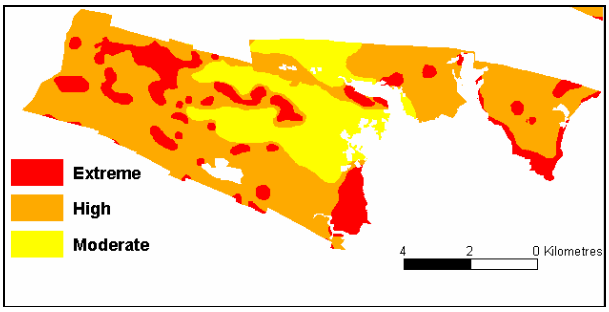

Figure 2b. Vulnerability

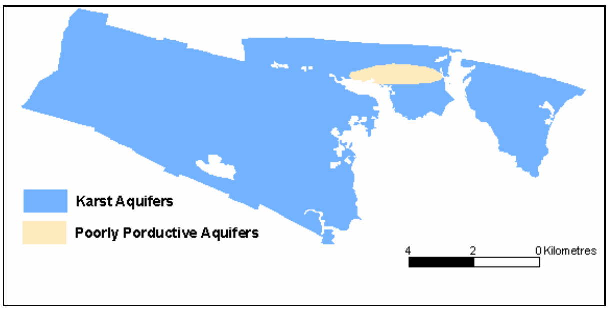

Figure 2c. Aquifers

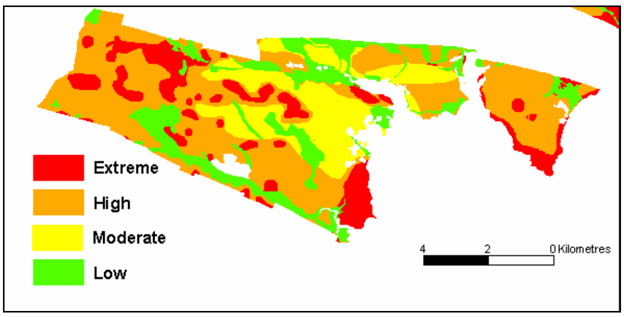

Figure 2d. Pathway Susceptibility

Figure 2. Dungarvan GWB Pathways and Pathway Susceptibility.

Description	Interpretation
In Figure 2d, the influence of the ***poorly draining topsoil*** (Figure 2a) can be seen –the majority of the Low (green) pathway susceptibility.	Where soil is poorly drained, mobile inorganic contaminants are less likely to drain through the topsoil, and more likely to be incorporated in the surface runoff. In addition, denitrification may occur.
No areas of 'low' permeability ***subsoil*** were identified in this GWB. Apart from the areas of poorly draining topsoil, the dominant factor influencing susceptibility over the Karst Aquifers (Figure 2c) is the ***vulnerability*** (Figure 2b).	If nitrate leaches through the topsoil, the subsoil permeability and thickness, i.e. vulnerability, will control the quantity and rate of infiltration into the underlying aquifer. if the subsoil permeability is: a) 'low' (not exhibited in the above GWB), the contaminant is less likely to be able to infiltrate into and percolate through the subsoil and, in addition, denitrification is more likely. b) 'moderate' or 'high', the contaminant can percolate through to the aquifer. If the subsoil is thinner and more permeable (e.g. 'Extreme' vulnerability), travel times are quicker, resulting in the pathway having a higher susceptibility than thicker, less permeable (e.g. 'Moderate' vulnerability) subsoil.
The influence of the ***Poorly Productive Aquifers*** (Figure 2c) mainly results in a Moderate susceptibility. This overrides the influence of the Extreme and High vulnerability, but not of the poorly drained topsoil.	If any mobile contaminants percolate through the subsoil, the flow regime of the underlying aquifer will then determine the contaminant's fate. In karstic or highly fissured aquifers, groundwater can often travel large distances at high velocities. The contaminant could potentially influence a wide area, many water supplies, ecosystems etc. In poorly productive aquifers (poor connection of fewer fissures), flow paths will be generally shorter, thus limiting the contaminant's influence. Travel times may be slower and reducing conditions may be present, potentially facilitating denitrification. Thus such aquifers have a lower susceptibility than for the karst or highly fissured aquifers.

2.5 PRESSURE MAGNITUDE

The sources of diffuse nitrates used in this assessment comprised:

- Densities of cattle/sheep per DED (5-year averages; Department of Agriculture)
- Densities of pigs/poultry per DED (June 2000 data, Central Statistics Office)
- Percentage areas of tillage (10 crop categories; Department of Agriculture)

The pressure loadings were subdivided into four categories as shown in Table 2. The highest pressure threshold for Livestock Units (LUs) was presumed to be approximately equivalent to the 170 kg organic N/ha limit in the Nitrates Directive. The tillage categories were based on research in the Barrow Valley (Neill, 1989). The pressure loading thresholds related to the data available at DED-scale and therefore do not relate to individual farm thresholds.

Table 2. Thresholds for Pressure Magnitude

Pressure Loading	Cattle/Sheep and Pigs/Poultry (LU/ha)	Tillage (%)
High	>2.0	>33
↓	1.5-2.0	18-33
	1.0-1.5	3-18
Low	<1.0	<3

In order to realistically distribute these data within the DEDs, the densities of both cattle/sheep and pigs/poultry were directly applied to areas of 'grazing', and the percentage areas of tillage were applied to areas that are tilled, hereafter referred to as areas of 'tillage'. The CORINE (2000) land use dataset was used to identify areas of 'grazing' (land use categories 231 and 243) and 'tillage' (category 211). The land use categories for the Dungarvan GWB are shown in Figure 3.

