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THE GSI GROUNDWATER NEWSLETTER

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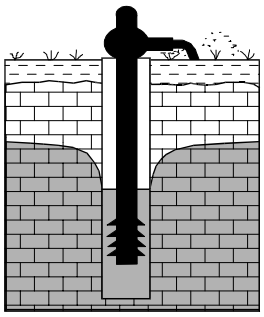

NUACHTÁN SCREAMHUISCE SGÉ

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Are Consulting and Good Science Compatible?

One of the noticeable features of the Irish groundwater scene in the last 2-3 years is the ever increasing number of **young groundwater scientists**. The number of articles in this Newsletter written by 'younger' contributors – Colette Cronin, Malcolm Doak, Yvonne Doris, Margaret Keegan and Susan O'Shea – is a welcome illustration of this change. It is also illustrated by the increased membership of the IAH (Irish Group), which stands at over 60.

While the contribution to environmental assessment and protection by hydrogeologists has undoubtedly increased, there is still a need for further improvement, as shown in the article by Susan O'Shea and Catherine Coxon (page 9), which **gives an evaluation of the extent to which environmental impact assessments take groundwater into account**.

What role will **geothermal energy** play in Ireland in the future? In particular, what is the **role of normal temperature groundwater**? On page 2 Brian Connor describes a national survey which will provide some answers, and Bob Aldwell summarises a **seminar** on the topic.

If you haven't already heard of '**epikarst**', you are not 'with it'!! See the article on page 4 for further details.

A considerable amount of applied **hydrogeological research** is being carried out in **Irish Universities**. This is summarised on page 12. On page 16, summaries of presentations given at the IAH Younger Hydrogeologists' Forum are given: Colette Cronin describes **an assessment of the impact of groundwater abstraction on a fen**; Margaret Keegan recounts her experiences with **site investigations for landfill sites**; and Malcolm Doak describes a NPWS study on **raised bogs and their restoration**. Yvonne Doris describes **a groundwater protection study** near Letterkenny on page 7.

Are consulting and good science compatible? Yes, but .....! is the answer given by David Cehrs and William Bianchi in a thought-provoking article on page 19.

Editor

National Survey on Low Temperature Geothermal Energy

The present energy supply, conversion and demand system in the EU contributes significantly to a number of environmental problems including urban air pollution, acidifying emissions and the emission of greenhouse gases. The utilisation of geothermal energy can replace some of the fossil fuels currently in use and reduce the environmental problem.

Ireland has no known high temperature geothermal resources - there are some tepid groundwater sources where the temperature of the water is at 20^{o}C (e.g. Mallow) but in general the groundwater temperature in Ireland is 10^{o}C. Energy can be extracted from normal temperature groundwater but the economics are marginal, due to the high cost of drilling wells, disposing of the water after the heat is extracted and also the risk factor where there may not be sufficient water to match the heating requirements.

In Ireland, at least 25% of the water supply is from groundwater sources and these sources are capable of producing heat energy. As these are existing wells the risk factor is eliminated as is the problem of disposing of the water after the heat is extracted – it is used for public or other supply. The heat can be considered to be borrowed from the water supply source. In addition all the capital costs of well drilling, testing, disposal of water are already expended in the water supply project. This will improve the economics of the geothermal system.

The above concept was presented to the Energy Directorate of EU (DG XVII) and they have funded the study under the Thermie Programme on utilisation of energy from existing groundwater systems in Ireland, Austria and Portugal. This project is being co-ordinated by Brian P. Connor & Associates Ltd of Tramore, Co. Waterford.

If the results of the study are positive it may be possible for the well owners to gain additional value from their water resources. The utilisation of this heat energy can contribute to the employment in the manufacture, installation and maintenance of heat pumps and, as mentioned above, improve the environment.

Brian Connor, Brian P Connor & Associates Ltd.

Seminar on the Uses of Low Temperature Geothermal Energy

This seminar was organised by Brian P Connor & Associates at the launch of a new EU Thermie project to harness the energy from a number of existing large supply wells. The countries taking part in the project are Austria, Ireland and Portugal with technical assistance provided by France. The seminar was held in Tramore on 20 January and opened by the Minister of State, Brian O'Shea.

The Minister began by stressing it was Government policy to seek to exploit all forms of renewable energy. In 1995, as a result of a Government initiative, some 111 MW of additional electricity generating capacity from alternative sources were offered to independent electricity producers.

The Government's energy policy takes into account environmental considerations and aims to derive as much energy from indigenous sources as is economically possible. In 1996, Minister of State Emmet Stagg launched a renewable energy support strategy with targets up to the year 2010. The Minister has earmarked, subject to EU approval, a sum of £7.5 million under the Economic Infrastructure Operational Programme to support successful AERIII projects up to the end of 1999. In addition, the strategy allows for direct sales by renewable energy generators of electricity to consumers and commits to the development of an appropriate scheme to encourage the use of small scale renewable energy systems for reasons of local energy self sufficiency.

In an effort to support technology development the renewable energy strategy allows, subject to EU approval, for the commitment of £1 million for the construction and operation of Ireland's first wave energy to electricity pilot plant. As a further support for innovative projects, the Minister's

strategy guarantees electricity market access for successful renewable energy Thermie projects. Each MW of renewable energy installed, instead of conventional generation, reduces CO_2 emissions by some 1000 tonnes/yr and cuts oil imports by £100,000/yr. In the longer term renewable energies are the only sustainable fuel sources.

Brian Connor explained that the seminar was being held in order to focus attention on the new Thermie project. It took advantage of the presence in Tramore of the visiting speakers to provide information to an Irish audience on the availability and use of low temperature geothermal energy in the four participating countries.

Johann Goldbrunner from Graz summarised the situation in Austria. Deep sedimentary basins contain aquifers at depths of over 2000m with water at more than 100°C. Reinjection is not needed on quality grounds but reducing head pressure due to an increase in the number of wells is now making it necessary. In Austria warm waters are used for district heating and greenhouses. Up to now the capacity of geothermal installation is 20MW. The use of warm waters for baths, both for spas and recreational use is important in Austria, especially in the eastern part of the country (Styria). An indication of their importance can be gained from the fact that the Loipersdorf spa receives 3500 visitors per day, while a new spa is being constructed at Blumau at a cost of IR£60 million.

Christian Boissavy from Paris provided an overview of geothermal development in France. Low temperature geothermal energy is used widely in France for space heating - district heating, blocks of flats etc. Much of this development dates from the 1970s when France moved quickly to harness this energy in the wake of the energy crisis. The French have established a comprehensive approach to low grade geothermal energy which covers technical, legal and insurance aspects. At present, there are some 50 sites in France which provide heating from low temperature geothermal energy.

Altogether such energy provides a saving of about 40,000 toe/yr. In recent years, much effort has gone into improving techniques including the optimisation of heating networks and the development of special tools for the prediction and planning in future reservoir exploitation. These improvements, along with the environmentally favourable aspects of geothermal energy, have ensured the continued success of geothermal energy in France even during times of relatively low prices for conventional energy.

Jose Carvalho described the situation in Portugal. In that country waters are available of between 25°C and 75°C. The waters occur as springs and are also tapped by boreholes. For instance, in the Lisbon area, wells of between 1500m and 2700m yield water of from 50°C to 75°C. The greatest use of the warm waters is for spas with twenty seven springs being used for such purposes. In some of the spa towns there is a concern that attempts to use the water for energy purposes could endanger the tourism and spa industries. 1990 legislation places geothermal resources in public ownership but licenses to explore and exploit it can be obtained from the Ministry of Industry.

