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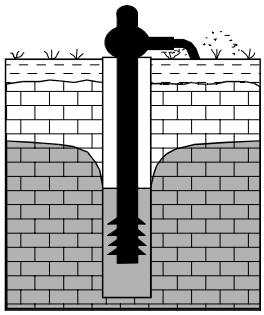

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IN THIS ISSUE

Nitrogen (N) in groundwater continues to be a major environmental issue in EU countries. According to Noel Culleton and Hubert Tunney (pages 2-4), N loss to water has increased several fold over the last 50 years, with agriculture accounting for over 60% of this loss. Work at Johnstown Castle Research Station has shown that about three quarters of N inputs in Ireland are not recovered in soil or in animal products and must therefore be lost to water and the atmosphere. This represents a financial loss to farmers and a potential hazard to the environment. Losses to water in Ireland are estimated as 14% of total N inputs. This article provides useful figures on the N inputs and outputs in Ireland, discusses the use of biological N fixation by white clover and comments on the future prospects.

The risk to groundwater by **silage effluent** in vulnerable areas is illustrated by the research of David Drew in the Burren plateau in Co. Clare (see page 5). A survey of silage clamps has shown that 60% are in the high risk category, with only 17% classed as low risk. About 92% of clamps are estimated to allow effluent to reach groundwater - a figure that merits serious attention by relevant state bodies and agricultural groups.

On page 7, Ted Nealon provides an **up-date on landfill design and practice in Britain**, particularly regarding the use of liners. He draws attention to the problem with 'dry entombment', which means that the consequences of waste production and disposal are passed on to future generations - a policy that does not follow the sustainable development principle. One possible solution is to use the landfill as a bioreactor - this is a topic that is likely to be a source of discussion in the next few years.

A summary of the **groundwater situation in the Nore River Basin and South Wexford (Sheet 23)** is given by Eugene Daly, in his last articles as a GSI hydrogeologist, on pages 13 and 14.

Septic tank systems continue to be one of the main sources of groundwater pollution in Ireland. Details on a **forthcoming conference**, which should be of interest to local authority and Health Board staff, are given on page 19.

Editor

NITROGEN USAGE AND RECOVERY IN IRISH AGRICULTURE

Nitrogen (N), as a plant nutrient in the soil, is the engine that drives agricultural productivity. Its widespread use has made possible the dramatic increases we have witnessed in output per hectare in recent decades. Figure 1 sets out the trend in agricultural production in Ireland since 1970 and also shows how this steady increase was tracked by increases in N usage within agriculture. However, the justification for the full extent of this increase has been questioned in the context of whether fertiliser N contributes materially to increased amounts of nitrates in water, to eutrophication, and to increasing emissions to the atmosphere with implications for global warming and acid rain. It is timely therefore to take a closer look at the overall efficiency of N usage in Irish agriculture in terms of its recoverability in aggregate farm production.

Fig. 1 : Trends in agricultural output and fertilizer N usage in Ireland.

Outputs and inputs

Nitrogen loss to water has increased several fold over the past 50 years. Agriculture is the main source of nitrate loss to water accounting for over 60% of the total. Moreover, the loss is high in most European countries. As a response to this development the European Union introduced its first piece of legislation relating to agriculture and the environment in 1991. The Nitrate Directive (91/676/EEC) aims to reduce pollution of water by nitrates from agriculture and requires limits to be set to the amount of N that can be applied to farm land in vulnerable zones. Under the agri-environmental measures accompanying the major reform of the Common Agricultural Policy in 1992, Member States of the European Union are empowered to provide financial incentives to farmers to implement environmentally-friendly farming practices, including reducing or maintaining low inputs of chemicals such as fertiliser N.

Work at Johnstown Castle Research Centre indicates that phosphorus inputs in Irish agriculture are more than double the amounts recoverable in the range of farm outputs. A similar approach for N indicates that the surpluses are higher, as the N budget for Irish agriculture presented in Table 1 shows. Inputs include applied fertiliser N, inputs through biological fixation by clover, atmospheric deposition, and the N present in concentrates fed to animals. The most obvious categories of outputs of N are those contained in farm products (milk, meat and arable crops). Total output in these products account for only 16% approximately of total inputs of N. Allowing for a further 12% which may be immobilised in the soil, this means that about three quarters of N inputs are not recovered in soil or in animal products and must therefore be lost to water and to the atmosphere. This represents both a financial loss to farmers and a potential danger to the environment. It is estimated that combined volatilisation losses from grazing and from recycling of organic wastes account for approximately 19% of total N inputs to agriculture.

As can be seen from Table 1, the largest quantifiable component of N output is in the form of volatilisation of ammonia, at 130,000 tonnes N. Approximately half of this quantity of ammonia N which is volatilised to the atmosphere from farms in Ireland each year is deposited, due to the direction of the prevailing winds, in the North Sea, where N from agriculture is considered to be the main factor contributing to increasing problems of eutrophication. In this context, it must be pointed out that most of the N in the North Sea comes via the rivers of mainland Europe.

Losses from soil to water within Ireland have been estimated at 14% of total N inputs. This brings the total N which can be accounted for in outputs to

Table 1 : Nitrogen Balance for Irish Agriculture - 1988 (tonnes N)

INPUTS			
	Chemical fertiliser		340,000
	Biological fixation		219,000
	Atmospheric deposition (10 kg/ha on 6.5 m.ha)		65,000
	Concentrates fed to animals		60,000
	Total N Inputs		684,000
OUTPUTS			
	Milk (5.4 m.t @ 6.4 kg N/t	35,000	
	Meat (1.381 m.t @ 130 kg N/ha)	17,000	
	Tillage Crops (451,000 ha @ 130,kg N/ha)	60,000	
	Volatilisation of ammonia	130,000	
	Losses to water @ 14% of Inputs	96,000	
	Immobilised in soil	85,000	
	Denitrification @ 10% of Inputs	68,000	
	Total thus accounted for		491,000
	Unaccounted for (possible denitrification)		193,000
	Total N Outputs		684,000

491,000 tonnes, or about 72% of total inputs. there is no satisfactory explanation as to where the rest of N input is lost, although it is suspected that denitrification may account for more extensive losses than were previously attributed to this source.

Percentage recovered

An estimate has been made of the total N in agricultural output for each year from 1970 to 1992. When the N recovered in product is expressed solely as a percentage of the fertiliser N applied, the outcome is as shown in Fig. 2. It is clear from this linkage that the apparent recovery of N has declined dramatically at the same time as the amounts of N used where increasing. Several factors help to explain this phenomenon.

1. Diminishing returns. As N usage increases the response in terms of kg DM harvested per kg N applied declines, thus lowering the percentage of N recovered.

2. It is well known that as fertiliser N usage increases, white clover tends to die out of the sward. In the early 1970s white clover was making a significant contribution to the N budget of farms and much of the N output could well have been due to biological N fixation in the soil. This suggests that the apparently high recovery rates in the first part of Fig. 2 are due to uptake from clover. As many farmers intensified their production per unit of land, they applied more fertiliser N to the detriment of clover, with the result that clover played a progressively smaller role in agriculture productivity.