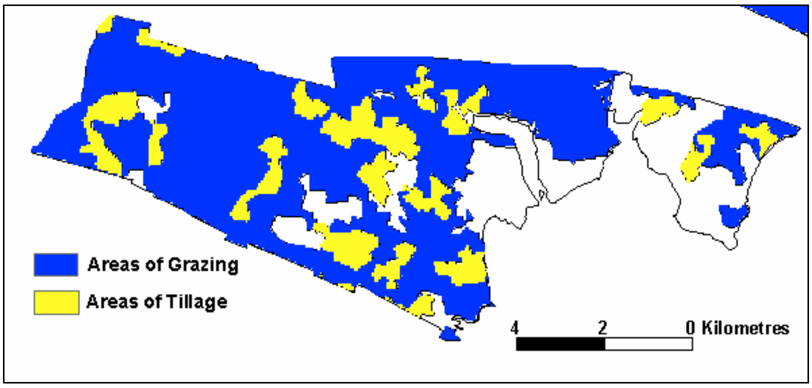

Figure 3. Grazing and Tillage Land use for the Dungarvan GWB.

2.5 IMPACT POTENTIAL

The Impact Potential was determined by combining the pressure magnitude with the pathway susceptibility, as outlined in Table 3 below.

Table 3. Deriving Impact Potential

IMPACT POTENTIAL*		Pathway Susceptibility (from Table 1)			
		Extreme	*High*	*Moderate*	*Low*
Pressure magnitude	>2.0 LU ha^{-1} or >33% tillage	High	High	Moderate	Low
	1.5-2.0 LU ha^{-1} or 18-33% tillage	Moderate	Moderate	Low	Low
	1.0-1.5 LU ha^{-1} or 3-18% tillage	Low	Low	Low	Low
	<1.0 LU ha^{-1} or <3% tillage	Negligible	Negligible	Negligible	Negligible

The method for producing the total Impact Potential percentage areas per GWB for the three pressure layers is outlined in the steps below:

1 Susceptibility and Pressure Magnitude layers comprised 50 m x 50 m pixels (raster format).

2 Each pixel had a unique ranking for Pathway Susceptibility, and for ***each*** of the Pressure Magnitude layers (cattle/sheep, pigs/poultry ***and*** tillage). Therefore, each pixel had four unique characteristics. The four resulting raster layers for the Dungarvan GWB are shown in Figure 4.

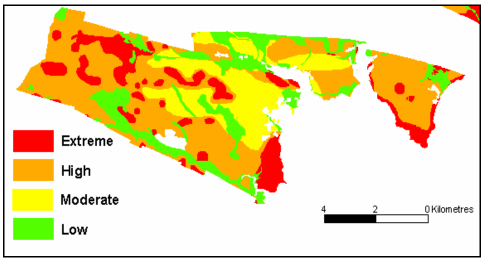

Figure 4a. Pathway Susceptibility

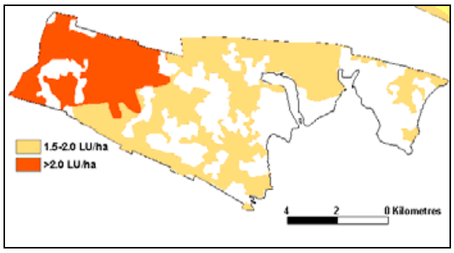

Figure 4b. Pressure Magnitude: Cattle/Sheep

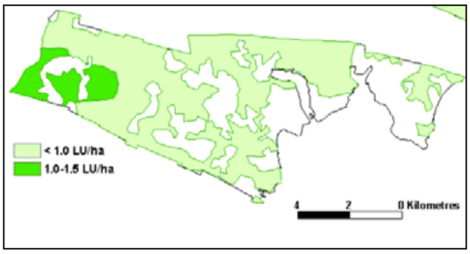

Figure 4c. Pressure Magnitude: Pigs/Poultry

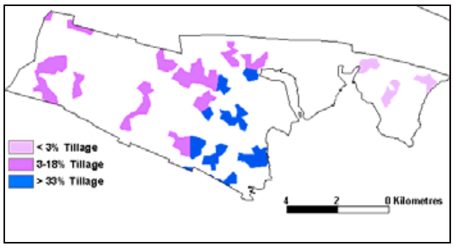

Figure 4d. Pressure Magnitude: Tillage

Figure 4. Dungarvan GWB Susceptibility and Individual Pressure Magnitude Layers.

3 Each Pressure Magnitude raster was individually combined with the Susceptibility raster using ArcGIS. A unique Potential Impact category – specific to the pressure type – was derived for each pixel, depending on the different combinations of susceptibility and pressure parameters outlined in the Table 3 above e.g. where susceptibility is Extreme or High, and there are greater than 2 LU/ha of cattle, the Impact Potential was High. The process resulted in an individual Impact Potential raster for cattle/sheep, pigs/poultry and tillage, as illustrated in Figures 5a, b and c.

4 To determine the ***total*** impact potential for all three pressures, the highest Impact Potential category within each pixel was taken, irrespective of the pressure type. The total area of each Impact Potential category was then determined for the GWB, e.g.:

	Pixel	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Impact Potential*	Cattle/Sheep	H	N	M	M	N	L	N	M	H	L
	Pigs/Poultry	L	N	L	H	N	L	N	L	H	M
	Tillage	N	M	N	N	L	N	H	N	N	N
	Overall	**H**	**M**	**M**	**H**	**L**	**L**	**H**	**M**	**H**	**M**

In the example above, 40% of the GWB is categorised as High Impact Potential, 40% is Moderate and 20% is Low. The total Impact Potential for the Dungarvan GWB (Figure 5d) results in 21% being categorised as High, 23% as Moderate, 33% as Low and 12% as Negligible.

