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THE GSI GROUNDWATER NEWSLETTER

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Edited by: Donal Daly

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In This Issue

In the recently published Final Report of the Three Rivers Project, unsewered populations were estimated to contribute 7%, 8% and 3% of the Total Phosphorus loss in the Suir, Boyne and Liffey catchments, respectively. While these proportions are low in comparison to the input of agriculture (57%, 63% and 58%), it is likely that the relative proportion from unsewered development would be greater in small catchments where there is a relatively high density of houses. Also, if the proportion of wells polluted by faecal bacteria from each activity were compared, they are likely to be far more comparable. This issue contains two articles on **unsewered development** and **on-site wastewater treatment systems**; the first (page 3) looks at the **density** of houses and makes recommendations on how it can be dealt with by local authorities; the second (page 7) deals with some of the **implications of houses in rural areas**. The article concludes that the implications are significant and that we need to give the issue a high priority and make changes to our current practices.

Is **bypass flow** or **preferential flow** in soils and subsoils relevant to Ireland? An article on pages 10-16 reviews the literature and concludes that it is. It is particularly significant here as groundwater flow in our bedrock is either in fractures or conduits, thereby providing little attenuation, particularly from microbial pathogens. Therefore, we are largely dependent on the overlying soils and subsoils to provide protection.

The EPA has recently initiated **research projects** that link with the requirements of the Water Framework Directive. Four groundwater-related projects are described by Margaret Keegan on page 19. David Drew (page 21) outlines two important **research projects** on karst that are being undertaken in the Department of Geography, TCD.

Editor

GSA Denver 2002: *Science at the Highest Level*

In late October I was able to attend the annual meeting of the Geological Society of America (GSA) in Denver, Colorado (*the mile high city*), so here are a few thoughts and impressions……………

Firstly, GSA is BIG! The meeting, held in the massive Denver Convention Center, attracted some 6,300 attendees (including one-day registrations), about 3,500 abstracts were accepted (including posters), for 246 sessions, not to mention the 'fringe' meetings held in nearby hotels. The meeting also included a large exhibition of geoscience publications, equipment, products (fossils, minerals, tee-shirts), services, agencies and educational institutions.

The entire organisation was very impressive and professional, as indeed it had to be for such a large gathering. All Powerpoint files (used by most presenters) were downloaded by each presenter at least one day before their presentation to a network server and then sent to the appropriate session room, where they were available on a laptop. Session chairpersons were equipped with a digital clock with orange and red lights appearing at the appointed times to signal '3 minutes to go' and 'end of talk' respectively! (*I finished mine with just 10 seconds to spare!*)

Talks (apart from keynote and other commissioned presentations) were normally limited to 12 minutes, with just 3 minutes for questions, introductions and changeovers – a very tight schedule. Chairpersons' instructions were that any 'no-shows' were to be taken as 15-minute breaks or discussion periods, so that the published schedules would be maintained; this was generally, but not universally, adhered to. Some sessions allowed little or no time for discussion, which was a pity. However, other sessions had good discussions, facilitated by aisle microphones, so that intending contributors could make their way to these mikes in advance.

On any given day, up to 30 sessions could be under way simultaneously, including up to 21 oral presentation sessions! This inevitably led to several frustrating clashes between presentations that I wanted to attend. For example, at the same time as my own presentation (see below) there were four other oral sessions I would like to have attended, besides a poster session on 'Physical Hydrogeology'. However, the format of the meeting makes it easy to slip in and out of the sessions. I soon learned that I had to be selective. The main sessions I attended were:

- #27: *Effective Communication and/or Partnership Among Geoscientists, the Public and Policy Makers: Case Studies* (my talk, co-authored with Donal Daly, was "Groundwater Protection Schemes in Ireland: Putting Geology at the Heart of Spatial Planning")
- #43: *Hydrogeology and Water Resources of the High Plains Aquifer: Issues for Public Policy*
- #47: *Injecting Geoscience into Public Policy: Strategies that Work*
- #70: *Groundwater Depletion and Overexploitation: A Global Problem*
- #71: *Rivers in Karst: Processes and Applications*
- #127: *Mining in the 21st Century: Meeting the Environmental Challenges*
- #155: *Physical Hydrogeology*
- #186: *Chemical Hydrogeology*
- #230: *Delineation of Contributing Areas for Wells in Challenging Hydrogeologic Settings: Methods, Uncertainty, and Verification* (particularly worthwhile in the context of GSI Groundwater Section's work in this field.)