3. It is possible that in recent years, many farmers are simply applying too much fertiliser N. Johnstown Castle recommendations are for 100 and 80 kg/ha for first and second cut silages, respectively. Many farmers use significantly more than this. In terms of grassland management, high N levels in silage swards can often lead to poorer preservation, apart altogether from the fact that the diminishing response would make such high rates of application difficult to justify economically. Furthermore, high N applications coupled with late cutting of silage can severely damage the persistency of the sward. It is also probable that many farmers are exceeding the recommended application rates on grazed pasture.

4. There is increasing evidence that there is considerable leaching of N from grazing systems. It has been shown in work at Johnstown Castle that at moderate rates of fertiliser N, the amounts leached from pasture in the first half of the year are negligible but are considerable where application is carried out during the second half. This would indicate that where N is applied to

pasture late in the year, reduced N recovery rates can be expected, with an ensuing increased risk of causing pollution.

5. There has been a steady trend towards the production and spreading of greater quantities of animal manure leading to increased ammonia volatilisation and denitrification.

It is clear that there must be a greater emphasis on the more efficient use of nitrogenous fertilisers in agriculture and, where possible, alternatives must be sought. Biological N fixation using white clover warrants more intensive examination, as the extent to which fertiliser N can be replaced by fixation using white clover has not yet been clearly demonstrated. Output of swards containing 35-40% clover is generally some 80-85% of that receiving 235 kg N/ha. However, typical annual N usage on pasture in Ireland is closer to 60-80 kg per ha, while white clover swards could be expected to fix 90-100 kg N/ha/year. On that basis there would appear to be considerable scope for the incorporation of more white clover into Irish pastures.

Fig. 2 : Linkage between the volume of fertilizer N and the proportion recovered in aggregate farm production. Usage figures are those pertaining to the years 1972-1990.

This is not to suggest that N from clover offers a solution to the problems associated with optimising production from our grassland. It has several advantages, including being a low-energy input of 80-130 N/ha/year, providing highly digestible and palatable feed with a high mineral content On the downside, clover pastures have only 80% of the potential production of a high N system, they require more skilled management, particularly since they provide poor growth in spring when pasture is so valuable, and since clover's persistence in the sward is unreliable over the longer term. It must also be pointed out that N from clover-based pasture carries the same pollution risk as moderate rates of fertiliser N applied in spring.

Quite an important attraction of clover pastures is that they can be especially effective in extensive systems, and if these become more widely-practised as a result of policies now being promoted within the European Union, we are likely to see clover playing a more significant role in Irish pastures.

The future

- Nitrogen will continue to play a vital role in intensive agricultural production for as long as the ratios of product prices to N prices remain as favourable as they are now.

- A move towards more extensive grazing systems would see greater use being made of white clover.

- Much more attention will be paid to both the rates and the timing of N application which will be undertaken on the basis of a scientifically-measured need rather than as a standard routine.

- As a result of the recent reforms in the Common Agricultural Policy, increased incentives are being offered for environmentally-friendly farming which are conditional on using low inputs of chemicals, including fertiliser N.

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Noel Culleton and Hubert Tunney, Teagasc, Johnstown Castle.

POTENTIAL GROUNDWATER CONTAMINATION BY SILAGE EFFLUENT IN THE BURREN

Introduction

The Burren plateau of County Clare is perhaps the most extreme karst environment in Ireland, characterised by patchy, thin soils, a lack of surface drainage and a highly organised, conduit dominated groundwater system.

Since accession to the European Union and in particular as a result of Common Agricultural Policy initiatives, attempts have been made to raise farm incomes and to modernise agriculture in areas such as the Burren. Due to the encouragement of land reclamation, which converts areas of scrub or limestone pavement into level, manageable re-seeded fields, silage making has largely replaced hay making for winter fodder, and larger cattle housing units have been erected. These changes pose a threat to water quality by way of enhanced leaching of artificial fertilizers applied to the reclaimed fields and by point sources of pollution such as silage clamps and cattle parlours. The Burren is obviously highly vulnerable to water pollution particularly from silage effluent and in an attempt to estimate the degree of threat posed to water supplies a detailed survey of silage clamps on the Burren was made in the summers of 1991 and 1992. The project was funded by the National Heritage Council and included a survey of reclaimed areas also.

The Survey

For each site, data concerning the character of the clamp itself and the nature of the immediate environment were collected insofar as they were germane to the potential for pollution at that site. Silage clamp data included:

1. The volume of grassed ensiled
2. The type of site preparation undertaken (rock and overburden clearance, construction of a concrete pad and walls, etc.)
3. The type of effluent management practised (e.g. tank storage, troughs,covering, none)

In the case of (2) and (3) the site was graded according to the likelihood that any effluent would escape from the clamp site with the scale ranging from 1 (no escape of effluent) to 10 (all effluent likely to leave the site).

4. Derived data included the volume of silage effluent likely to be produced by the clamp.

The site environmental data collected were ranked according to the degree of protection they offered to groundwater from leachate contamination. The factors included :

i) Soil type and thickness: lithosol, rendzina, brown earth, peat - zero thickness to >0.7m
ii) Overburden: (glacial/colluvial etc.) : zero to >3m
ii) Extent of openings in epikarst: (joints/bedding partings): zero to extensive
iv) Extent of superficial karstification: (solutionally enlarged conduits) - minimal to extensive
v) Proximity to point groundwater recharge site: (doline, sink etc.): distant to close
vi) Slope of ground: zero to >60°

From the above factors an approximate index of vulnerability of groundwater to leachate pollution was produced for each site. Thus each site was characterised by an estimate of total effluent likely to be produced; an estimate of the proportion of that leachate likely to leave the site and an estimate of the amount of leachate likely to enter groundwater. In addition large cattle yards producing quantities of animal waste were located and analysed in the same manner.

Results

In 1991 some 93 silage clamps were located and in 1992 some 110 clamps giving an average density of 1 clamp per 3.7km^2. The overall mean weight of individual clamps was 157 tonnes. It is estimated that in 1991 some 1800m^3 of silage effluent was generated in the Burren area of which some 57% reached groundwater.

In 1992 the corresponding figures were 2,020m^3 and 66%. The distribution of silage clamps was similar in each year; the greater number of clamps in 1992 probably reflecting the wet summer of 1991 which made hay-making exceptionally difficult and influenced farmers' practice in the following summer.

There is a marked concentration of silage clamps in the east and particularly the northeast of the Burren and these areas are also wholly reliant on groundwater for both public and private supplies. The more barren areas of the western Burren mainly drain directly to the sea but also have a much lower density of silage clamps.