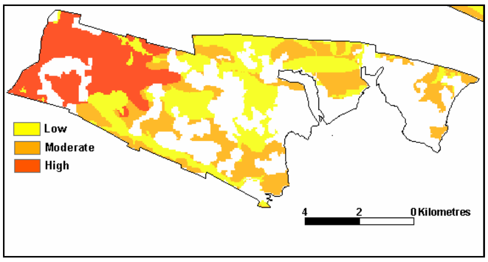

Figure 5a. Impact Potential: Cattle/Sheep

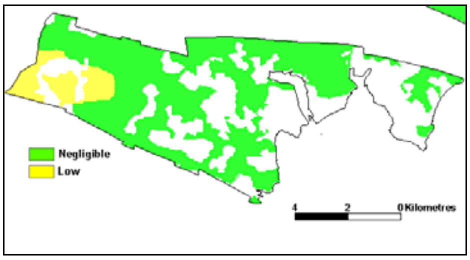

Figure 5b. Impact Potential: Pigs/Poultry

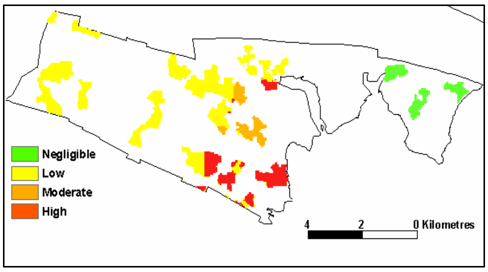

Figure 5c. Impact Potential: Tillage

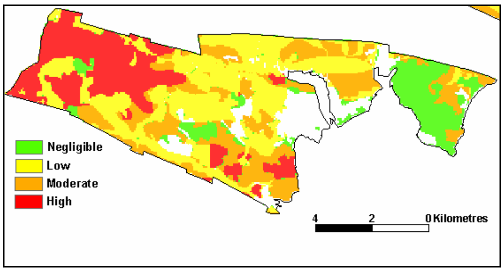

Figure 4d. Total Impact Potential

Figure 5. Impact Potential for the Separate and Pressure Layers and the Total Impact Potential for Dungarvan GWB.

2.6 NITRATE DATA AND IMPACT POTENTIAL

Representative nitrate data were available for all of the study GWBs. Only data for the last five years were used, as these reflect current land use practices. As a means of obtaining a single, representative value, a weighted 'average of averages' method was used, i.e. the time-series data from each monitoring point were averaged. All of these resulting values were then given a weighting depending on their relative discharges/abstractions. Larger discharges/abstraction imply larger zones of contribution and therefore are likely to be representative of a larger area. The weighted values per monitoring point were then averaged to give a representative nitrate concentration for the GWB.

For each GWB, the percentage areas of High and Moderate Impact Potential were compared to the mean nitrate concentrations by plotting them on a graph, as shown in Figure 6.

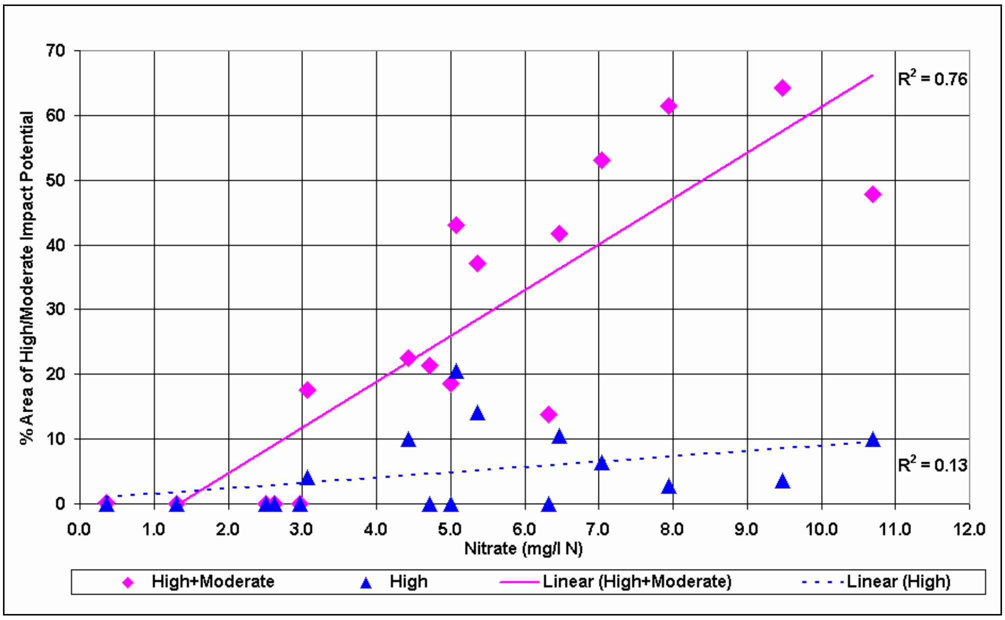

Figure 6. Impact Potential against Nitrate Levels for each GWB

It was anticipated that the GWBs that were most susceptible and had the highest pressures would result in the highest nitrate concentrations. However, examination of the relationship between the proportions of the GWBs with High Impact Potential and the nitrate data showed a poor correlation ($R^2 = 0.13$; dashed line). By including the area of Moderate Impact Potential, i.e. total percentage of High+Moderate, the correlation is significantly improved ($R^2 = 0.76$; solid line), indicating that lower levels of pressure over the most susceptible areas and/or very high pressures over less susceptible areas also have an impact on the concentrations of nitrate in the groundwater.

2.7 DETERMINING THE PERCENTAGE OF 'AT RISK'

Overall, the combination of Pathway Susceptibility and Pressure Magnitude to give Impact Potential, as shown in Figure 7, has enabled a good fit with the actual groundwater nitrate levels. Therefore, the percentage areas of High+Moderate Impact Potential can be used to 'predict' what the groundwater nitrate levels are likely to be. For example, if approximately 40% of a GWB has High+Moderate Impact Potential, a nitrate level in the region of 7 mg/l N would be expected. In addition, percentage areas that relate to 'significant' levels of nitrate, i.e. those that indicate groundwater is 'at risk', can be identified, e.g. 30% High+Moderate GWB area corresponds to the threshold level of 5.65 mg/l N (RA sheet for groundwater dependant rivers, lakes and estuaries) and 50% corresponds to the 8.5 mg/l threshold (RA sheets for GWB and DWPA). The actual percentage areas used are 25% and 40%, respectively, which are more precautionary than those obtained from Figure 7.