Bob Aldwell outlined the situation in Ireland. 29 springs with temperatures of 13°C to 22°C have been identified in ten southern counties. Groundwater with a temperature of about 14°C is present at a number of sites in Central Dublin. Up to now, the main users of this low grade energy have been Cork County Council in Mallow and Trinity College in Dublin. The only spa still active in Ireland is Lisdoonvarna and the spring there is a cold water one.

Pat Walsh presented the case study of Mallow, from the discovery of the warm spring in 1724, through its period as a famous spa, to the use of the warm water for heating the town swimming pool in 1988. Since then Cork County Council have been successful in obtaining support from the EU for nine energy related projects. The long term aim of the County Council is to establish a Renewable Energy Park, incorporating a visitors centre and an Energy Demonstration Trail in Mallow town.

Bob Aldwell, Geological Survey of Ireland.

Epikarst : A 'New' Concept in Irish Hydrogeology

Introduction

Think of an intensively karstified area and most of us would conceptualise sinking streams, large resurgences (springs), bare limestone, caves, underground 'rivers' and minimal surface drainage. Now a new concept - epikarst - is adding to our understanding of karst. Until David Drew mentioned it during a short course on karst four years ago, I had hardly heard of the word, and in any case did not see it applying to Ireland. Now it is one of the 'in' words; so popular that a well known English professor of hydrogeology who started off sceptically and suspiciously with phrases like "what you call epikarst", now lets the word 'epikarst' trip off his tongue as easily and freely as the word hydrochemistry!! My own understanding has improved by my involvement with the EU organised COST (Co-operation in Science and Technology) Action 65 *"Hydrogeological aspects of groundwater protection in karst areas*" and by recent work on the flooding in the Gort area (which is being undertaken by a consortium of Southern Water and Jennings O'Donovan & Partners, involving David Drew, Paul Johnston and David Ball). While my understanding needs to be improved further, I will attempt to introduce the concept here mainly by way of quotations (given in italics) from karst researchers. Hopefully future articles by those involved with the Gort project will elaborate on this article and apply the concept to the Irish situation.

What is Epikarst?

Epikarst is the uppermost layer of a karstified rock in which a large proportion of the fissures have been enlarged by solutional erosion (Drew, 1995). *An epikarst allows rapid infiltration and some storage of large quantities of infiltration water. In karstic areas the epikarst may extend to a depth of several metres or may be absent altogether.*

The conceptual model of a karstic aquifer proposed by Doerfliger and Zwalen (1995), shown schematically below, illustrates the role of the epikarstic zone in collecting and storing recharge in the unsaturated zone and then funneling it rapidly to the saturated zone.

Conceptual model of a fissured karstic aquifer (from Doerfliger and Zwalen (1995)

Epikarst in the Scientific Literature

Most researchers emphasise the impact of the epikarst on groundwater storage. Also, the

development of epikarst can influence landforms such as dolines (collapse features). This is described below by Ford and Williams (1994): *Recharge from rainfall will be relatively diffuse, depending on soil cover, and percolating water will accomplish 50-80% of its solutional work within about 10 m of the surface. Hence fissures that are considerably widened by corrosion beneath the soil close rapidly with depth. As a result, infiltration into the top of this highly corroded subcutaneous zone is much easier than drainage out of it. The bottleneck effect results in much storage of water in this zone after heavy rain, constituting a perched epikarstic aquifer with a base that is essentially a leaky capillary barrier. Because of initial spatial variability in fissure frequency and permeability arising from tectonic and lithological influences, preferred (low resistance) vertical leakage paths develop down connected pipes at the base of this aquifer. These paths are enlarged by solution with the result that a depression develops in the overlying subcutaneous water table similar to the cone of depression around a pumped well. Flow paths then adjust in the epikarst aquifer to converge on the dominant leakage route. The extra flow encourages more solution and with it the enhancement of vertical permeability.*

Tyc (1996) points out the relevance of the epikarstic zone in water quality variability. *The epikarst is a specific, independent perched aquifer within carbonate massifs, characterised by specific hydrologic processes which occur both within it and at its base. Storage and dispersed flow within the epikarstic zone causes karstification processes as well as human impacted additions of solutes to the carbonate aquifer. The epikarstic zone plays an important role in recharge and transmission of pollutants from surface non-point sources to the aquifer. Storage which delays the flood response of the aquifer and concentrated recharge of underlying vadose* (unsaturated) *zone of transformed water by hydrochemical processes during storage are complementary processes within the epikarst. Hydrologic processes concerned with the concentration of flow at the base of the epikarst zone focuses concentration of pollutants at a certain depth in the rock profile. It causes observed pulses of increasing and decreasing contaminant concentrations in water discharged from the aquifer.*

A recent midwest US view on epikarst is give by Aley (1997):

Some Physical Characteristics of the Epikarstic Zone.

The thickness of the epikarstic zone is commonly of the order of 10 metres, but can vary from essentially zero to 30 metres (100 feet) or more. Factors affecting the thickness of the epikarstic zone include climate, time since the last glaciation of the site, patterns and depth of groundwater circulation, characteristics of the bedrock and the vegetational history of the area.

The intensity of epikarstic development, which can be expressed as a percentage, routinely decreases with increasing depth below the surface. In many epikarstic zones sediments partially or almost completely fill most or almost all of the voids within the bedrock; in other situations many or most of the voids are largely free of sediments. The percent of the bedrock void volume which is filled with sediment can range from less than 5% to more than 95%.

Permeability rates within the sediment fillings of the epikarstic zone are also highly variable. The permeability rates of the sediment fillings are often greater than might be anticipated from soils having similar textural characteristics. This is especially true when the fills are silts and silty clays that have been subjected at some time in the past (perhaps only during the 100 year or longer interval droughts) to some desiccation. Periods of desiccation commonly result in compaction of silts and silty clay sediments with associated development of compaction cracks within the sediments filling the voids. These compaction cracks and other structural and textural features within the sediment fills often provide matrixes with high permeability rates. The net result is that permeability rates through the sediment fills of the epikarstic zone are commonly orders of magnitude larger than those in the adjacent carbonate bedrock.

Hydrological Classes of Epikarsts

We have divided epikarstic zones into three hydrological types based upon their ability to store water; they are: (1) rapid draining epikarsts, (2) seasonally saturated epikarsts and (3) perennially saturated epikarsts. This classification is useful in planning and designing groundwater tracing studies and is developed for this purpose. The quantities of tracer dyes needed and typical groundwater travel rates vary with the type of epikarstic system.

Especially in some thick epikarstic zones, but to some extent in all epikarstic zones, conditions

typical of two or more of the hydrological classes of epikarsts may be present. As an example, a rapid draining epikarst may occur in the upper part of the zone while conditions typical of seasonally saturated epikarst or perennially saturated epikarst are found in the lower part of the zone.

Rapid draining epikarsts are characterized by having little if any of the epikarstic zone saturated with water for more than a few hours at a time even following major storm events or snow melt periods. In these cases there is little water storage or detainment within the epikarstic zone. Dissolutional voids are typically relatively free of fine textured sediments. However, as is the case with all epikarstic zone drainage, waters entering the subsurface at a particular point may subsequently discharge from multiple points in multiple areas. Areas commonly characterized by rapid draining epikarst include: (1) many alpine karst areas, (2) areas with high topographic relief, and (3) areas where the soluble purity of the carbonate bedrock is high and external sediment sources are negligible; these conditions typically result in thin soils and minimal residuum.