Table : Estimated degree of dilution of silage effluent released to groundwater in six Burren groundwater catchments, summer 1991

Some 60% of all clamps fell into the high risk category in terms of potential for groundwater contamination, 23% were medium risk and 17% low risk. It was estimated that some 92% of clamps are likely to allow at least some leachate to escape and to reach groundwater. The concentration of any pollutant in groundwater or springs within a groundwater catchment will depend, not just on the absolute quantity of effluent entering the groundwater system and the rate and period of time over which it is generated, but also on the rates of groundwater flow, extent of contaminant dispersion, groundwater flux and patterns of recharge to groundwater. Groundwater flow in the Burren aquifer is known to be conduit dominated and hence conservative in terms of contaminant dispersion, with flow velocities within the range 50-150m/h. Hence, contaminant concentrations are largely a function of the amount and temporal distribution of recharge. An index of silage effluent dilution within each of the six major Burren groundwater catchments was obtained by relating the quantity of effluent presumed to have been discharged to groundwater during the silage season (May to August) to the quantity of recharge (effective rainfall) within the catchment during the same period. The dilution factors for each catchment are shown in the table. Dilutions are least for the north-eastern area of the Burren (8000-12,000 fold).

Catchment	**Number of Clamps**	**Effluent Produced (Litres)**	**Groundwater Flux ($x10^6$ m^3)**	**Contaminant Dilution**
Ballyvaghan	7	113,900	5.1	x 44,000
Bellharbour	40	407,600	5.87	x 14,000
Corranroo	4	66,250	0.5	x 8,000
Southeast Burren	13	106,500	1.3	x 12,000
Fergus River	24	312,000	15.6	x 50,000
Fisherstreet	6	18,500	1.0	x 58,000

As in many of the karstic or semi-karstic areas of western Ireland, episodic summer groundwater pollution events apparently associated with silage effluent are common in the Burren. Severe pollution of Lough Inchiquin near Corofin, a lake on the course of the upper River Fergus which derives most of its water from the Burren plateau has concentrated the attention of the local fisheries Board and Clare County Council on the problem of silage effluent in the Burren catchments. Using the information described above they have systematically visited all the clamp sites and attempted to prevent the more obviously polluting sites from future operation using both persuasion and if necessary Section 12 of the Water Pollution Act. An attempt to introduce an order which would permit only baled silage to be made on the Burren was abandoned on grounds of political expediency but in fact over the past two years the proportion of baled silage on the Burren has increased dramatically, despite the extra cost involved in its production, and thus the potential for silage effluent pollution has decreased somewhat.

David Drew, Department of Geography, TCD.

LANDFILL DESIGN AND PRACTICE IN THE UK - THE LESSONS LEARNT

Introduction

The last six years, 1988 - 94, have seen major changes in landfill design and practice in the UK. These changes have been encouraged by new and impending legislation from the EU, by UK national legislation such as the Environmental Protection Act of 1990 which led to the privatisation of local authority waste disposal operations, to new waste management legislation, and to the reorganisation of the Waste Regulation Authorities, and by the adoption of technical developments and innovations.

Several useful lessons have been learnt during this period of change which may be applied to landfill design and practice in Ireland and elsewhere.

Lessons Learnt

1. Composite Liners

All landfill sites in the UK are now designed to provide containment of any leachates produced. Earlier landfill sites operated to the dilute and disperse method, where leachate was allowed to migrate through the sides and base of the site and the natural environment was depended on to provide sufficient attenuation to prevent serious pollution of surface and groundwaters.

Several different landfill designs have been experimented with in an attempt to optimise containment. Recent research and experience has shown the composite liner, where a flexible membrane liner (FML), composed of high-density polyethylene (HDPE), is laid directly on a low-permeability soil, bentonite enhanced soil (BES) or bentonite mat, to offer the greatest potential for containment. This is because the two layers enhance the containment performance of the other by virtue of their different hydraulic and mechanical properties. The HDPE offers an extremely low permeability which complements the self-healing properties of a natural soil or BES layer. The soil layer also offers a physical durability which complements the lack of any such durability in the FML.

Extensive research carried out on potential leakage rates from liners indicates that the rate of leakage through liners is reduced by at least two orders of magnitude by using a composite liner. Multiple liner systems, such as double liners, have been constructed with a leachate leakage monitoring system, comprising a drainage layer between the two liners. Unfortunately, if a leak occurs, the presence of the drainage layer allows the leachate head within the waste to be transmitted over the full surface area of the second liner, thus allowing the leachate to exploit any weaknesses in this second liner. It is therefore now generally accepted that the use of composite liners is to be preferred over double or multiple liners.

2. QA/QC

Recent experience in the UK has shown the need for independent third party quality assurance during construction of the liner systems for landfill sites. This experience confirms earlier research carried out in the USA that good quality control during installation can dramatically reduce the number of leaks in all liner systems. Most Waste Regulation Authorities in the UK now require QA/QC during the construction of landfill sites.

3. Leakage Detection Systems

It is now appreciated that most damage to liners occurs during installation of the liner itself, during installation of the protective layer and leachate drainage layer, and during the deposition of the first layer of waste. Several leak detection systems have now been developed which use electrical fields and detectors placed above and below the FML. The location of any leak can be determined to within less than 0.5m, allowing identification and sealing. Several Waste Regulation Authorities in the UK will not issue landfill site licences unless the lined site has such a leakage detection system installed.

4. Monitoring

In recent years, as the quantity and quality of environmental monitoring on landfill sites has improved, the need for background information before the landfilling operation begins has become obvious. This means that it is now usual practice to initiate monitoring, especially of surface water, groundwater and soil gases, at least six months before the first waste is deposited. The information generated is equally useful to the operator and the regulator and allows meaningful limits to be imposed by licence conditions.

5. Training And Training Qualifications

The recently introduced waste legislation in the UK requires all landfill sites to be managed by

"Fit and Proper Persons". A system of Certificates of Technical Competence has been introduced to fulfil this requirement. The new legislation places much emphasis on training and training qualifications.

The Future Of Landfill

Until recently landfill philosophy in the UK followed the US approach of dry entombment of the waste. The accepted methodology was to line the site to prevent the egress of leachate and to prevent any surface water or groundwater entering the waste, to construct the landfill site in cells and to restore these cells progressively so as to minimise the ingress of rainwater, and then to cap the site to maintain the state of dryness. However, it became obvious that this approach was merely postponing possible pollution incidents as the full pollution potential of the waste was being preserved for when, or if, the integrity of the liner was breached.

The Department of the Environment in the UK is now considering the use of landfill sites as bioreactors. This would involve the controlled input of sufficient moisture, including the recirculation of leachate, to ensure the complete degradation of any wastes and the minimisation of any pollution potential. The new waste management legislation in the UK requires that landfill sites obtain Completion Certificates prior to closing. In order to obtain such a certificate the operator must demonstrate that the site retains no potential for pollution. It has been calculated that this could take hundreds of years using dry entombment practices. Many UK operators have already adopted these practices, mainly to optimise the production of landfill gas for utilisation purposes. Further guidance on the use of landfill sites as bioreactors has been promised by the UK Department of the Environment.

Ted Nealon, ESB International

BEYOND CLEANUPS FOR CLEANUP'S SAKE

In conversations with LUST (leaking underground storage tank) site managers in Minnesota and other states, I have sensed a growing frustration with the traditional LUST response mind-set, which presumes that corrective action is a foregone conclusion. This frustration, coupled with an awakened sense of responsibility toward the public resources that make LUST cleanups possible in many states, has prompted widespread interest in defining a new philosophy for LUST corrective action.