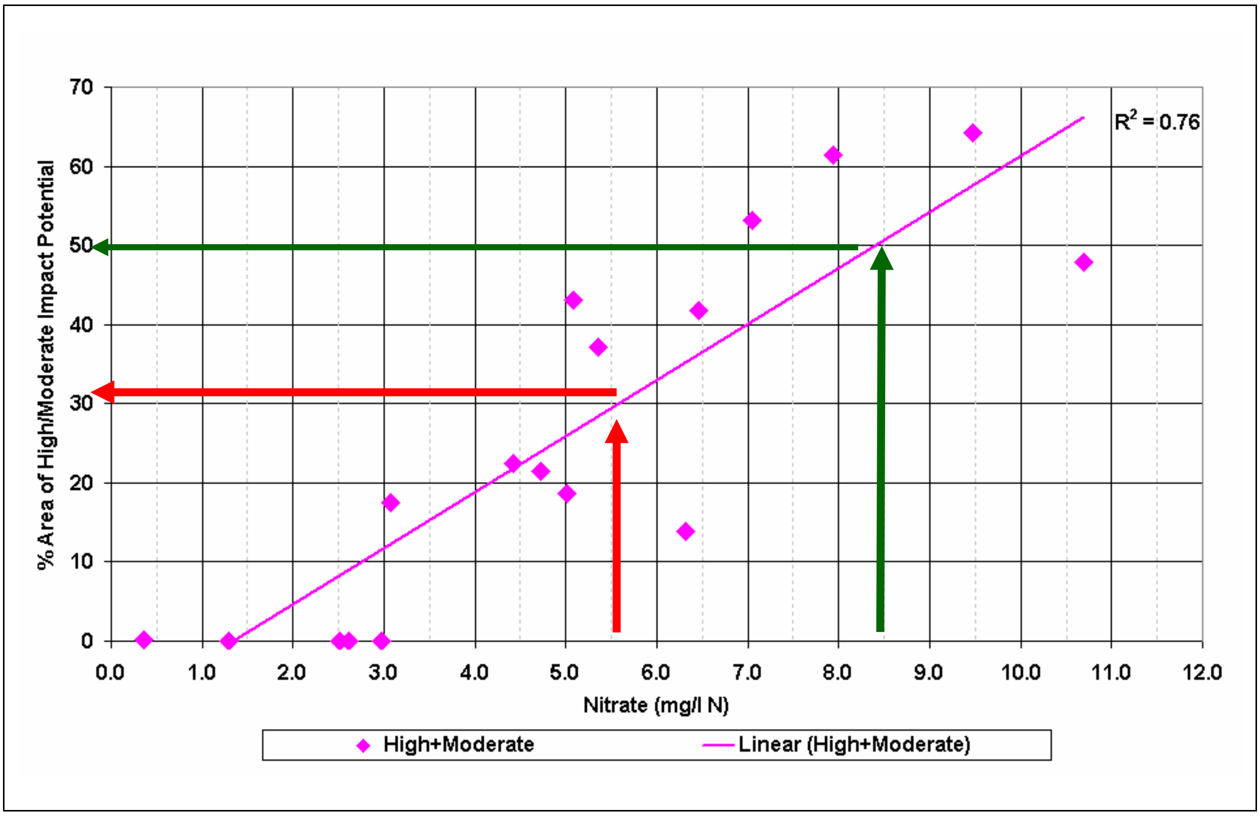

Figure 7. High+Moderate Impact Potential against Nitrate Levels for each GWB

2.8 RESULTS OF INITIAL CHARACTERISATION

Based on the results of the verification, the methodology was adopted by the Working Group on Groundwater in 2004 and formed the basis for the risk assessment undertaken by each of the RBD consultants. The results show that 78 (c.10%) of the 746 GWBs were 'probably at risk' of having significant levels of nitrate (category 1b) with the remaining GWBs categorised as either 'probably not at risk' or 'not at risk' of having significant nitrate levels. At the time of writing, additional data had been obtained from four of the RBD consultants. These data show that of the 572 GWBs in these

RBDs, just under 40% of them had representative monitoring data. These data led to the adjustment of 20 GWBs (3%) although only 7 (c.1%) were changed from 'probably not at risk' (category 2b) to 'probably at risk' (1b).

2.9 CONCLUSIONS

The aim of this study was to develop and verify a predictive risk assessment approach to determining the risk category of groundwater bodies from diffuse usage of nitrogen. A good correlation was found between mean nitrate concentrations in GWBs and the proportion of the GWBs mapped as having High+Moderate Impact Potential. Consequently, the relationship was used to predict the risk category for GWBs without adequate groundwater nitrate data. From the results of the risk assessment undertaken by the RBD consultants, the available representative monitoring data concurs the predicted risk assessment category in the majority of cases.

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Verifying the Predictive Risk Assessment Methodology for Mobile Diffuse Inorganic Pollutants (NO3) was undertaken by the Working Group on Groundwater, comprising: Donal Daly (Convenor), Geoff Wright, Vincent Fitzsimons, Coran Kelly, Taly Hunter Williams, Monica Lee (GSI); Henning Moe (Camp Dresser McKee); Paul Mills (Compass Informatics Ltd); Pat Duggan (Department of the Environment, Heritage and Local Government); Jim Ryan (NPWS), Aine O'Connor (NPWS); Margaret Keegan, Micheal McCarthaigh (Environmental Protection Agency); Peter McConvey (Environment and Heritage Service/Geological Survey of Northern Ireland); Grace Glasgow, Kieran Fay (Kirk McCLure Morton); Sean Moran, Gerry Baker (O'Callaghan Moran); Shane O'Neill (O'Neill Groundwater Engineering); Garrett Kilroy (Shannon Pilot River Basin – EPA/TCD Research Fellow); Colin Byrne (Southeastern RBD); Karl Richards (Teagasc); Paul Johnston, Catherine Coxon (Trinity College Dublin).

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Working Group on Groundwater (2004) Guidance Document GW8: Methodology for Risk Characterisation of Ireland's Groundwater, 69 pp.