On the day after the meeting we had an interesting field trip to Glenwood Caverns/Fairy Cave, with attendant discussions on speleogenesis and the role of bacteria. This was followed by a visit to the nearby Glenwood (hot) Springs (including a lengthy dip to experience the therapeutic properties of salty, sulphide-rich water at 40.5 degrees Celsius).

All in all, a great experience, certainly worth participating in at least once. If you're interested, check out the GSA's excellent website at www.geosociety.org. All your dealings with GSA about the conference – registration, submitting your abstract, even downloading your presentation, can all be accomplished electronically.

Finally, I must express my thanks to GSI for enabling me to attend.

Geoff Wright, Geological Survey of Ireland

Density of On-site Wastewater Treatment Systems

Introduction

In issue No. 39of the GSI Groundwater Newsletter, an article by Donal Daly argued that on-site wastewater treatment systems are one of the main sources of groundwater pollution in Ireland, particularly microbial pollution. It was also argued that while advanced systems have an important role in treating effluent and protecting the environment in certain circumstances, conventional septic tank systems are more sustainable than advanced systems for most areas deemed suitable by the EPA Manual (1999), provided that they are installed properly. Since then queries have arisen about the appropriate density of on-site systems and the required site sizes. This article does not provide definitive answers, but tries to provide a basis for local authorities and other statutory bodies to make decisions on these issues.

'Density' in the Literature

Yates (1985) concludes that "the most important factor influencing groundwater contamination by septic tanks is the density of systems in an area". She gives examples of pollution problems in areas of high densities. For instance in Connecticut, it was calculated that the density would have to be limited to one residence per acre to achieve the desired dilution. In Delaware, it was concluded that the regulation should be one 4-bedroom house per 2-acre lot.

Macler and Merkle (2000) give "density restrictions, possibly based on nitrate loading analysis" as an example of "source-specific control measures for septic tanks".

Influence of Density

The density of on-site wastewater treatment systems has 2 potential impacts for groundwater and surface water:
Impact 1: Overall Risk
Impact 2: Contamination by Conservative Contaminants (e.g. nitrate)

Impact 1: Overall Risk

In general, the greater number of hazards per unit area (i.e. density) the greater the probability of an impact on groundwater, and therefore the greater the risk to groundwater. However, a general statement such as this does not enable an appropriate density value to be estimated.

We do not agree fully with Yates that density is "the most important factor", in particular regarding pollutants such as bacteria and viruses, which are readily attenuated if the hydrogeological conditions are right. So, for instance, in an area with >10 m free-draining subsoil (e.g. sandy SILT) a greater density of houses will not result in pollution by faecal bacteria. As faecal bacteria pose the greatest threat to human health, it is the subsoil condition and not the density that is the most important factor. However, a high density could result in high nitrates, and therefore it is an issue that needs to be addressed.

Impact 2: Contamination by Conservative Contaminants

Some contaminants are conservative and therefore their attenuation, other than by dilution, is minimal. Nitrate (NO_3) and Chloride (Cl) are two good examples, although Cl does not pose a threat to human health. It is suggested that conclusions regarding density of on-site systems should be based on possible increases in NO_3 in free draining areas (as recommended by Macler and Merkle). The only attenuating mechanism considered is dilution.