So, what kind of new philosophy should this be? Anyone with several years of experience in the LUST cleanup business can verify that engineered corrective action is often better at reducing a large problem to a small problem than at reducing a small problem to no problem. Because engineered corrective actions are seldom able to return sites to pristine conditions, we leave contamination in the ground virtually every time a site is closed. We do this, however, with a large measure of certainty that the site poses no further risk to human health and the environment.

Perhaps, in evolving our new LUST corrective action philosophy, we need to replace the usual question of "what corrective action technique do we choose?" with a more fundamental question: "Why are we doing cleanups?" Restated, "Does 'how clean is clean?' really matter?".

The Minnesota LUST program, as well as other state LUST programs, was created in response to our need to deal quickly and effectively with petroleum releases that were affecting people - we needed a means to deal with such threats as petroleum-contaminated drinking water supplies, vapours in basements and sewer lines, or explosive conditions in homes and businesses. To be responsive to these dangerous situations, we set about treating every site as if it were a significant or potential threat to human health, requiring engineered corrective actions wherever feasible.

Over the years, however, we have realised that although some LUST sites pose significant health concerns, many do not. In fact, groundwater monitoring data collected from all kinds of sites in the Minnesota LUST program show that once a release occurs, the dissolved phase plume quickly reaches a limited size. After that, it doesn't change very much in size, unless there are unusual hydrogeologic conditions, such as human-made conduits, or nearby pumping wells.

This behaviour is due to natural subsurface processes, including natural biodegradation, dispersion, adsorption, and volatilisation. Researchers, consultants, and regulators have a basic understanding that natural biodegradation is a process that occurs at the fringe zones of virtually every dissolved petroleum plume. The result is analogous to the flow of glacial ice - the contaminant mass is conveyed toward the edges where it degrades, but the shape of the plume does not change very much. We call this a "self-limiting" or "stable" plume.

Cutting off the snowfall on the glacier, or halting the leak that's contributing to the plume eventually melts the glacier or degrades the plume. It's just a matter of time. The key question is, how much time are we willing to allow? That answer ultimately depends on the intended use of the site.

Because many sites pose a low or insignificant human health risk, and because our data indicate that many groundwater plumes are self-limiting, we can reasonably conclude that a "monitoring only" approach may well be appropriate for many sites, while still protecting human health and the environment. First, however, it is crucial that each site be investigated to sufficiently address human impacts for both present conditions and potential future conditions. At those sites where investigations show an elevated human health risk, we should be shooting for the best engineered corrective actions possible.

But, if investigation shows a plume to be self-limiting and human health and environmental impacts are not foreseen, we should at least ask ourselves what benefit there is in undertaking corrective action..... unless we simply want to cleanup for cleanup's sake. We should be asking ourselves: Given the information we have about this site, what level of action is most appropriate?

Any new LUST site management philosophy should focus our finite economic resources (i.e., public funds) on the LUST sites that are most likely to affect human health and the environment. "Plume management" is the term I use to describe an approach that addresses the risk posed by petroleum releases in terms of an appropriate level of corrective action. High risk sites would, of course, require engineered solutions that are designed to help speed up naturally occurring biologic cleanup processes, to protect both people and the environment.

But in the case of fully investigated low risk sites, where the contaminant source (i.e. tanks, lines) is removed and the contaminant plume can be shown to be stable, these sites might require no action other than sufficient groundwater monitoring to assure low risk. This strategy seems sensible and correct, and acknowledges that we haven't the resources to treat each discovered release as if it were a major environmental or human health problem.

Following the Plume Management Scenario

What would it mean to adopt plume management as a guiding strategy for addressing LUST sites? For one thing, it would free us from performing marginally beneficial cleanups.

Consider a site like the one I reviewed recently, where the investigation defined a release affecting the water table in a clay till. The contamination source had been removed, drinking water supplies had not been found, nor, based on our risk assessment, were they likely to be, and no utilities or basements were at risk in terms of vapour problems.

Knowing the tanks had been removed and that there had not been a recent massive release, but a suspected "slow leak" over a longer period of time, I checked the groundwater monitoring data. Quarterly results over one year showed that although contaminant concentrations exceeded the cleanup goal, the contaminant concentrations in the groundwater were decreasing significantly over time. In as much as the source had been removed and the exposure risk was low, we decided that natural biodegradation was sufficient to take care of the problem and no other corrective action was necessary. I expect that an additional year of groundwater monitoring will verify that the plume is degrading in place very nicely without any corrective action.

Alternatively, another feasible corrective action that I know of for a site of this type would have been to excavate and transfer the soils off site - potentially exposing many people at a probable cost of about $50,000. On the other hand, we could have employed a marginally effective pump and treat system, or even an in-situ technology, at a considerably higher cost, but without necessarily significantly reducing risk or increasing environmental benefit. In this case, the plume management alternative freed me to conserve corrective action dollars for some other site more worthy of the expense.

Plume management means we can prioritise not only corrective action dollars, but our efforts too. For example, over the years, the Minnesota LUST program has managed 6,678 sites, 3,592 of which are still on-going. This means that some project managers have about 150 sites each, and some hydrogeologists have up to 250 sites each, a sometimes overwhelming project load. Using plume management as a strategy, project managers can make relatively quick decisions on the low risk sites, saving valuable time for the proper management of sites that pose a greater risk to human health and the environment.

Plume management allows us to adopt the physician's pledge to "first, do no harm". Many misguided corrective actions are, thankfully, only ineffective, but there are some in the record that arguably worsened site conditions.

As an example, consider again a site like the one above, except suppose 2,000 yards of contaminated soils were excavated and trucked away. The excavation was then filled with clean sand. However, the soil removal was not a complete corrective action, and much of the contaminant mass remains in the excavation sidewalls from where it now migrates into the formerly clean fill. Now, heavily contaminated groundwater occupies the entire former excavation and whatever stability the plume may have had has certainly been disturbed.

In this case, the initial corrective action has been undone..... and that's not all. Because the excavation came too close to the street and the original clay till soil (the one naturally occurring protective feature of the site) has been removed, the city now reports vapour impacts in the sewer lines and trench backfill.

In plume management terms, managing LUST releases means managing the risk posed. Most people in this business would probably agree that where drinking water has been affected by a LUST release, or where vapor problems emerge, or where the dissolved plume does not appear to be stable, there is a clear risk to human health and the environment, and we should devote all necessary resources and effort to achieve a proper corrective action to address the problem.

But where a LUST release poses a low to negligible risk to human health or the environment, why require corrective action? (Of course, bankers, lenders, and property transfer issues add another dimension to the apparent simplicity of this concept, but that's another article.) The question remains: Do we want to do cleanups for cleanup's sake or do we want to prevent unacceptable risk to human health and the environment? Let us graciously acknowledge that there is also honour in making a decision against unnecessary or ineffectual corrective action.

And while the debates rage on, many would agree that natural biodegradation is occurring by default. One researcher claims that even at sites where engineered corrective actions have been installed, natural biodegradation is the dominant mechanism of contaminant mass reduction. At many low risk sites, perhaps no other response is necessary. But .... will the public accept this approach?

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Jim Lundy, Minnesota Pollution Control Agency.