Seasonally saturated epikarsts routinely store water seasonally or after major precipitation periods. The water storage may persist for periods of weeks or months. Dissolutional voids are commonly partially to almost completely filled with fine textured sediment; some preferential flow routes which contain appreciable air-filled void space typically exist. Lands commonly characterised by seasonally saturated epikarst include: (1) humid lands, (2) areas with moderate relief, (3) areas where the soluble purity of the carbonate bedrock has permitted the development of appreciable soil and residuum thicknesses, and (4) areas where most or all of the epikarstic zone is at elevations greater than the elevations of nearby perennial streams.

Perennially saturated epikarsts are characterised by most of the epikarstic zone being perennially saturated with water. This situation is common in: (1) humid lands, (2) areas with low to moderate relief, and (3) areas along perennial streams. Cavities within the bedrock are commonly mostly filled with fine textured sediments."

Why is our understanding of the epikarst concept important?

The decisions made and the advice given by hydrogeologists are influenced by our conceptual knowledge of the different Irish groundwater environments and flow regimes. Also, numerical modelling is becoming an increasingly important tool both in aiding our understanding of Irish hydrogeology and in improving the predictive component of our work. In my experience, producing the conceptual model is often the most critical component of numerical modelling. (After all, the rest is really just a computer game with a nice colour output!!!!!). It is vital that we continue to improve and update our conceptual model of the limestone aquifers, which have been karstified to varying degrees. The epikarst concept helps in doing this.

References

Aley, T. 1997. *Groundwater tracing in the epikarst*. Proceedings of Conference: 'The Engineering Geology and Hydrogeology of Karst Terrenes. Eds: Barry F. Beck and J. Brad Stephenson. A.A. Balkema, Rotterdam. pp207-211.

Doerfliger, N. and Zwahlen, F. 1995. *National report from Switzerland*. In: COST Action 65 Report 'Hydrogeological aspects of groundwater protection in karstic areas. European Commission. 446p.

Drew, D. 1995. *Glossary of karstic terminology*. In: COST Action 65 Report (see last reference).

Ford, D. and Williams, P. 1994. Karst geomorphology and hydrology. Chapman and Hall, London. 601p.

Tyc, A. 1996. *The nature of epikarst and its role in dispersed pollution of carbonate aquifers*. Proceedings of International Conference: 'Karst-Fractured Aquifers – Vulnerability and Sustainability. Katowice-Ustron, Poland. 310p.

Donal Daly, Geological Survey of Ireland

Groundwater Protection in the Glen Swilly Valley, County Donegal

This study aimed to assess the vulnerability of and facilitate the protection of the sand and gravel aquifer in the Swilly Valley. Protection of the Glen Swilly gravel aquifer is essential as the resource is to be used as a public drinking water supply that will meet the needs of Letterkenny town into the next century.

The study began as part of a larger investigation by Donegal County Council and Minerex Environmental Limited on the feasibility of abstracting water from the Glen Swilly gravel aquifer, near Letterkenny, Co. Donegal for use as a drinking water supply to augment existing supplies to the town.

The Geological Survey of Ireland Groundwater Protection Scheme was used in the designation of Vulnerability categories and in the delineation of Source and Resource Protection Areas. This was achieved by the assessment of bedrock geology, Quaternary geology, depth to gravels, hydrogeology and hydrochemistry. From the resulting maps, groundwater vulnerability was assigned to various areas of the aquifer. Hydrogeological parameters were obtained from pumping tests and used to calculate times of travel. These times of travel were used to delineate Source Protection Zones for each of the five proposed production wells in the lower part of the valley. Source Protection Areas (SPA's) provide additional protection for the groundwater source(s) themselves (boreholes). The Source Protection Area for each borehole was subdivided into three areas, the source site, the Inner Protection Zone and the Outer Protection Zone.

The River Swilly valley is a flat-bottomed glaciated valley. Bedrock outcrops frequently on these hills and on the valley sides, as two to three metre high crags with striations and where the bedrock does not outcrop it is only covered by relatively thin till deposits. The valley widens out past New Mills (4km west of Letterkenny) in the townland of Ballyconnelly, and is characteristically flat with a floodplain of about 500m width at its widest point, close to Letterkenny town. There are a few drumlins on the southern side of the valley which follow a west south-west to east north-east direction. The river is tidal to a point approximately half a kilometre downstream of New Mills.

The Glen Swilly gravel aquifer is a semi-confined aquifer with less confined conditions at its westernmost extent, near New Mills. Increasingly confining conditions are a characteristic of the aquifer system moving eastwards to the eastern limit of the aquifer at Letterkenny town, in the area called Ballymacool. The Glen Swilly gravel aquifer is a locally important aquifer, based on the methodology of assessment of the Geological Survey of Ireland Groundwater Protection Scheme.

The aquifer is a fluvio-glacial outwash in a river valley. The deposit consists of sand and clean gravels deposited during the last deglaciation as ice retreated up the Swilly valley at the end of the last ice age. It is a shallow aquifer of less than 20m depth, and of limited areal extent. Geophysics investigations revealed a palaeochannel of gravels at New Mills and again closer to Letterkenny town and this is believed to be the main section of the aquifer where most of the groundwater resource is found. This palaeochannel is approximately 50m wide and less than 1km^2 in areal extent. Borehole logs confirm the presence of the palaeochannel. The bedrock geology of the area under the aquifer is metamorphic schists of the Termon Pelite formation of the Dalradian Supergroup. In general, these schists are fairly impermeable and only where they are weathered do they provide increased permeability. The Quaternary deposits in the area consists of the sands and gravels of the aquifer itself which are overlain by estuarine silts near the coast and by sandy lenses, clay lenses and peat lenses further up the valley. The estuarine silts have a low permeability and act as a confining layer, increasing the potentiometric pressure and creating artesian conditions and they also provide good protection and high attenuation capacities. The more permeable sandy deposits further upstream allow more recharge to the aquifer and also provides quicker access for contaminants to enter groundwater.

Water quality is generally considered to be good except for exceedances of maximum admissible concentrations (MAC) for Iron and Manganese and Ammonia. Iron and manganese levels are likely to originate from the clay layers rich in organic matter overlying the aquifer, or they may be coming from organic waste pollution of the groundwater. High levels of ammonia may be due to septic tank effluent seeping into the groundwater. Hydrogen sulphide was detected in some of the boreholes. High levels of iron and manganese are due to the semi-confined conditions in the aquifer. Only one of the boreholes was positive for coliform analysis. Potential sources of pollution are usually localised point sources of pollution, mainly farmyard waste and septic tanks. These two sources are likely to be responsible for the above MAC levels of ammonia in the groundwater. Diffuse sources of pollution such as fertiliser, manure and silage spreading on the land surface may be responsible for background levels of nitrate but farming practices in the river Swilly catchment are not of an intensive nature.

Most of the Swilly Valley aquifer has a vulnerability classification of moderate due to the thickness of low permeability silts overlying the gravels (5-10m). The areas of high and extreme vulnerability close to New Mills are due to thin highly permeable Quaternary deposits of sand over the gravel aquifer. Due to the complex nature of the deposit and the rapid changes in stratigraphy over short distances in the aquifer, extrapolation of the vulnerability classifications could not be justified over large areas. The middle section of the aquifer where no wells were installed and no borehole logs or geophysical data is available, is classed as probably moderate vulnerability.

Source Protection Areas were calculated for the five proposed abstraction wells at Ballymacool. For the purposes of protection, each source protection area is sub-divided into three zones: the source site, in which all activities should be prohibited, the Inner Protection Area, which encompasses the area within the 100 day travel time radius and is intended to protect the source from bacterial contamination and the Outer Protection Area, designed to protect the source from chemical and trace organic contamination. The delineation of the Outer Protection Area is based on the area required to generate a sufficient recharge volume to provide a given well yield. This method for the delineation of the Outer Protection Area is a calculated fixed radius method which like the Inner Protection Area calculated above, has limitations. It is over protective on the down-gradient side of the well and under protective on the up-gradient side of the well.