In Table 1, we have calculated the impact of septic tank effluent on moderately permeable subsoils. The calculations are based on the following assumptions:

- quantity and quality of effluent from EPA Manual.
- potential recharge (soil moisture excess) is 600 mm/year (range in Ireland is from 350->1000 mm; about 66% of country has >600 mm).
- just over 50% of the soil moisture excess infiltrates to groundwater in moderately permeable soils.
- no denitrification (with all N. converting to nitrate.)

Table 1: Example Dilution Calculations

Variables	Population	1	5	10
	Area (ha)	1	1	1
	Volume from septictank (m3/d/person)	0.18	0.18	0.18
	Concentration in effluent (mg/l N)	50	50	50
	Recharge to groundwater across the area (mm/yr)	350	350	350
	Concentration in recharge (mg/l N)	0.1	0.1	0.1
Calculations	Load in Septic Tank (kg/day N)	0.0090	0.0450	0.0900
	Load in Recharge (kg/day N)	0.00096	0.00096	0.00096
	Total Load (kg/d N)	0.0100	0.0460	0.0910
	Total Conc (kg/m3 N)	0.0010	0.0044	0.0080
	Total increase in Conc due to Septic Tank effluent (mg/l N)	1.0	4.4	8.0
	Total increase in Conc due to Septic Tank effluent (mg/l NO3)	4.5	19.4	35.4

An example of the procedure used to derive these estimations is provided at the end of this paper. Table 1 shows that increasing the population density by only two or three people per hectare can significantly increase the nitrate concentration in groundwater below an area. For example, just one additional house per hectare, each with 4 or 5 people, could increase the concentration in the area by ~15 mg/l NO_3. Keep in mind that the impact would be somewhat greater in the drier areas of the east and midlands, where recharge is less. In an area where the recharge is only 200 mm/year, the increase in concentration for 5 people/hectare would be ~30 mg/l NO_3.

Implications

The figures in Table 1 clearly indicate that problems due to high nitrates could be caused by septic tank systems in areas with a high density of systems. Due to the relative lack of dilution, private wells and small group scheme wells are more at risk than regional-scale public supplies:

- *Local scale:* The worst case scenario is at the local scale in a situation where there is direct recycling of wastewater from the percolation area to a private well. The resulting NO_3 concentration in the well water could theoretically be as high as 220 mg/l. A five-fold dilution is required to bring the concentration below the EU MAC (50 mg/l). Problems can arise in particular where there is a grouped housing scheme with each site having both a well and on-site system.
- *District scale:* An assessment of nitrate levels in a small (27 m^3/d) public supply in Offaly (Cronin and Daly, 1997), concluded that 6 septic tank systems in the well's recharge catchment area (6.6 ha) would increase the NO_3 levels by 16 mg/l (where it was assumed that the N. conc. in the effluent was 45 mg/l N). In this area the background concentration was ~21mg/l, so the increase due to septic tank systems was significant. This calculation would also apply to small groundwater-fed streams or to small streams in areas with minimal soakage.
- *Regional scale:* The larger well-fields and springs will derive their recharge from catchment areas of several square kilometres. The influence of localised concentrations of septic tank systems within these areas will be averaged out. Thus, the average unsewered population density can be used to help estimate the increases in NO_3 due to on-site systems in regional water supply schemes. If the unsewered population density were 1 person per 4 ha within the catchment of a well-field and if the recharge across the area were 300 mm/year, the increases in NO_3 due to on-site systems would be only 1 to 2 mg/l.

Discussion – Resulting Questions

1. What scenario should be used as the basis for decision-making?
   - Private well situation
   - District/areal situation.

2. What increase in NO_3 should be taken as a cut-off in deciding on a density? Should a maximum of 25 mg/l be set as the preferred limit for NO_3 at the district scale from all hazards? Should, for instance, 10 mg/l be apportioned from on-site systems and the remainder from agriculture? However, there are many areas in the east, south-east and south where NO_3 concentrations are close to or above 25 mg/l. If 25 mg/l were taken as the limit in these areas of the south-east, it would mean no more increases in NO_3 concentrations could be allowed and that no new unsewered houses could be built unless the NO_3 concentrations were reduced in some other way.