AN ACID MINE DRAINAGE PILOT STUDY IN AVOCA, CO. WICKLOW

Mining, when properly regulated, can have minimal environmental impact. The present day major Zn - Pb mine operated by Outokumpa/Tara at Navan is a good example of a well operated mine from an environmental viewpoint. Unfortunately, many past examples of mining activity exist where poor regulatory control has resulted in severe environmental damage. The quality of the air, soil and water, surrounding many such abandoned mines is often adversely affected. The effects on water quality are frequently most severe where sulphide minerals were perviously mined. Many of these mineral compounds dissolve when exposed to water and oxygen allowing high concentrations of hydrogen ions, metals and sulphate to develop and enter the surrounding groundwater. The resulting mine water is therefore commonly referred to as "acid mine drainage" or AMD and is invariably toxic to human and aquatic life.

A number of approaches are currently being investigated which could reduce the impact of AMD on the environment. Accelerated bioleaching is a technique which uses particular strains of (B-ferroxidons) bacteria to enhance natural leaching rates, thereby making the acid generating mine waste inert over a shorter period of time. An EU-funded study, co-ordinated by the Environmental Sciences Unit TCD. is currently underway to investigate the application of accelerated bioleaching techniques to AMD generating sites within the European Union. The GSI is working jointly with TCD. on the project with support from other research institutes in Britain, France, the Netherlands and Greece. Two sites of different climatic and geological settings have been selected for initial pilot studies, the former copper mines at Avoca, Co Wicklow and Laurium in Greece.

Site characterisation studies are clearly the most important first step in any protocol designed to tackle AMD. At the Avoca site, GSI staff have integrated a new digital topographic survey of the mining district with existing surface and subsurface archival geological and mine data using computerised mapping techniques. Surface maps showing ordnance information, bedrock geology, location/size of mine waste heaps, location of adits, vegetative cover and current land use can be generated at any predetermined scale. Subsurface perspectives of the underground mine workings (adit system) are equally accessible. It is intended that all of the extant geodata, together with that generated in the course of the project, will ultimately be transferred to a GIS (Arc Info) environment which permits a greater degree of "dynamic" analysis. The preliminary computerised maps are being used by TCD and GSI staff engaged in field campaigns in 1993/94. Part of the GSI campaign involved a preliminary 8 week hydrogeological/hydrogeochemical study of the Avoca site.

The Avoca Copper Mines are located within the Avoca River Catchment. The area is mainly underlain by low permeability bedrock and subsoil units. Limited discharge data for the Avoca River suggest that the groundwater flux through these units is low, as reflected by low baseflow during prolonged dry periods. Flow rates are seen to increase rapidly during wet periods.

The volcanic succession which hosts the AMD generating sulphides underlies a small proportion of the catchment. The rock units consist of sericitic and chloritic tuffs and a number of minor lithologies. The bedrock dips steeply to the south-east and is cut by a number of major NNW-SSE trending faults. Sulphide mineralisation is most intense towards the top of the succession. Pyrite and chalcopyrite are the main sulphides which were mined in the past at Avoca.

The volcanic rocks are suspected to have a higher permeability compared to other bedrock units although insufficient data exist to determine their precise influence on baseflow in the Avoca River. The effect of faulting on groundwater flow patterns has not been determined.

Systematic sulphide mining started in Avoca in the early eighteenth century and continued there until 1982. Early mining was carried out below ground and required a complex of shafts and adits to lower the watertable and allow access to the ore. Additional ore was subsequently extracted using open cast techniques from the 1960s onwards. The mining district is subdivided into hydrogeologically-separate areas at East Avoca and West Avoca. The preliminary hydrogeological study focused on East Avoca.
The shaft and adit complex in East Avoca continues to drain from the former underground mines. The watertable in the mined zone has a lower head than its surroundings, thus causing

groundwater to flow into the mined zone from the adjacent area. Water also enters the mine as direct recharge and inflowing surface runoff. Tentative flow balance calculations suggest that up to 80% of the mine water originates as inflowing groundwater. Most of the mine drainage is discharged to the Avoca River via a single adit (Tigroney deep adit), although a proportion discharges as diffuse groundwater flow and minor outflows from smaller adits.

The mine drainage is highly acidic and contains high levels of dissolved Fe, Mn, Zn, Cu, Mg, Al, and SO^4. Fe, Mn, Zn, Cu, and SO^4 are believed to be largely derived from dissolution of sulphides. In contrast, the high levels of Mg and Al in the mine waters are suspected to be the products of hard rock dissolution in low pH mine waters. Iron and aluminium hydroxides precipitate out of solution when the mine waters discharge into the Avoca River. Notwithstanding this, the waters remain highly contaminated with heavy metals which are detrimental to the quality of the river water and biota further downstream. The influence of the mine discharge is greatest during periods of low river flow but is significantly reduced during periods of high rainfall when the diluting capacity of the river increases substantially, despite increased mine discharge.

Based on the results of this preliminary hydrogeological study, an initial strategy could be to treat the AMD discharging from the Tigroney adit. The treated water could then be discharged to the Avoca River during periods of high flow, thus maximising the river's capacity to dilute the contaminated mine water. It is hoped that further data collection, currently under way, will allow the project team to better characterise the site and suggest appropriate remediation strategies.

Ray Flynn*, Eugene Daly, Pat O'Connor and Vincent Gallagher, Geological Survey of Ireland.

(*now Geraghty & Miller, Inc., Chicago, U.S.A.)

NEWS FROM ABROAD

US: Radon Poses Greater Cancer Risk than any other Regulated Contaminant in Water.

The US EPA reports that about 19 million people in the US are exposed to a radon level above the proposed maximum contaminant level of 300 pCi/l. At this level, about two of every 10,000 individuals exposed would develop a fatal case of cancer. The threat from radon in drinking water is about 48% due to inhalation and nearly 52% from ingestion of drinking water.
Source: The Groundwater Newsletter of the Water Information Centre, Inc. Vol. 23, No. 11, 1994.

Connecticut : State Regulates Land-Use in Groundwater Protection Zones.

The Connecticut Aquifer Protection Area Programme will ban certain land-uses, such as petrol stations and dry cleaners, in designated areas around 143 wellfields in more than half the state's 169 towns. Over one million people use groundwater for their potable supply. Detailed maps of wellhead protection areas will be prepared, together with land-use inventories in these areas. The land-use rules will be phased in. In the first phase high risk activities such as bulk storage of petroleum will be prohibited. In the second phase, rules will require best management practices for facilities using, storing, handling or disposing of potential groundwater contaminants. By 1998, water companies will be required to conduct groundwater monitoring within aquifer protection areas.
Source: The Groundwater Newsletter of the Water Information Centre, Inc. Vol. 23, No. 10, 1994.

Compiled by the Editor.

GROUNDWATER IN THE NORE RIVER BASIN

The Geological Survey has carried out an investigation into many aspects of the hydrogeology of the Nore River Basin. The work has been written up in over 25 reports, theses, papers and chapter contributions. The abstract of a summary report is given below.