Working Group on Groundwater (2005) Guidance Document GW10: Verifying the Predictive Risk Assessment Methodology for Mobile Diffuse Inorganic Pollutants (NO3), 19 pp

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A NATIONAL ASSESSMENT OF GROUNDWATER ABSTRACTION PRESSURES

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ABSTRACT

The national groundwater abstraction risk assessment that was submitted by Ireland to Europe in 2005 has been updated and revised on the basis of new soil/subsoil and groundwater vulnerability mapping, as well as an updated national register of abstractions. Identified quantitative impacts are localised, and groundwater abstraction is generally not considered to be a significant water management issue. However, abstraction pressures are expanding in line with national growth, and expanded use of groundwater resources will require improved monitoring and centralised water resources management. The revised risk assessment builds on the work carried out by individual river basin district projects as part of Water Framework Directive implementation in Ireland. A national groundwater recharge map has been developed from GIS processing of related hydrogeological inputs, and forms an important basis for assessment of new and significant groundwater abstractions.

INTRODUCTION

The EU Water Framework Directive (WFD) requires characterisation of pressures from significant water abstractions, including a national risk assessment and regulation on the quantitative status of all types of water bodies, including groundwater. An initial abstraction pressure assessment was performed in Ireland by individual river basin district (RBD) projects and reported by the EPA in the national Article V report, "The Characterisation and Analysis of Ireland's River Basin Districts" (EPA, 2005).

Table 1 presents the number of water bodies "at risk" or "probably at risk" from abstraction pressures from the initial characterisation in 2005. For surface waters, the risk assessments compared net abstractions (total abstractions minus total discharges) to an estimate of Q_{95} flows. Risk levels were set at threshold values for highly sensitive surface waters established in guidance documents from the UK and Northern Ireland; except in cases when a dam or weir was present which defaulted the assessment to "at risk." Risk levels for lakes and transitional waters were then derived from the results of the riverine risk assessment. The initial risk characterisation for groundwater was based on a predictive methodology developed by the UK Technical Advisory Group (TAG) and adopted by the WFD National Technical Coordination Group for consistent application in all RBDs.

Table 1: Initial Characterisation Risks for Abstraction Pressures

Risk Level	Rivers	Lakes	Transitional Waters	Ground Waters
Water Bodies At Risk (1a)	95	133	6	6
Water Bodies Probably at Risk (1b)	107	147	5	36
Total No. of Water Bodies	4,467	805	196	757
% of 1a or 1b of Total	5	35	6	6

Even though Table 1 would suggest that abstraction pressures are not, in general, considered a significant risk to Irish water bodies, abstraction pressures are growing in line with national growth, and further examination of relevant water bodies is important because the financial and political costs of returning a water body affected by abstractions to good quantitative or ecological status is likely to be significant. The types of measures that could be needed are: (1) implementing water conservation programs for the domestic and industrial sectors; (2) reducing the leakage from public water supplies; (3) restricting development; and (4) identifying and building the infrastructure for alternative sources of water.

Further characterisation is underway at the national level to address specific questions raised by the initial results and to improve confidence in the predicted risk assessment for all water body types. For rivers and lakes, this entails efforts to establish linkages between water quantity and ecology. For groundwater, this entails reducing uncertainty associated with the Article V risk assessment and to establish important linkages between ground and surface waters where these are considered to be at risk from meeting environmental status objectives. It also entails incorporating the outcomes of a relevant parallel study on groundwater dependent terrestrial ecosystems (GWDTEs) or wetlands, led by the EPA and the National Parks and Wildlife Service (NPWS).

GROUNDWATER ABSTRACTION RISK ASSESSMENT (2005)

The initial groundwater abstraction risk assessment, summarised in Figure 1, was based on comparing estimated abstraction levels against computed recharge for each groundwater body across the country. Recharge was computed by applying recharge coefficients associated with defined physical scenarios to a national map of effective rainfall based on a 30-year mean annual rainfall map developed by Met Eireann. The recharge coefficients were assigned on the basis of physical scenarios involving different soil type and texture classes and groundwater vulnerability categories, which in turn are defined by depth and subsoil permeability criteria (GSI, 1999). Criteria for abstraction risk were based on relative percentages of abstraction vs. recharge volumes computed for each groundwater body, as defined by the UK TAG.

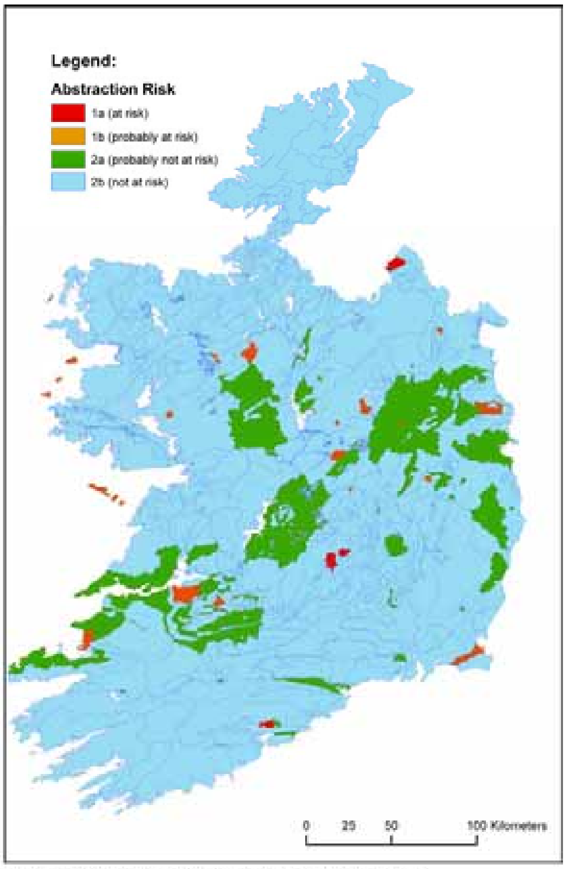

Figure 1: Groundwater Abstraction Risk Assessment (2005)

Where groundwater level data were available, these could be used to support or overwrite the predictive risk results, and to add confidence to the risk assignments. Because groundwater abstraction impacts can also be of a local nature, water level trends could also be used to justify subdividing the officially designated groundwater bodies, to reduce the perceived risk across otherwise much larger areas.