3. If 10 mg/l was taken as the maximum allowable effect from on-site systems, the maximum no. of people on conventional systems would be 3/ha, i.e. 1 'small' house/ha. However, the question that arises from this is 'over what area does this apply?'. Areas with ribbon development could have population densities > or < 3/ha depending on the shape of the area taken. The shape of the area taken would be influenced by whether private wells are in use.

4. In areas where groundwater is used for public supplies, how should existing NO_3 levels be taken into account? The **Groundwater Protection Response (DoELG/EPA/GSI, 2001)** mentions NO_3 – see $R2^3$, $R2^4$, $R3^2$ and $R3^1$.

5. How do 'alternative' systems change the situation? Is the N. conc. from these systems lower than conventional systems?

6. How does all of this affect site sizes? Site size is a term relating to the whole plot of land on which a house will be built. Minimum site sizes may need to be stipulated by planners as a result of density considerations and/or by the need to keep the percolation area at a certain distance from a well. It is therefore a key practical question for planners and developers.

Site Sizes

The site size could depend on (a) whether wells are used on site or nearby (e.g. within 60 m), (b) existing NO_3 levels in the area, and (c) the conclusion drawn during the site characterisation on the minimum distance between the well and on-site system, assuming that a well is or may be down-gradient of the system. The site size must also take into account the possibility of microbial contamination, in that certain minimum separation distances are required.

Where good protection is provided by the subsoil (30 m separation situation between the well and percolation area), the minimum site size could be 2,100 m^2. (Assumes a site length of 70 m (10 m from well to boundary + 30 m to percolation area + 20 m length of percolation area + 10 m to boundary) and a width of 30 m). If it is decided to adopt this approach, one possibility is to draw these figures on a simple diagram.

Where the protection is relatively poor (60 m separation distance), the minimum site size could be 3000 m^2. (Assumes a site length of 100 m and a site width of 30 m.)

Where groundwater is not abstracted in the immediate area, the minimum site size could be 1500 m^2. (This is the same as in S.R.6:1991. (NSAI, 1991))

Giving sizes such as these has the advantage that they can be applied to all types of systems, they are relatively simple to apply and they are similar to those in S.R. 6., so local authorities are familiar with them. However, site sizes are not mentioned in the EPA Manual or the Groundwater Protection Responses, and **therefore decisions on site sizes are a matter for the planning authority!**

Site Specific Evaluation

According to the **Groundwater Protection Responses**:

"*Where nitrate levels are known to be high or nitrate loading analysis indicates a potential problem then consideration should be given to the use of treatment systems which include a de-nitrification unit*."

Therefore the recommended approach is that each site should be evaluated using the local conditions as the basis for decision-making.

Example of a Dilution Calculation to Assess the Impact of Effluent on Nitrate Concentrations in Water

Assumptions:

– Recharge (Rainfall – (Evapotranspiration + Runoff)) = 9.6 m^3/d/ha (350 mm/yr)
– Average nitrogen (N.) concentration in effluent = 50 mg/l N.
– Average flow from septic tank (4 persons) = 0.72 m^3/d

- Nitrogen concentration in recharge = 0.1 mg/l N.
- No denitrification occurs.

Nitrate concentration resulting from 1 on-site system/ha

$$= \frac{(50 \times 0.72) + (0.1 \times 9.6)}{0.72 + 9.6}$$

= 3.58 mg/l N.

= **15.9 mg/l NO_3**

The only parameter that local authorities would need to vary is recharge, which could be reduced in the drier east and south-east.

This calculation can be combined with knowledge/data on existing nitrate levels in an area. In areas with high nitrates, it could be used as a justification for refusing permission or requiring a system that includes a de-nitrification unit.