The Nore River Basin (see figure below) is situated in the southeastern part of the Central Plain of Ireland and covers an area of 2,530 sq.km. The River Nore is over 140km. long and flows through five different physiographic regions. Groundwater is a significant source of water supply in the region.

In the mid-1970s the Geological Survey chose this river basin for its first detailed hydrogeological investigation of a large area. The overall objectives of the study were to provide an understanding of the hydrogeology of the basin, enable the results to be extrapolated to adjacent areas of similar geology and hydrology and provide experience in carrying out hydrogeological investigations in Ireland.

The river basin has a complex geological history and been subjected to extensive structural deformation The geological succession is typical of that elsewhere in the southeast of Ireland and contains all but one of the principal aquifer types. The succession consists of basement rocks overlain by an almost continuous sedimentary succession from the Upper Devonian to Upper Carboniferous. Quaternary deposits of variable thickness and lithology overlie the bedrock strata and are widely distributed throughout the area.

Potential recharge is estimated to be over 500mm/yr throughout the basin resulting in very large volumes of water being available to recharge the aquifers. The bulk of the recharge occurs in the October to March period. In addition to direct recharge some of the aquifers also receive significant amounts of indirect recharge. Owing to the generally shallow water tables and low storage in the bedrock strata much of this recharge cannot be retained and has to be rejected.

It has been found that the groundwater component is about half the total river flow or a quarter of the rainfall over the basin. A large proportion of this flow is generated by the principal unconfined aquifers, namely the Dolomitised Limestones, the Cullahill Limestone and the sands and gravels.

The strata in the basin have been subdivided into four major and four minor aquifers, with the remainder being classified as aquitards. The three major rock aquifers, the Kiltorcan Sandstone, the Dolomitised Limestones and the Cullahill Limestone crop out in two areas whereas the sands and gravels occur in eight areas of the river basin. In all but one instance the aquifers are separated by an aquitard. A detailed investigation has been carried out in at least one area of each of the major aquifers.

The rock strata in the Nore River Basin are old and indurated and consequently secondary permeability is dominant. The geological processes that developed the fissures, fractures, cavities and joints in the rocks of this area are structural deformation, karstification, dolomitisation and general weathering. It has been found that the permeability and related parameters in these strata are extremely variable but generally highest in the upper 30m of geological strata. Storage in the bedrock strata is low. The extensive faulting of the rocks in this area has a considerable impact on the overall hydrogeological regime.

Although unconfined conditions are dominant in the main rock aquifers, the hydraulic conditions can vary appreciably over relatively short distances. The bulk of the groundwater movement occurs in the outcrop/subcrop areas, at shallow depths, relatively rapidly along short flow paths and discharges into

the normally effluent (gaining) streams which cross the aquifers.

The Quaternary deposits have a major influence on the hydrogeology and hydrochemistry of the underlying rock aquifers and aquitards. They provide a variable degree of connection between the surface and bedrock water systems. In certain circumstances they may also provide significant protection, to the bedrock groundwaters, from contaminants at or close to the ground surface.

The sand and gravel aquifers, although limited in area, have significant resources owing to their relatively high storage and infiltration capacity. Their hydrogeology is mainly a function of the type of deposit and hence is very variable.

The groundwaters in the strata of the Nore River Basin are typically hard, calcium/magnesium bicarbonate type waters owing to the dominance of carbonate material in the strata of the area. The less common sodium bicarbonate waters signify confining conditions and the softer, mixed type waters reflect the absence of calcium carbonate in the host strata. The hydrochemical studies confirmed many of the conclusions of the hydrogeological analysis.

Although there are numerous mainly low yielding wells that have been polluted locally by point sources, the quality of the groundwaters in the Nore River Basin are generally good and potable.

The throughput of the major and minor aquifers from direct recharge is estimated to be almost 275Mm^3/y. Although the overall use of this resource for industrial, domestic and farm water supplies is small it does sustain the river system and various faunal habitats, during dry periods, with a supply of good quality water.

The existing groundwater developments and the results of this investigation have clearly shown that each of the aquifers can be developed successfully. It has also been demonstrated that appropriate groundwater investigations are necessary if optimum well yields are to be achieved. The hydrogeological characteristics of the locations for optimum development of the individual aquifers are given in the report.

This report will shortly be available from the Public Office in the GSI.

Eugene Daly*, Geological Survey of Ireland.

*In February, Eugene will be leaving the GSI after 24 years to set up his own consulting firm "EDA".

HYDROGEOLOGY OF SHEET 23 (SOUTH WEXFORD)

The explanatory booklets to accompany the Geological Survey of Ireland's Bedrock Geology 1:100,000 Map Series contains a short note on the hydrogeology of each sheet. The note on the South Wexford sheet is given below.

The hydrogeological characteristics of the strata in the South Wexford area are very variable. All but the Quaternary sediments are indurated and dominated by fissure (cracks, joints,etc.) permeability. The water table is generally within 10m of the surface. The aquifer strata can be developed to provide reasonably large water supplies. Well yields in most of the remaining aquitard rocks generally range from 20-50m^3/d except along faults where they may be in excess of 200^{3}m/d.

Sheet 23 covers one of the driest parts of Ireland and potential recharge to the aquifers ranges from 400-600mm/yr (see figure below). The bulk of this recharge occurs between November and February.

Basement Rocks

The Precambrian, Lower Palaeozoic and Leinster Granite underlie most of the region, have similar characteristics and can be described together. Apart from the volcanic rocks, these strata are impermeable and considered to be aquitards. Groundwater flow in these areas is normally restricted to the top 30m of rock, the overlying Quaternary deposits and fault zones. Well yields in these strata are generally only sufficient for domestic or farm (25-50m^3/d) supplies. Well yields are greatest in the lowlying or weathered

parts of the granites and least in the metamorphic rocks.

The volcanic rocks of the Duncannon Group are considered to be an aquifer. The rhyolites are the most permeable of these rocks, however the individual units thin out rapidly away from the volcanic vents. This aquifer has been developed to provide part of the regional water supply in County Wexford and around Waterford City.

Old Red Sandstone
The Carrigmaclea Formation generally crops out on high ground, is impermeable except along faults and is considered to be an aquitard.

The Kiltorcan Formation which crops out in the Thomastown area and around the Carrick-on-Suir Syncline is an aquifer. Sandstone units dominate the upper part of the formation and mudstone the lower part. The aquifer is confined downdip by the overlying Carboniferous rocks and artesian conditions are frequently encountered.

These strata have recently been developed to augment the water supply for the Thomastown area.

Lower Carboniferous Strata
The thin sandstones that occur at the base of the Porter's Gate Formation have moderate permeability and are best developed in conjunction with the underlying Kiltorcan Formation.

The overlying limestones have different hydrogeological characteristics in the three areas where they crop out.

South Wexford. Although the complete succession is considered to be an aquifer, the dolomites and some of the cleaner limestones have been found to be more permeable. Recharge to this aquifer is restricted by the thick clays and till which cover most of the area and also confine much of the aquifer. This aquifer is a major source of public water supply.

Carrick-on-Suir Syncline. The permeability of all the limestones in this area has been enhanced by the extensive folding and faulting to which they have been subjected. The Waulsortian (frequently dolomitised) and clean, coarse limestones are the most permeable and give the highest well yields. The more argillaceous and fine grained limestones are the least permeable.