There is only one aquifer classification in the Resource Protection Area, i.e. locally important sand and gravel aquifer (Lg). Therefore, the delineation of Resource Protection Zones was straightforward and simply involved converting the vulnerability zones in the Resource Protection Area into protection zones. Most of the Resource Protection Area is classed as Lg/M i.e. of moderate vulnerability. The high and extreme areas near New Mills are classed as Lg/H and Lg/E.

In conclusion, the protection scheme is designed for use as a planning tool by Donegal County Council and Letterkenny UDC in making decisions and the siting of potentially polluting activities. The protection scheme is designed to protect the groundwater from contamination and to ensure that this groundwater resource is maintained in as pristine a condition as possible for use as a potable water supply for Letterkenny town.

This article is summarised from the above titled thesis which achieved part-fulfilment for the degree of Master in Environmental Science at Trinity College, 1996. Dr. Catherine Coxon of the Environmental Sciences Unit at Trinity College supervised the thesis. Data, assistance and advice were provided by Minerex Environmental Limited.

Yvonne Doris, formerly Geological Survey of Ireland, now EPA.

An Evaluation of the Extent to which Irish Environmental Impact Assessments Take Groundwater Issues into Account

Introduction

Environmental impact assessments (EIAs) have been carried out in Ireland for eight years, since the implementation of EC Directive 85/337/EEC [1]. Many activities requiring an environmental impact statement (EIS) have implications for groundwater [2]. This article summarises some of the findings of a research project evaluating the extent to which Irish EIAs take groundwater issues into account.

Two main approaches were taken in the evaluation of the groundwater component of Irish EIAs, a survey of existing EISs and a questionnaire survey of Irish groundwater specialists. A broad overview was carried out of the groundwater components of 56 EISs for developments with the potential to affect groundwater, submitted between January 1995 and May 1996. The length of the groundwater components, the nature of the investigations and the geological and hydrogeological data provided were recorded on an evaluation form. Three types of development (piggeries, quarries and holiday developments) were singled out for more detailed examination, and 57 EISs for these developments submitted between 1992 and 1996 were evaluated (28 piggeries, 20 quarries and 9 holiday developments, reflecting the proportion of the total EISs represented by each type of development).

The questionnaire survey of Irish groundwater specialists aimed to determine the number of EISs for developments with the potential to affect groundwater that had expert groundwater input at the production and evaluation stages. It was also used, in conjunction with personal interviews, to obtain the opinions of the groundwater experts on the appropriate level of input of hydrogeologists in EISs for piggeries, quarries and holiday developments and the appropriate nature of the investigations for each of these types of development. (Information and opinions were obtained from eight private consultancy companies, three university hydrogeologists, the GSI and the EPA).

Overview of groundwater components in EISs with the potential to affect groundwater

The broad overview focused on the following categories of development: animal rearing units, extraction, chemical industry, wastewater treatment plants, holiday developments, slaughter houses and the food processing industry, roadways, railways and runways, waste disposal, metal industry, textile, leather, wood and paper industries and water management schemes. Only 4 of the 56 EISs (7%) stated that hydrogeologists were involved in the investigations. The only categories of development providing comprehensive geological descriptions were (i) slaughter houses and food processing, (ii) waste disposal, (iii) textile, leather, wood and paper and (iv) water management schemes. Hydrogeology was seriously neglected in most of the EISs evaluated, with the exception of waste disposal EISs.

Piggeries

The questionnaire survey showed that, in the groundwater specialists' opinions, groundwater issues are involved in all EIAs for piggeries. In practice, however, only ten out of 98 piggery EISs produced up to May 1996 (10%) were identified by the questionnaire survey as having groundwater experts involved in their production. The detailed evaluation of 28 piggery EISs produced a similar picture: the qualifications of the investigators were apparent in 18 EISs and groundwater specialists were only known to have been involved in one of these.

The questionnaire revealed that the groundwater specialists considered both desk and field investigations to be a necessary part of EIAs for piggeries, and the majority considered that trial pits should be dug during the field investigations. However, most of the experts questioned said that their actual piggery EIA investigations were not ideal, due to an inadequate budget. The limitations of the groundwater work were borne out by the detailed evaluation of the 28 piggery EISs: the majority involved both desk and field studies, but trial pits were only dug in 10 of the 28 and boreholes were drilled in just 6 (Table 1a). Monitoring of the impact of the developments on groundwater was only proposed in a minority of EISs (39%), but there was increasing awareness of this issue over time, with proposals for groundwater monitoring increasing to 5 out of 7 EISs in 1995. The hydrogeological information in the EISs evaluated for piggery developments was very basic (Table 1b).

Table 1: Summary of the groundwater components of EISs examined for piggery, quarry and holiday developments (samples from 1992-1996)

1a: Nature of the hydrogeological investigations

Development type (sample size)	Piggeries (28 EISs)		Quarries (20 EISs)		Holiday developments (9 EISs)	
	No.	%	No.	%	No.	%
Trial pits dug	10	36%	6	30%	3	33%
Boreholes drilled	6	21%	10	50%	3	33%
Surveys of existing wells	13	46%	8	40%	5	56%
Water quality sampling	.13	46%	1	5%	3	33%
Monitoring proposed	11	39%	6	30%	0	0%

1b: Hydrogeological data provided

Development type (sample size)	Piggeries (28 EISs)		Quarries (20 EISs)		Holiday developments (9 EISs)	
	No.	%	No.	%	No.	%
Depth to water table	8	29%	13	65%	3	33%
Groundwater flow direction	4	14%	3	15%	1	11%
Groundwater gradient	4	14%	1	5%	0	0%
Permeability	. 6	21%	3	15%	3	33%
Specific yield	1	4%	3	15%	2	22%
Recharge	2	7%	1	5%	0	0%

Quarries

The experts also considered that hydrogeologists should be involved in all EISs for quarries. However, the questionnaires indicated an involvement of hydrogeologists in only 21 out of 73 quarrying and mining EISs produced up to May 1996 (29%), while the detailed evaluation of 20 quarrying EISs determined that hydrogeologists were known to have been involved in just two investigations (10%).

Trial pits and monitoring wells were considered necessary in all quarrying EIAs by the majority of groundwater experts. However, as seen from Table 1a, field investigations included the digging of trial pits in just 6 of the 20 EIAs, and although boreholes were drilled in 10 EIAs, these were often exploraton rather than monitoring wells. Monitoring of groundwater impacts was proposed in 30% of the EISs, with these proposals becoming more frequent over time. Detailed hydrogeological information apart from water table depth was generally lacking (Table 1b).

Holiday developments

The groundwater specialists considered groundwater to be an issue in EISs for holiday developments where the site is on an aquifer of regional or local importance, if there is no mains water supply and/or no mains sewerage. They felt that groundwater experts should be involved in these situations. Again, the evidence is that actual involvement is somewhat less than this. The questionnaire survey identified specialist hydrogeological involvement in just five out of thirty-four holiday development EISs submitted up to May 1996 (15%) (although the proportion of the 34 developments meeting the criteria specified by the groundwater specialists is unknown). Nine EISs were evaluated for holiday developments, all in situations with no mains sewerage, seven of which proposed to use a groundwater supply, and hydrogeologists were known to have been involved in just three of the EISs (33%).