Only 6 groundwater bodies were considered to be at risk, while a further 36 were considered to be "probably at risk", involving less certainty and reduced confidence in the assessment. Of the 36 "probably at risk" cases, only 12 were the direct result of abstraction rates or saline intrusion issues, while 24 were associated with GWDTEs. The saline intrusion test was based on assessing rates of abstractions and distance from seawater, and most of the "probably at risk" cases involve the islands off the coast of Galway and Mayo. The test for GWDTEs was based on volumes abstracted at different distances from the boundaries of preliminary mapped wetland areas, or the presence of arterial drainage, also as a function of distance from wetland boundaries. Some of the "probably at risk" GWDTEs are very small, but nonetheless ecologically significant.

The initial risk characterisation of 2005 represents an important first step in the understanding of groundwater abstraction issues nationally, and importantly, provided the opportunity to define what merits or requires further study. On the basis of these results and subsequent discussions among the National Technical Coordination Group, groundwater was added as a component to the abstraction pressure assessment to be implemented nationally ahead of the Programmes of Measures phase of the WFD.

GROUNDWATER ABSTRACTION PRESSURE ASSESSMENT

The updated national groundwater pressure assessment includes several tasks that link groundwater to surface waters and wetlands. As a first measure, it provides an update on the 2005 risk assessment following the same UK TAG methodology, but incorporating new (and improved) information as follows:

- An updated national register of abstractions;
- Recent national maps of soils and subsoils produced by Teagasc in 2006;
- A new national map of groundwater vulnerability derived from GSI with input from RBD projects;
- Consideration of additional recharge coefficients for an expanded set of physical scenarios.

UPDATED NATIONAL REGISTER OF ABSTRACTIONS

The national register of abstractions has been updated with the input from each RBD, relevant local authorities, and others (e.g., GSI, industries, private consultants). The updated register is considered an improvement over 2005 as supply wells and springs have been cross- and error-checked, new wells have been added as appropriate, and some wells have been removed (e.g., if decommissioned). The register does not include domestic wells, as these are simply too numerous and considered less important from a resource quantity point of view. Most of the domestic abstraction is returned to ground via septic systems, and while this has an impact groundwater quality, it has less of an impact on quantities. Emphasis was therefore placed on identifying permanent supply wells and springs where groundwater is "exported" (out of respective groundwater bodies).

It is believed that most, if not all, public and group water schemes have been identified and included, but it is unlikely that all industrial and miscellaneous small private abstraction schemes (e.g., schools, hospitals) are captured in the new register. Table 2 summarises all groundwater abstractions included in the national register, as reported by individual RBD projects.

Table 2: Summary of Groundwater Abstractions for Supply Purposes

River Basin District	Total No. Wells	Public	Private/GWS/ Industrial	Total Estimated Abstraction (m^3/day)
Northwest	64	29	35	34,003
Neagh-Bann	41	34	7	23,820
Shannon	843	172	671	144,117
West	182	22	160	42,779
East	249	86	163	39,590
Southeast	180	116	64	153,387
Southwest	315	163	152	96,053

Table 2 incorporates supply wells and springs that serve public supply and industrial purposes. It does not include wells or springs used for domestic purposes whereby water is returned to septic systems. A provisional breakdown of groundwater abstractions by county is provided in Figure 2. The numbers presented are believed to provide a reasonably complete picture of total abstractions, although a few scenarios have yet to be fully verified, notably related to mine dewatering and quarry abstractions.

Approximately 530,000 m^3/day is presently being abstracted from almost 1,900 identified supply wells or springs. The highest total groundwater abstractions occur in the Shannon and Southeastern RBDs. The single largest groundwater abstraction nationally is associated with the Lisheen mine in Tipperary North, at 65,000 m^3/day, or more than 10% of the national total. Approximately 100 abstraction points nationally supply more than 1,000 m^3/day, while a further 500 abstraction points produce greater than 100 m^3/day. The majority of supply wells and springs produce between 10-100 m^3/day.