Mid-Kilkenny. There has been extensive dolomitisation of parts of the Ballysteen, Waulsortian and Butlersgrove Formations in this area. As a result the permeability of these strata has been increased considerably. The dolomitised limestones in this area discharge via a number of large springs which emerge close to the channels of the Nore and Kings Rivers.

Upper and Post Carboniferous Strata
Very little is known of the hydrogeology of these strata. The sandstone units at depth probably do contain significant permeability. However recharge is likely to be limited and owing to the proximity of the coast there is a good possibility that significant development would lead to saline intrusion.

Quaternary Sediments
The hydrogeological significance of these sediments is very variable and is largely a function of their permeability, thickness and extent. The low permeability material protects underlying aquifers, restricts recharge and where sufficiently thick may confine them. The high permeability material allows a high level of recharge, provides additional storage to the underlying bedrock aquifers and where sufficiently thick can be an aquifer in its own right.

The sands and gravels along the River Nore at Thomastown (10-15m thick), along the Slaney north and south of Enniscorthy (10-20m), in three small areas of South Wexford (10-20m) and the extensive deposits in East Wexford (15-50) are all considered to be aquifers.

Hydrochemistry and Water Quality
These aquifers contain mainly calcium magnesium bicarbonate type waters with Total Dissolved Solids of less than 500mg/l. The Total Hardness of the

limestone waters usually range from 250-350mg/l ($CaCO_3$) whereas the sandstone and volcanic waters are generally less than 200mg/l ($CaCO_3$).

The groundwaters in these strata are usually of potable quality except for very small local areas where they have been contaminated by the runoff from mainly organic wastes.

Eugene Daly, Geological Survey of Ireland.

MAGNETOMETER PROFILING

Peter Bennett, in GSI Groundwater Newsletter No. 25 commenting on the article on magnetometer profiling by Gibson and Lyle (GSI Groundwater Newsletter No. 24), made some comments which we would like to address. He commented that no mention was made of remanent and induced magnetism or the effect that orientation has on a magnetic signature. The purpose of this short article was to inform readers of the applicability of a technique they may not be aware of, not produce an academic paper which included references to susceptibilities, diurnal variations, asymmetric character of anomalies etc. We refute the suggestion that magnetometer profiling techniques are only applicable to situations akin to the location of igneous intrusions beneath thick drift. Experiments have been conducted on a wide range of rocks and an inventory of signatures for different geological structures (faults, fractures, fault zones, plugs and dykes) obtained. In the original article a fault between a sedimentary and metamorphic rock is clearly identified. The figure below shows the results of a magnetic traverse over two fractures in Silurian greywacke through which measured flow rates were an order of magnitude greater than the bulk rock. The background readings have a small variance averaging around 48920nT. Fracture 1 is marked by a positive and negative anomaly with a magnitude of 220nT whereas the second fracture has values that are over 350nT different from the background. Conventional geological mapping took approximately six hours and failed to detect one of the fractures whereas the pumping tests detected both fractures but entailed the drilling of boreholes, provision of pumping equipment, precise levelling and about seven days monitoring. The magnetic profiling took 40 minutes, detected both fractures, was performed by one operator and was completely non-destructive.

Magnetometer profiling is not a technique that should replace other ones or will unambiguously provide all the answers in all situations - no geophysical technique can do that. However, it remains a cost-effective, non-destructive method for quickly assessing areas where there is no exposure and a poor knowledge of the local geology and can provide useful information about unknown faults and fractures.

P.J. Gibson, Dept. of Geography, St. Patrick's College, Maynooth & P. Lyle, Dept. of Civil Engineering and Transport, University of Ulster, Jordanstown.

THE DAVID BURDON PAPERS

A ceremony was held in the Geological Survey of Ireland on Wednesday the 9th of November at which the achievements of one of Ireland's outstanding geologists, the late David Burdon (1914 - 1987) were recalled. The ceremony marked the dedication of David Burdon's Memorial Library collection, which has been kindly donated by his family to the Geological Survey of Ireland.

The large gathering included three members of David's family and a number of colleagues who had worked with him both in Ireland and overseas. Brief outlines were given of David's life, career and the contents of his papers. Professor John Lloyd of The University of Birmingham who worked with David in Jordan, gave a Memorial Lecture on "The role of the UN Agencies in Groundwater Development". The lecture was illustrated with descriptions of groundwater studies in the Middle East many of which have followed on from the pioneering work of David Burdon.

David was a compulsive writer and notetaker. He has left behind a wealth of material of interest to colleagues and friends who knew him, succeeding generations of hydrogeologists and geological historians.

His papers contain a considerable amount of information on his particular interests in hydrogeology, ie. arid zone hydrogeology, hydrochemistry, karst, springs and groundwater and agriculture. He also left much material on the many places where he worked, for instance, India, countries of the Gulf, Eastern Mediteranean and North Africa and later work in Ireland.

The papers span a period of over 40 years. - a period which coincides with the emergence of hydrogeology as a separate discipline within the geological sciences. Aside from his own publications the papers contain his yearbooks, lecture notes of the courses he gave, journals and original signed papers by many eminent hydrogeologists.

Of particular interest will be the unpublished material in his notes and the yearbooks he compiled of each year's work. I am certain they will reveal many useful ideas and insights into the geology and hydrogeology of the countries he worked in and those aspects of hydrogeology that most interested him.

David was an individual with catholic interests and these papers reflect them, for example:

A contribution on Mine dust and Mining Methods to a paper on "Pneumokoniosis on the Kolar Gold Field" (1947);
A paper on The Thermo-Magnetic Properties and History of some Plutonic Rocks from the Leinster Granites, Ireland (1955);
Hydrology of water supply. A UNESCO Course on Hydrogeology, Cairo (1958);
The handbook of "The Geology of Jordan (1959);
Papers on Some Chemical Types of Groundwater from Syria (1958), The Great Karst Spring of Mesopotamia (1963) and Hydrogeological control of development in Saudi Arabia (1968);
Contributions to a "Guide to the Hydrology of Carbonate rocks" (1972);
A paper on Flow of Fossil Groundwater (1977);
Geothermal Energy Investigations in Ireland (1983); and .
Histories of the Burdon Family and the parish of Buttevant (c1984).

The Geological Survey is indeed fortunate to have such material in its Library. It will be housed alongside the Portlock Library the collection of another famous geologist, who worked in Ireland from 1824-1843. The Geological Survey and the Irish Branch of the IAH (David was its first President) hope to be able to have the papers catalogued over the next year or two.

Those wishing to consult the papers are advised to make an appointment through David Ivers on Dublin 6707444 ext. 3217.

Eugene Daly, Geological Survey of Ireland

RETURN FROM OMAN

In mid-1988, I left Ireland to work in the Sultanate of Oman, and sent back a newsletter article a few months later, promising more.....well, it's taken longer than I intended, but here is more....