Again, the level of hydrogeological investigation was generally unsatisfactory (Table 1a). Trial pits

are considered necessary in field investigations for these developments by the majority of the groundwater experts surveyed, yet just three out of nine EIAs involved the digging of trial pits. Monitoring was not proposed in any of the EISs evaluated. Basic hydrogeological information was often lacking (Table 1b), with water table depth determined in only three EISs and groundwater flow direction in only one.

Conclusion

This research determined that groundwater issues are not taken into account to a great extent in Irish EIAs. The inadequacy of hydrogeological information presented in EISs for developments with the potential to affect groundwater reflects the low level of involvement by hydrogeologists in these EISs: the standard of the groundwater components which have had expert hydrogeological input is greater than in those EISs lacking such input. Although there is some evidence of improving standards over time, clearly the situation is still unsatisfactory, and there is a need to increase awareness among those producing and evaluating EISs of the need to deal in a serious manner with groundwater issues.

(This work was carried out as a dissertation by Susan O'Shea in part fulfilment of the M.Sc. (Environmental Sciences) in T.C.D. The contribution of the groundwater specialists who completed the questionnaires and provided advice, opinions or assistance is gratefully acknowledged).

[1] Council Directive of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment (85/337/EEC), implemented in Ireland by S.I. no. 349 of 1989 and S.I. no. 25 of 1990.

[2] See Proceedings of IAH Irish Group 11th Annual Groundwater Seminar, Groundwater Aspects of Environmental Impact Assessments, Portlaoise, 9th & 10th April 1991.

Susan O'Shea and Catherine Coxon, Environmental Sciences Unit, T.C.D.

News from Abroad

Britain: 'Safer' Sheep Dips Causing an Increase in Surface Water Pollution

The Environment Agency and the Scottish Environment Protection Agency are now reporting an increase in sheep dip pollution. The reason appears to be due to a move away from traditional organophosphate dips towards formulations based on pyrethroids, particularly cypermethrin. This shift follows increasing concern about the health effects of organophosphates. However, pyrethroid dips are much more toxic to aquatic life. One Scottish source estimated that the incidence of sheep dip pollution has increased ten-fold in the last year due to pyrethroids. The lengths of five rivers affected varied from 3-30 km.

Source: The ENDS Report, No. 263, December, 1996.

Britain: Pesticide Leaching Greater than Predicted

Recent research by the Ministry of Agriculture (MAFF) has shown that leaching of pesticide from clay soils into surface waters is greater than predicted by leaching theory. Applications of seven commonly used pesticides (isoproturon, simazine, dimethoate, MCPA, atrazine, carbofuran, aldicarb) were made to crops at recommended rates and the resulting concentrations in soils and drainage waters were monitored.The resulting peak concentrations in surface waters were potentially significant for wildlife, and greatly exceeded the 0.1 μg/l for pesticides in drinking water - 264 μg/l in the case of carbofuran. It was concluded that the greater than expected degree of pesticide leaching was due to by-pass flow of water through cracks in the soil and that processes such as sorption and degradation within the soil were of limited effectiveness in preventing leaching losses. These results are regarded as significant as approximately one-third of UK soils have a similar hydrological regime as that at the research farm.

Source: The ENDS Report, No. 243, April 1995.

Compiled by the Editor

Hydrogeological Research in Irish Universities

Introduction

The IAH Technical Discussion Meeting of 7th January 1997 was entitled "Research in Irish Universities". The meeting provided a forum for those involved in hydrogeological research to outline their current and recent research areas.

Six speakers presented at the meeting:

1. Catherine Coxon, Environmental Sciences Unit, Trinity College, Dublin.
2. David Drew, Geography Department, Trinity College, Dublin.
3. Tiernan Henry, Department of Engineering Hydrology, University College Galway.
4. Paul Johnston, Department of Civil, Structural and Environmental Engineering, Trinity College, Dublin.
5. Bob Kalin, Environmental Engineering Research Centre, Department of Civil Engineering, Queen's University, Belfast.
6. Bruce Misstear, Department of Civil, Structural and Environmental Engineering, Trinity College, Dublin.

The following article describes the current and research areas of five of the speakers (details on the sixth will be in the next Newsletter).

Catherine Coxon, Environmental Sciences Unit, University of Dublin, Trinity College.

Present and recent past research areas

Research carried out by Dr. Catherine Coxon and research students in the Environmental Sciences Unit, T.C.D. focuses on groundwater quality problems and groundwater protection. The main quality issue currently under investigation is nutrient input to water, particularly nitrate from both diffuse and localised sources. This includes a Ph.D. project by Karl Richards, nearing completion (involving T.C.D., Teagasc and the G.S.I.), which examines nitrogen inputs from a dairy farm to a limestone aquifer. Current research on phosphorus losses from agricultural grassland focuses on surface and near-surface routes (in a Ph.D. project by Isabelle Kurz), but it is hoped to extend this work to groundwater in the near future. Another topic of investigation (in an M.Sc. project by T.J. Mahony) is the risk to Irish groundwater resources posed by road runoff.

Groundwater protection work includes the production of protection plans for particular aquifers and supply sources (e.g. M.Sc. projects by Yvonne Doris and Cecilia Gately) and an evaluation of the extent to which groundwater protection is considered in Irish EIAs (M.Sc. project by Susan O'Shea). Following on from the STRIDE groundwater research project (1992-94), the Environmental Sciences Unit has an ongoing interest in the use of GIS technology for groundwater protection (e.g. M.Sc. project by Niall Fahy).

A particular area of interest is groundwater quality and the evaluation of groundwater vulnerability in karst limestone aquifers. This involved work on groundwater vulnerability in the Fergus catchment, contributing to E.C. COST project 65 and research on this topic will be continued under COST project 620 (1997-2002).

List of relevant theses (1995-96) in partial fulfilment of the M.Sc. degree in Environmental Sciences, T.C.D.

- Doris, Y. (1996) Groundwater protection in the Glen Swilly valley.
- Gately, C. (1996) Groundwater protection scheme for the Dower spring, County Cork.
- Fahy, N. (1996) Vulnerability mapping of two karstic spring catchments in County Clare with the aid of Geographic Information Systems.
- O'Shea, S. (1996) An evaluation of the extent to which Irish environmental impact assessments take groundwater issues into account.

David Drew, Geography Department, University of Dublin, Trinity College.

Recent Research Areas

1. Using multi-tracing techniques with fluorescent dyes, optical brightener and bacteriophage in conjunction with the Gort Flood Study project to try to build up a detailed model of a complex karst groundwater system and also to assess the relative merits of the various tracers.

2. Involvement with the COST action-65 project on formulating criteria for the protection of karstic aquifers.

3. Compilation of a water quality and hydrometric database for a part of the lowland karst in the Burren National Park.

Recent Theses (ongoing):

- Morgan Burke: Assessing the extent of karstification in Ireland.
- Barbara Yeates: Analysis of enclosed depressions on the Burren.
- Lianda d'Auria: Development of an EIA methodology for use in karst areas; example of the Burren karst.

Things thought desirable for the future

1. Facilitating the production of a book on the karsts of Ireland and their importance in all respects.
2. Facilitating the production of a book on the Hydrogeology of Ireland preceded by a bibliography (both as summaries of present state of knowledge).

Tiernan Henry, Department of Engineering Hydrology, University College Galway

Though still primarily involved in surface hydrology issues, the Department of Engineering Hydrology is becoming more involved in groundwater studies. While most post-graduate students are pursuing research hydrology, there have been several recent M.Sc. projects which have focused on groundwater.