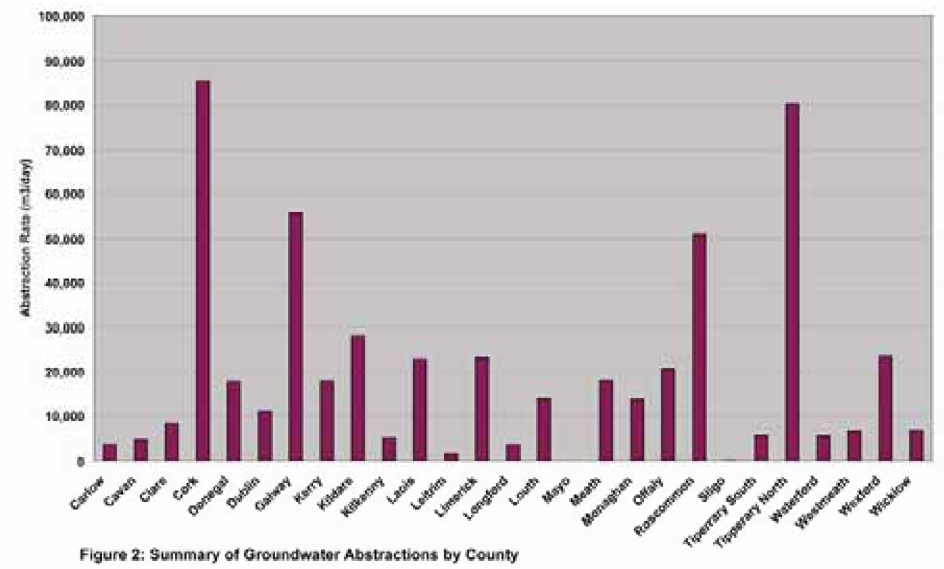

Figure 2: Summary of Groundwater Abstractions by County

UPDATED RECHARGE ESTIMATION

The revised risk assessment also includes updates to important inputs which are used to compute diffuse recharge spatially across Ireland. The most significant updates relate to the assigned distribution of recharge coefficients which define the proportion of effective rainfall that becomes recharge. Recharge coefficients depend largely on the permeability and thickness of the soils, subsoils and bedrock overlying groundwater. Recharge coefficients have been defined for several new combinations of soil and subsoil scenarios, and reflect the recently published national soil and subsoil maps by Teagasc (2006) as well as the new (2006) national groundwater vulnerability map of Ireland, distributed by GSI and reproduced in Figure 3. In areas not yet covered by detailed GSI mapping, recharge coefficients were assigned according to subsoil permeability indicated by either GSI drilling or Teagasc mapping.

The ranges of recharge coefficients used are shown in Table 3, reproduced from the WFD-related national guidance on assessing impacts from abstraction pressures (Working Group on Groundwater, 2005). Table 3 is partly based on GSI studies as well as research by others (notably Fitzsimons and Misstear, 2006). Recharge in larger urban footprints is calculated using a coefficient of 20%.

Particular attention was given to poorly productive aquifers (PPAs), as these cover two-thirds of Ireland. Because of their low transmissivity and storage, PPAs are not capable of accepting all the recharge that may be available, resulting in rejected recharge and discharges to local streams via shallow pathways (overland flow, top of bedrock). As a result, PPAs incorporate small, localised groundwater flow systems, generally tens to hundreds of metres in length.

Table 3: Recharge Coefficients for Different Hydrogeological Settings

Vulnerability category		Hydrogeological setting	Recharge Coefficient		
			Min (%)	Inner Range	Max (%)*
Extreme	1.i	Areas where rock is at ground surface	60	80-90	100
	1.ii	Sand/gravel overlain by ‘well drained’ soil	60	80-90	100
		Sand/gravel overlain by ‘poorly drained’ (gley) soil			
	1.iii	Till overlain by ‘well drained’ soil	45	50-70	80
	1.iv	Till overlain by ‘poorly drained’ (gley) soil	15	25-40	50
	1.v	Sand/ gravel aquifer where the water table is ≤ 3 m below surface	70	80-90	100
	1.vi	Peat	15	25-40	50
High	2.i	Sand/gravel aquifer, overlain by ‘well drained’ soil	60	80-90	100
	2.ii	High permeability subsoil (sand/gravel) overlain by ‘well drained’ soil	60	80-90	100
	2.iii	High permeability subsoil (sand/gravel) overlain by ‘poorly drained’ soil			
	2.iv	Moderate permeability subsoil overlain by ‘well drained’ soil	35	50-70	80
	2.v	Moderate permeability subsoil overlain by ‘poorly drained’ (gley) soil	15	25-40	50
	2.vi	Low permeability subsoil	10	23-30	40
	2.vii	Peat	0	5-15	20
Moderate	3.i	Moderate permeability subsoil and overlain by ‘well drained’ soil	25	30-40	60
	3.ii	Moderate permeability subsoil and overlain by ‘poorly drained’ (gley) soil	10	20-40	50
	3.iii	Low permeability subsoil	5	10-20	30
	3. iv	Basin peat	0	3-5	10
Low	4.i	Low permeability subsoil	2	5-15	20
	4.ii	Basin peat	0	3-5	10
High to Low	5.i	High Permeability Subsoils (Sand & Gravels)	60	85	100
	5.ii	Moderate Permeability Subsoil overlain by well drained soils	25	50	80
	5.iii	Moderate Permeability Subsoils overlain by poorly drained soils	10	30	50
	5.iv	Low Permeability Subsoil	2	20	40
	5.v	Peat	0	5	20

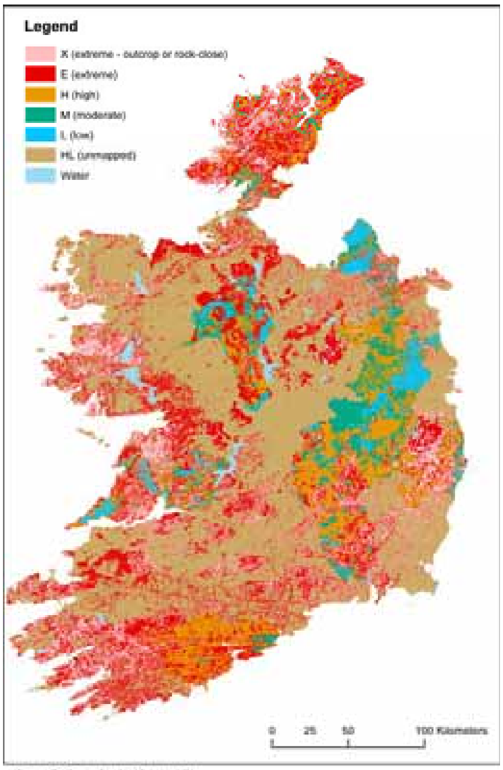

Figure 3: Groundwater Vulnerability

To account for rejected recharge, a maximum recharge limit or 'cap' is used. Based on GSI estimates of throughflow in aquifers classified as poor (Pl and Pu), a maximum recharge rate of 100 mm/yr is used for most poorly productive aquifers, irrespective of the vulnerability categories in Table 3. Areas underlain by locally important but generally unproductive aquifers (except for local zones, Ll) such as the Calp limestone, are capped slightly higher at 150-200 mm/yr.

Table 4 summarises the recharge computations for all groundwater bodies by the major types of groundwater flow regimes. Normalised to groundwater body areas, and capped where applicable, computed recharge ranges from 60 to 890 mm/yr. The higher values are associated with vulnerable groundwater scenarios in high rainfall areas, and are mostly associated with sand and gravel and karst aquifers.