Occupying the SE corner of the Arabian Peninsular, bordered by Yemen, Saudi Arabia and the United Arab Emirates, Oman has about two million people (including half a million expatriates, mostly Asian) and an area of some 300,000 km^2, most of which is uninhabited or sparsely inhabited mountain and desert. The main populated areas lie in the north, along the flanks of the mountains, and in the south, around Oman's second city, Salalah.

For a hydrogeologist, Oman is extremely interesting to work in, having very substantial groundwater resources on which the country's agriculture depends. The oil boom, the resultant population boom (possibly fivefold since the 1960's) and the resulting new investment have led to a large expansion in irrigated area. The demand for domestic water supply has also increased, as living standards have risen. Oman is having to tackle simultaneously, within a compressed timescale, the need to evaluate its groundwater resources and manage them effectively. In 1989, my government agency evolved into a full Ministry of Water Resources, the first in the region, and its staff expanded from about 100 to more than 1200 within four years.

My own work was within the Directorate General for Regional Affairs (one of four directorates in the ministry), which grew from five to ten regional offices and from 60 to 450 staff, of whom more than 80 are university graduates. Regional offices undertake routine monitoring (some 4000 measurements per month, including over 2000 water levels in wells), permit evaluation (permits are required for all new wells or well deepening), enforcement of regulations (all contractors must be registered), local studies, project support, and liaison with other government agencies.

The main aquifers of Oman are:

- Quaternary sands/gravels, either in valleys or as accumulations on the plains: these tend to be cemented with carbonate - sometimes so highly cemented as to form a natural concrete, with only fracture permeability!
- Limestones and dolomites, Mesozoic and Tertiary, and karstified to varying degrees (Oman has some very spectacular caves and deep limestone gorges).

Traditionally, most groundwater usage was from *Aflaj (pl., sing. Falaj),* the most important of which are like the Persian qanats, i.e. underground galleries, often having their sources in alluvial fans in piedmont areas. Other *aflaj* are supplied from springs, usually from Mesozoic limestones. There are also some important thermal springs.

The well-known Samail Ophiolite (a massive chunk of the oceanic crust and mantle, thrust up in Cretaceous times) occupies much of northern Oman, forming a very distinctive mountainous topography. Most igneous rocks of the Ophiolite look very unpromising as aquifers, but intensive fracturing and alteration in some rock types has produced significant permeability, giving some good well yields and also giving rise to many springs. The high pH of the water results in copious carbonate deposition around the springs and in boreholes.

In the past few years, a lot of progress has been made. The Ministry's workforce (around 90% Omani) now includes a good number of Omani graduates, plus many locally-trained technicians. A number of graduates and technicians are receiving further training abroad. The Ministry is also very well equipped, with the highest level of computerisation of any ministry in Oman.

Regional water resource evaluations have been completed or are in progress over most of the aquifers, regional monitoring networks have been expanded, and by the end of 1995 the current phase of regional assessment should be essentially complete. A nationwide well inventory should also be nearly completed by then, and will be the basis for all future management schemes.

How to manage the substantial but overstretched water resources of Oman is the outstanding challenge, and one which will require firm resolve and both technical and political ingenuity.

In March 1995 Oman will hold a major inter-national conference on Water Resources Management in Arid Countries. Having helped to organise the conference, I hope to be there. Any hydrogeologist looking for something different would be rewarded with a wonderful experience. The March weather in Oman is usually superb. Think about it!

Geoff Wright, Geological Survey of Ireland

IAH ANNUAL GROUNDWATER SEMINAR

The Irish Group of the International Association of Hydrogeologists (IAH) will hold the Annual Groundwater Seminar in the Killeshin Hotel in Portlaoise on Tuesday and Wednesday **25th and 26th April**. The theme of the seminar this year is "The Role of Groundwater in Sustainable Development and Planning". Papers given at the seminar will cover a wide range of topics under the following headdings:

- ◊ sustainable development;
- ◊ groundwater flow regimes in Ireland;
- ◊ groundwater protection schemes;
- ◊ numerical modelling and groundwater protection;
- ◊ landfill sites
- ◊ landspreading of organic wastes;
- ◊ trace organics;
- ◊ the hydrogeology of Northern Ireland;
- ◊ sustainable well design and construction.

Speakers will include: David Ball,Hydrogeological Consultant; Shane Bennet, K.T. Cullen & Co.; Gerry Carty, EPA; Frank Convery, UCD; Donal Daly, GSI; Eugene Daly, EDA; Jonathan Derham, M.C.O'Sullivan & Co.; Paul Johnston, TCD; Bruce Misstear, TCD; Billy Moore, Tipperary (SR) Co. Co.; and Nick Robins, British Geological Survey.

Further details are available from:

Donal Daly,
IAH Seminar Secretary,
Geological Survey of Ireland,
Beggars Bush,
Haddington Road,
Dublin 4.
☎(01)6707444
℡(01)6681782

CONFERENCE ON UNSEWERED DEVELOPMENT 10th FEBRUARY 1995

A conference "Unsewered Development : The problems and possibilities of disposing of wastewaters on-site", being organised jointly by Sligo RTC and the GSI, will be held in the GSI on 10th February. This is a repeat of a successful conference held in Sligo in December 1993. The speakers and paper titles are as follows:

The use of package plants for the treatment of wastewater in the west of Ireland by Siobhan Crinion-Sheil, NW Region Fisheries Board, and Richard Thorn;
Legal and planning considerations of unsewered development by Billy Moore, Tipperary (SR) Co. Co.;
Unsewered development - the policy issues by Jack O'Sullivan, An Taisce/Environmental Management Services;
Septic tank systems - the conventional approach to on-site wastewater disposal by Donal Daly, GSI;
Low flow treatment - available technologies - priblems and potential by Billy Fitzgerald, Sligo RTC;
*Design and operational criteria for low flow wastewater treatment plants*by Noel Connaughton, Sligo RTC;
The Biocycle System by Frank Kavanagh, Biocycle Ltd.;
The Puraflow System by Hubert Henry, Bord na Mona;
FM Systems by Eamon Fitzpatrick;
The BMS Systems by Seamus Butler.

For further details contact either Louisa McConville ☎(071)44131 or Tony Glackin ☎(01)6707444

CONFERENCE PROCEEDINGS

The conference on "**The Balance of Water - Present and Future**" organized jointly by the AGMET Group and the Agricultural Group of the Royal Meteorological Society was successfully held at Trinity College Dublin in September. Over one hundred and twenty delegates from Ireland, the United Kingdom and continental Europe attended the meeting. Fourteen papers were presented over the three days. The authors of the thirteen posters on display presented short summaries of their work. A field visit was made to the Bord na Mona Research Laboratories at Newbridge and Clara Bog. The delegates also attended a reception given by the Lord Mayor of Dublin in the Mansion House.

A limited number of the conference proceedings are available from the AGMET Group, c/o Meteorological Service, Glasnevin Hill, Dublin 9. They are priced at £15.

Eugene Daly, Geological Survey of Ireland

CONTRIBUTIONS FOR THE NEXT ISSUE OF THE NEWSLETTER

The GSI Groundwater Newsletter aims to improve communication among scients 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.

Your contribution to the dialogue would be welcome. These should reach the GSI before 15th April 1995.