Specific topics for possible research include:

1. Carrowbrowne Landfill Study:
The site is situated about 8km north of Galway, on the Headford Road. Lough Corrib is a few km to the west. The geology consists of partly Karstified Carboniferous limestone, usually found a couple of metres from the surface, overlain by post-glacial lake deposits, and peat. Work has been done recently on surface water quality of the streams passing this landfill, but there has been no extensive work undertaken to examine the groundwater quality. A 1991 M.Sc. study at UCG looked at groundwater quality, but only in the area immediately surrounding the site. It is hoped to get a study underway in the spring/summer and set up a sampling array that will be more areally extensive. This will involve installing a network of piezometers to ascertain whether the groundwater moving west to Lough Corrib is affected by the landfill. It is hoped to get some undergraduate students involved with the aim of doing an extensive project. Using a system such as MODFLOW one could predict the 3D movement of a plume, if any, through the system towards the lake.

2. Flow to Wells in Karstified Limestone Aquifers:
Several students have worked at Athenry, and one is currently involved in a study at Kinvarra, on disentangling the complexities of flow to wells in Karstified limestone.

3. Farmstead Assessment System (F.A.S) Modification.
Having worked on the F.A.S project in Madison, Wisconsin, it may be a useful tool for researchers and farmers to assess the groundwater pollution risk potential of activities in and around the farm, with particular reference to siting of the water-supply well. The FAS worksheets are being modified to suit the Irish situation.

4. Underground Storage Tanks (USTs)
There are thousands of tanks in use throughout the country. Many are leaking to some extent. An extensive survey of those still in use, and those no longer in use could prove extremely useful.

5. *Construction Studies:*
With a good deal of large capital investment projects being undertaken throughout the country, there is a need to better understand movement of water into excavations on construction sites. The present methods of solution are idealised, and work best in homogeneous, isotropic and confined situations. Applying these solutions to sites in weathered, fractured or karstified limestones introduces too many uncertainties.

Recent M.Sc. dissertations:

- Osman, Y.Z. 1996. Basic Study on Groundwater Flow and Contamination Modelling.
- Saeed. M.M. 1995. Analysis of Pumping Tests in a Burren Limestone Aquifer used as a Supplementary Water Source for Athenry, Co. Galway, Ireland.

Bob Kalin, Environmental Engineering Research Centre, Department of Civil Engineering, Queen's University, Belfast.

Groundwater research at QUB includes hydrogeology and contaminated land investigations, modelling and studies of naturally occurring differences in chemistry and isotopic data in mathematical models of groundwater flow. Research on palaeohydrology is also providing

insights into changes in the hydrology of Ireland over the last seven millennia.

On-Going Research Projects:

1. Coupled Reactive-Transport Modelling of Organic-Metal Interactions.
The transport of heavy metals and radionuclides in soil and groundwater are affected by surface reactions and by speciation and chelation with organic compounds. Risk analysis of land contaminated by heavy metals is dependent on our understanding of the movement and fate of these elements. The goal of this research is to produce a reactive-transport solution for modelling of organic-metal interaction in soils and groundwater.

2. Validation of Natural Bioattenuation using Stable Isotopes.
Natural bioattenuation of contaminated land generally takes place at most contaminated sites. Though we may understand the microbiological controls, there is no technique to accurately define the rate of bioattenuation. This research is using novel techniques based on isotopic measurements to develop a measure of the flux of degradation by-product, thus allowing for estimates of the rate of natural bioattenuation.

3. Using radon as a proxy for Vapour Phase Transport in Unsaturated Media.
Radon is a naturally occurring inert gas with a high molecular weight. Its diffusion coefficient is similar to some lighter vapour phase contaminants. This research is developing a systems-based model of Radon movement in soils and groundwater, potentially for use as a proxy for understanding the controls on vapour-phase contaminant transport.

4. Oxygen Isotope Measurement of Recharge Fronts.
There is a two to three permil annual variation in the stable oxygen isotopic composition of precipitation in Ireland. Little is known about recharge mechanisms through glacial soils in Ireland. The goal of this research is to develop a method for measuring the oxygen isotopic composition of soil water with depth and estimating the temporal nature of water movement in recharge zones.

5. Preferential vs. Darcian Flow through Glacial Tills.
Permeability measurements on glacial tills and soils in Ireland suggest movement of water in the recharge zone on decade to century timescales. Thus, preferential flow paths likely dominate the recharge mechanisms in many areas. Preferential flow, like fracture flow, is very difficult to quantify. This research will study intact soil and till cores in an attempt to better understand recharge mechanisms through the glacial deposits of Ireland.

6. Groundwater Flow Modelling of the Sherwood Sandstone, N. Ireland.
A 3-D finite difference model of the Sherwood Sandstone aquifer in the Lagan Valley and N. Strangford Lough is being developed to better understand the flow of water through this aquifer and ultimately as a tool in the management of groundwater resources and protection.

7. Use of Isotopes and Geochemistry in the Modelling of Groundwater Flow and Transport Dynamics.
This IAEA co-ordinated research programme involves researchers from the USA, Canada, Australia, France, Germany, Poland, Turkey, Austria, Russia, Israel and the Queen's University of Belfast. The work at QUB is focused on development of a coupled inverse reactive-transport model for groundwater investigations.

8. Chemistry and Isotopic Indications of Groundwater Flow through the Antrim Basalt.
This research project, in the Department of Geology at QUB, is using chemistry and isotope hydrology to identify the diffuse fracture vs. Karstic flow of water in the Antrim Basalt and the underlying Chalk unit.

9. Development of a 3-D Eularian-Langrangian Solution to Sharp Concentration Fronts in Contaminant Transport Modelling.
This research, carried out through the QUESTOR Centre at QUB, is developing computer code for the model SUTRA that will use Eularian-Langrangian solutions to solve for contaminant concentrations at sharp fronts. Current methods generally fail to accurately describe variations in concentrations under these conditions.

Postgraduate courses in Environmental Engineering: M.Sc. or Diploma.

These courses provide an opportunity for graduates in Civil Engineering, Geology or the Sciences to extend their knowledge in a range of subject areas, particularly relating to environmental engineering. This course is comprised of formal lectures, course-work assignments, and in the case of the

M.Sc., a research project, or in the case of the Diploma a short study report. Students can choose lecture topics from a list which includes:

- Environmental Engineering
- Hydrogeology
- Chemistry of Natural Waters
- Contaminated Land
- Computer modelling of contaminant transport
- River and Coastal Engineering
- Traffic and Highway Engineering
- Water and Wastewater Engineering
- Geotechnical/Soils Engineering
- GIS
- Additional selectives in Environmental Sciences

Examples of Current M.Sc. Projects

- GIS for groundwater management
- Study of recharge mechanisms
- Geothermal use of groundwater in Ireland.
- Mixing and modelling of large regional systems.
- Estimation of potential saline intrusion in coastal aquifers.
- Geochemistry and nitrogen isotopes in karst systems.
- Bioremediation of contaminated land.
- Oxygen isotopes of landfill leachate as an indication of water source and movement.

Examples of Past M.Sc. Projects:

- Nitrogen isotopes as an indicator of nitrate pollution.
- Groundwater flow modelling at a landfill site.
- Carbon and Oxygen isotopes in speleothems.
- Radon in groundwater Co. Wicklow.
- Radon in groundwater Co. Leitrim.
- Radon in groundwater Co. Down.
- Carbon isotopes in tree-rings, palaeohydrology.
- Lead isotopes in tree-rings, sources of lead in the environment over time.
- Structural geology and fracture flow in the groundwater of north Co. Down.
- Oxygen isotopes in surface waters.
- Carbon and Oxygen isotopes in cemented glacial deposits, palaeohydrology.

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

1. *Well design, monitoring and maintenance*.