Based on this work, a national groundwater recharge map has been produced which is intended to be made available online (e.g., through the GSI), and be updated as new subsoil information becomes available in counties undergoing continued GSI vulnerability mapping. Further improvement could be made if a national effective rainfall map was developed in time with the assistance of Met Eireann.

Some of the mapping layers associated with recharge calculations do not extend to islands, and recharge estimates for such values were developed independent of the GIS-based methodology. Abstraction risks associated with island scenarios is therefore assigned based on the site-specific knowledge of respective RBD projects and local authorities.

Table 4: Summary of Computed Recharge by Flow Regime for all Groundwater Bodies

	Computed Recharge (m^3/day per km^2)			Computed Recharge (mm/yr)		
Flow Regime	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**
Sand and Gravel	1,030	413	2,112	376	151	771
Karst	711	189	2,449	260	69	894
Fissured	618	163	1,600	226	60	584
Poorly Productive	385	166	1,264	140	61	461

UPDATED GROUNDWATER ABSTRACTION RISK ASSESSMENT (2007)

Provisional results of the updated groundwater abstraction risk assessment are shown in Figure 4. Overall, patterns of risk are similar to those from 2005. Identified quantitative impacts are localised around the Bog of the Ring wellfield in Fingal, Knockatallon area wells in Monaghan, Lisheen mine in Tipperary North, Galmoy mine on the Kilkenny/Laois border, Midleton area wells in Cork, and the Fardystown supply in Wexford.

It should be noted that in many cases, actual risk may be influenced by hydrogeological factors which are not captured in the predictive risk assessment methodology. An example involves several small groundwater bodies where rates of abstraction within the groundwater body may be high compared to calculated total recharge. Rule-based methodologies do not necessarily consider the potential for groundwater flow across groundwater body boundaries, or 3-dimensional influences of overlying deposits or deeper aquifers. Each river basin district project has therefore examined each potential risk case to ensure that hydrogeological principles and analysis are adequately and appropriately considered.

All schemes deemed to be either “at risk” or “probably at risk” are included in the new EPA water level monitoring programme. Additional wells associated with “not at risk” scenarios are also included for long-term trend monitoring.

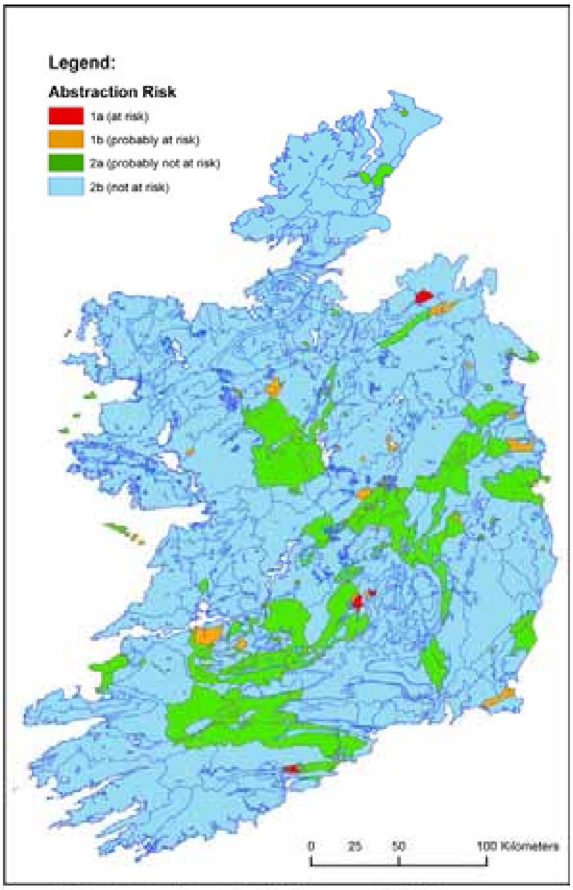

Figure 4: Groundwater Abstraction Risk Assessment (2007)

Saline intrusion is reported in a few localised cases in the west of Ireland. Supply wells on Inishmaan and Inisheer have reportedly been affected, and Inishmaan is seasonally operating a small-scale desalination unit in line with increased demands. Well operators in karst areas along the coast in Galway and Kerry are reportedly also experiencing seasonal salinity problems, and these cases are presently being investigated further. Despite the mentioned occurrences, saline intrusion is not wide-spread, and is not considered a major water management issue. Future groundwater supply development in coastal areas and on islands must be accompanied by proper studies and monitoring, and given the growing demands for water in coastal populated areas, this should involve regulatory agencies.

Changes to the delineation of GWDTEs have not yet been effected and so there are no changes to the risk assessment of related groundwater bodies. An ongoing national study of GWDTEs by the EPA and NPWS are improving the resolution of wetlands mapping, and when ready, is expected to influence the outcome of risk analysis and subsequent monitoring. GWDTEs will be subject to specialised monitoring as part of EPA’s WFD-related monitoring programme.

FUTURE SUPPLIES

While available groundwater resources vary across the country, groundwater is increasingly being explored for public and private supplies. Some rivers and lakes are reaching their capacity as primary sources of water supply and questions are being raised over the health and status of freshwater aquatic ecosystems. Industrial growth is adding new abstractions, although not on the same scale as local authority efforts to meet the growing domestic water demands. There are several large-scale groundwater exploration schemes currently underway in counties such as Meath, Kildare, Wexford, and Louth. These are partly driven by Environmental Impact Assessment regulations and partly by concerns over local ecological impacts. Even counties with limited groundwater resources such as Wicklow are exploring groundwater options to augment present supplies. The housing boom in commuter belt and rural areas are adding to overall abstractions but this is regarded less as a quantity and more as a quality issue, on account of the return of water through septic systems in unsewered areas.

The increasing use of groundwater as a primary source of water supply implies that new schemes will require increased regulatory attention in the context of WFD-required water resources management. The various national studies led by individual river basin district projects are drawing attention to a variety of water management issues which combined will broaden the understanding of groundwater and surface water interactions, and impact how groundwater is monitored and managed.

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