Produced a guidance document with Peter Howsam of Silsoe College and Charles Jones of Mott MacDonald) which has been published by the Construction Industry Research and Information Association (CIRIA). The report encourages a co-ordinated approach to well management by relating the performance of the water well to the condition of the whole abstraction system, and to the physical, chemical and microbial processes involved.

2. *Reliable outputs of wells and springs*.

Recently completed (with Groundwater Development Consultants) a research project for UK Water Industry Research to produce a standard methodology for estimating reliable outputs of groundwater sources. The proposed methodology is intended to be relatively simple and easy to apply, auditable, and sufficiently flexible so as to encompass a wide range of groundwater source types, from springs and single well sources to those consisting of many wells and complex adit systems. A TCD MSc. student (A. Cronin, 1996) has recently examined reliable yields of groundwater sources in Ireland.

3. *Contamination of groundwater by leaking sewers.*

Co-authored a research project on sewer-related groundwater contamination in England and Wales which was published by CIRIA at the end of 1996. Supervised a TCD MSc student project (S. MacMahon, 1995) which reviewed the evidence for sewer-related groundwater contamination in Ireland.

4. *Aquifer recharge.*

Engaged on research into groundwater recharge in Ireland. Groundwater recharge is perhaps the most difficult component of the hydrological cycle to quantify, yet an understanding of recharge is fundamental to resource assessment and protection. The research project will include a review of existing methodologies for recharge assessment in Ireland (including soil moisture balance techniques and baseflow separation), field experiments in soil physics and other methods, and development of proposed methodologies.

5. *Groundwater contamination from non-aqueous phase liquids (NAPLs)*

Have been involved in a number of consultancy projects (not pure 'research' as such, but including a research element!) concerned with the behaviour of NAPLs - especially chlorinated solvents - in fissured aquifers. This is an area more research is required in Ireland.

Compiled by Yvonne Doris, formerly Geological Survey of Ireland, now EPA.

Summaries of Talks Given at the March IAH Technical Discussion Meeting

Links between Groundwater Abstraction and Wetlands in Thetford, Norfolk.

The two wetland areas of Ringmere and Langmere located north of Thetford, Norfolk are designated Sites of Special Scientific Interest on the basis of their unique flora and fauna. The demand for water, for both public supply and spray irrigation, is ever increasing in this area. This, coupled with natural fluctuations in the wetland water levels has generated strong concern that the wetlands will remain drier for longer periods with knock on effects for their ecology. In order to understand the relationship between groundwater and wetland water levels, the geology, hydrology and hydrogeology of the surrounding area was studied and subsequently modelled.

Borehole records, obtained from the Environment Agency (E.A.), were analysed to develop a three dimensional picture of the geology within the study area. The Upper Cretaceous Chalk which forms the main aquifer in the area is fine grained and strongly fissured. Its upper surface is transected by a number of buried valleys which are approximately 2 km in width. The chalk is overlain by boulder clay which has a low permeability and acts as a semi-confining layer to the chalk. The wetlands form depressions in the boulder clay but have a strong hydraulic connection to the underlying chalk. Although absent in the vicinity of the wetlands, much of the surrounding areas are capped by Recent sands and gravels.

A hydrological investigation of data collected from the E.A. and the Institute of Hydrology was also carried out. Results indicate that rainfall is evenly distributed throughout the year although recharge is greatest in the winter months. In the summer months potential evaporation generally exceeds rainfall and strong soil moisture deficits occur. Many farmers have invested heavily in spray irrigation fed by abstraction from the chalk aquifer to ensure crops have sufficient moisture during the growing season which spans from April to September.

Water levels measured in 40 boreholes indicate that groundwater flows in a southerly direction towards the River Thet. Historically chalk water levels are highest in late spring and early summer and generally fall to a minimum around November. Water levels in the wetlands generally lag 2-3 months behind those of the chalk and therefore fall to a minimum around January/February. In the past, following a period of low winter recharge, wetland water levels have not been able to recover sufficiently and so they have remained dry for prolonged periods of time. The E.A. restrict abstraction within 5 km of the wetlands to ensure pumping does not exacerbate this trend.

The aquifer system was subsequently modelled to investigate the sensitivity of groundwater to pumping. Initially a two dimensional model was established. FLOWPATH was deemed the most appropriate model to use on the basis of its visual

output and ease of use. It was largely used to constrain aquifer properties obtained from the British Geological Survey. A good calibration with measured piezometry was achieved. A sensitivity analysis indicated that variable recharge was most important in accounting for changing water levels. However, increased pumping levels also have a significant effect. Since aquifer geometry is quite complex it was decided that a three layer model should be set up using MODFLOW. Steady state conditions were initially simulated. However, steady state conditions are rarely achieved in a real system, therefore the need for a transient model. The model was calibrated for the period 1980 to 1996 and results compare quite favourably with actual chalk water levels monitored for that period.

A sensitivity analysis involved turning off all pumps within 2 and 5 km of the wetlands. Results indicate that pumping within 2 km causes drawdowns of 30-40 cm in chalk water levels near the wetlands, but at least half these drawdowns can be attributed to abstraction at the nearest farm. Pumping within 5 km causes drawdowns of 65-70 cm.

Based on an understanding of the hydrology and the results of groundwater modelling of the wetland areas of Thetford, it was recommended that the E.A. estimate the effects of individual abstractions using a model similar to the one established in this project. This would ensure that abstraction within 5 km of the wetlands which has no significant effect on their water levels is not restricted during the growing season. In the meantime the E.A. need to continue restricting abstraction in these areas to ensure their conservation.

(This article is based on research carried out as part of the MSc. in Hydrogeology at University College London, 1996)

Colette Cronin, Geological Survey of Ireland

Experiences with Site Investigations for Landfill Site Selection

There are different levels of investigation involved in the process of landfill development. One of the most important things to do is to set out the objectives at the start. There is usually a limited budget available and the investigations must be comprehensive enough to determine the potential impact of the landfill on the hydrogeological environment. The site investigation plan should be flexible to allow for modification of the drilling methods where the first choice is deemed unsuccessful.

Some of the methods of investigation include: rotary coring, percussion drilling, hand augering, trial pitting and geophysical surveys. The diameter of the core required dictates the type of rig used. A Knebel top drive rotary core rig was used successfully to drill 89 -110 mm core. It uses a triple tube system with an inner mylar plastic liner for greater core recovery. An air mist system was used to control the washing out of materials. In percussion drilling it is important to outline the minimum penetration depth required prior to drilling so that the driller will take the time to chisel and break boulders instead of considering it a refusal at shallow depths. Drillers have a lot of experience and knowledge of different ground conditions so it is always useful to outline the purpose of the investigation and look for and consider their opinions when there is some difficulty in the investigations.

Aquifer testing is a very important aspect of the site investigation as the type of aquifer is one of the determining factors during site selection. Pump tests, packer tests and variable head tests all give information on either transmissivity and /or permeability. Borehole completion is an aspect that requires a lot of consideration. The borehole logs and samples should be examined to determine the test (well screened) zone. It is important that the gravel pack and the bentonite seals are in the correct position so time should be taken to ensure that this occurs. Well development takes place

after well completion and is carried out to remove any agitated water in the vicinity of the well. Once the pH has stabilised the well development is complete.

It is important to ensure that any boreholes within the body of the landfill are sealed before construction commences. This is essential to ensure that there are no direct pathways to the groundwater from the ground surface.

To conclude, a good site investigation must be followed by a comprehensive description of the hydrogeological aspects to outline the potential impacts. This and subsequent good landfill management is essential to help to improve public confidence and acceptance of landfill in the future.

Margaret Keegan, EPA (formerly of Fehily Timoney Weston)

Raised Bog Restoration Project

In 1994/1995 a multidisciplinary study in the National Parks and Wildlife Service (NPWS) of the Department of Arts, Culture and the Gaeltacht investigated the conservation and restoration of selected raised bog sites in Ireland. The project was funded by European Cohesion Funds. The group members consisted of one botanist, one ecologist and one hydrogeologist - Dr. Lara Kelly, Marie Dromey and Malcolm Doak.

The primary objective of the study was to identify raised bogs which are suitable for declaration as NHAs as part of a network of SACs across Europe (EU Directive 92/43). Secondary aims were conservation and restoration procedures. Of over 200 raised bogs in Ireland, the project was concerned with 46 sites in a range of geomorphological and geological areas. A three volume document was produced.

Fieldwork took place during March - October 1994. the hydrogeologist's main concern was to classify the bogs geohydrologically and meteorologically to ensure that their full range of physical variation was identified. Four geomorphic settings best described the range of bogs. Geomorphic setting (Brinson) is the topographic location of the wetland in respect to the surrounding landscape. The four settings devised were Broad Floodplain, Ridge River, Ridge Basin and Basin.

Drainage and peat cutting are the raised bog's worst enemy. High face banks can cause slumping of the bog by the failure of Catotelm. Surface drains can destroy the living *Sphagna* (moss-Acrotelm) rendering this living hydrological layer useless. The watertable lowers and pools dry out and *Calluna* (heather) takes hold.

One of the 46 bogs, Sharravogue, illustrates some of the issues the project worked on. The bog lies 5 km south of Birr, Co. Offaly, and is a Ridge River type which has a rare example of an adjacent intact fen. A relatively high Waulsortian limestone bedrock ridge lies to the east of the bog and low permeability limestone till underlies the bog. The bog lies in a regional groundwater discharge zone, and the entire east side at the break in slope of the limestone ridge is a zone of upwelling groundwater where fen vegetation is prevalent. The present peat boundaries are similar to those in the 1860's GSI field sheets. However the high bog is flat and may have been burned. Twenty-two closely aligned drains on the surface of the bog are being blocked by the NPWS to stop the bog drying out. The NPWS have set up a management scheme in conjunction with the 4 owners. The management plan includes the east side of the bog and adjacent limestone ridge.

Malcolm Doak, Dames and Moore (formerly National Parks and Wildlife Service, OPW)

Are Consulting and Good Science Compatible?

In a perfect world, every consultants' work is the best possible, and data gathered and results and conclusions derived are 'fair'. Ideally, no consultant would advocate a given position, idea or result, good or bad, no matter what the outcome for the client.

This begs the question: are good science and consulting compatible? In the current business climate there are more consultants than jobs. Jobs are so competitive that there is enormous pressure on firms to get and promote jobs. One way to keep business is to remember "the customer is always right" and the outcome the client wants is paramount. This may bias the procedures and methodologies used by the consultant to develop and interpret the data. But what about good science: multiple working hypotheses, testing hypotheses against data, observation and interpretation of data, gathering more data to resolve questions and scientific objectivity? Do they have a place in this business market?

Our answer is yes, but . . . . .! The but will include cost and time restrictions imposed on the consultant by clients and regulations. The typical result is a compromise between science, cost and time. Another answer is: we don't need to do this, it's not in the regulations and protocols we're following. In most cases these are an engineering "cookbook" of required tasks, some decades old, with little or no room for science, new ideas or techniques. If the consultant gathers the data for each task according to the book, there is no need for further interpretation or data gathering. We would submit than this is disingenuous on the part of consultants and regulators. In reality the data may be sparse in time and space, and little effort or money will be spent in critically looking at the data or gathering additional data unless required by regulators or litigation. This checklist approach to consulting fulfils the letter of the law with no need to question or interpret the data. But is the result honest and ethical to science and society?

It is not unusual for a client to spend the cost of consultant fees defending the data before regulators or adversaries. Three factors are at work: (1) regulations may require minimal or specific spatial and temporal data to characterise a project/site; (2) the more data gathered, the greater the probability of finding some characteristics detrimental or fatal to project/site performance; and (3) we are a litigious society. For example, low level radioactive waste sites only require one year of data, yet some conclude that five years of background and regional data are needed. Many projects have little initial data. Most clients will drill only the minimum number of wells (3) at the site to characterise and monitor it. Yet, federal regulations indicate there is no set number or limit to the number of wells needed to characterise the site geology and hydrology. In regions with little extant data, the consultant may conclude from limited data that regional flow is down valley, but a neighbouring valley, with hundreds of data points, exhibits cross valley flow. Good science indicates one or two additional data points might be useful. Will client money, regulators, and time permit additional wells, or could new data be fatal to the project? Finally, lawyers can put constraints on or stop additional data gathering; they can make data gathering an adversarial process; and in most cases their clients have other, nonscientific, goals.

Currently, it seems that too much project/site characterisation is model driven with not enough thought given to geologic and hydrologic heterogeneity. Many models have tenuous initial assumptions and interpretations of aquifer homogeneity, transmissivity, discharge, and recharge, along with selective use of input data, which leads to inadequate investigations of complex physical and chemical properties and processes. In too many instances the consultants needs to assume the aquifer is a "homogeneous heterogeneous aquifer", i.e. one that can be modelled on minimal data points. Yet, the real geology consists of a heterogeneous, complex system of sedimentary deposits or fractured hard rock of disparate ages and sources. Alluvial and fluvial deposits exhibit enormous vertical and horizontal variability, ranging from sinuous paleochannel sands to discontinuous overbank clays. Hard rocks also display enormous variability with as many as five different rock types in 1,000 meters, all displaying different fracture and weathering patterns. These all affect groundwater flow and chemistry. In many cases the unsaturated zone is considered one dominated by uniform percolation and recharge rates. In few cases are preferred recharge pathways (fractures, unstable wetting fronts, and the geological heterogeneity) ever considered or studied; these pathways may have rates 10^1 to 10^8 times those assumed or measured at a single site. The poor quality input data (recharge, geology, saturated or unsaturated zones parameters, or water chemistry) that result

render many interpretations and models dubious at best.

Good science and consulting have been and can be compatible, but they conflict in some instances. Occasionally the desire for a predetermined outcome by the client and the need for continued jobs by a consultant will override good science. But more important is the insidious degradation of good scientific investigations by consultants and regulators to project engineering-driven site testing and characterisation that grants little room for scientific thought or interpretation. Consequently, scientific truth-testing in the public interest is left to the lawyers. The incipient scientific degradation bodes poorly for the future of consultants, science and society.

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David Cehrs and William C. Bianchi, California, USA.

Upcoming International Conferences

The **6th Conference on Limestone Hydrology and Fissured Aquifers, August 15th-17th 1997** and the **12th Intrernational Congress of Speleology, August 10th-17th 1997** will be held at La Chaux-de-Fonds, Neuchatel, Switzerland. These include an interesting programme of papers and fieldtrips. Further information can be obtained from SubLime, P.O. Box 4093, CH-2304 La Chaux-de-Fonds, Switzerland. Internet: http://www.unine.ch/UIS97/
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CONTRIBUTIONS FOR THE NEXT ISSUE OF THE NEWSLETTER

The GSI Groundwater Newsletter aims to improve communication among scientists and engineers involved in groundwater. It includes news, developments, reviews and opinions on all aspects of groundwater - exploration, development, management, water quality, pollution and energy. It is published three times each year.

Your contribution to the dialogue would be welcome. **Contributions should arrive before 1st September 1997** to:

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