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Donal Daly and Vincent Fitzsimons, Geological Survey of Ireland

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Recommended New Publication

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Implications of Use of On-site Wastewater Treatment Systems for Houses in Unsewered Areas

Introduction

Even the thought of writing on so called 'one-off rural housing' in the current climate brings to mind phrases like 'sitting duck', 'head over the parapet' or alternatively 'life is too short, why bother'. However, for those who mightn't agree with some of the views given below, keep in mind that neither I nor the GSI make the planning decisions! This article is based on my own experiences as a hydrogeologist looking at this issue over the last 15 years, and as someone with a rural background and a concern for the future of rural Ireland.

Summary of the Past and Present

- Over 50 million gallons of effluent are produced by on-site systems daily. This effluent is disposed of in the ground.
- Almost 36% of new houses in recent years are 'one-off', using on-site wastewater treatment systems.
- Effluent from on-site systems pose a threat both to human health and the environment.
- Conventional septic tank systems produce an effluent that is a significant hazard, particularly in terms of microbial pathogens (several million faecal bacteria per litre of effluent) and nitrogen (N) entering groundwater and surface water, and phosphorus (P) entering surface water. While effluent from advanced systems reduce the numbers of pathogens and the concentrations of N and P in effluent, and therefore reduce the risk of environmental pollution, the effluent nevertheless still poses a threat to human health and the environment. Also, advanced systems do not reduce the quantity of effluent.
- The degree of microbial contamination of groundwater in Ireland is very high. I am not aware of any other country in the EU with the same levels. The EPA recently recorded that 36% of samples tested contained faecal bacteria. In County Roscommon, 58% of samples from Group Schemes contained *E.coli*. It is likely that there are areas where more than 70% of private wells contain faecal bacteria at some time during their use. While the faecal bacteria themselves pose a threat to human health, particularly to babies and old people, viruses and Cryptospiridium may add to the threat. In my view, microbial pathogens are the single greatest threat to groundwater in Ireland. The two main potential sources are organic wastes from farming and effluent from on-site systems.
- **The key factor in Ireland leading to this situation is that our bedrock is fissured and provides little purification, and there are many areas of shallow rock. The depth of subsoil over bedrock is the critical factor in keeping our groundwater clean and safe and the critical consideration in the assessment of potentially polluting activities, from a hydrogeological perspective**.
- In Ireland, a significant proportion of the land surface (perhaps up to 40%) is not **readily** suitable for on-site systems. Two contrasting scenarios comprise this area:
  - Low permeability soils and subsoils, which become saturated in winter;
  - Outcrop and shallow bedrock, where the soil and subsoil thickness is <2.0 m (in areas where the bedrock permeability is high, the groundwater is under threat; where the permeability is low, surface water is at risk);
- The reality is that there are many houses, including relatively new ones, where the effluent is either piped into streams or is getting into the ground too rapidly. *(I have stayed in some of them while on holidays in the west of Ireland!)*
- For many houses in rural areas, wells and on-site systems are (or for future houses, will be) on the same site or nearby. In other words, we are getting our drinking water from a point a few tens of metres away from where we dispose of our faeces and urine, leaving the potential for a particular form of recycling that is not recommended, as the zone of contribution of private wells often includes the area containing the percolation pipes. This is inherently risky, unless the ground conditions are suitable, particularly with regard to the depth to bedrock.

The Future

In the coming years, hundreds of thousands of houses will be built. Could continued permissions for houses in unsewered areas, particularly urban-generated housing, pose a significant risk to the environment and human health? There can be no doubt but that the answer is 'yes'. A more critical question is 'can the risk be mitigated or managed such that there is no significant impact?' The answer is 'it depends!'. What does it depend on? How can the risks be managed and minimised? Are there areas/situations which are not suitable for on-site systems?

My views and recommendations are as follows:

- It is vital that the EPA Manual (2000) and Groundwater Protection Responses (2001) should become the guidance documents for the location of on-site systems (for instance, in the Building Regulations), and in particular, for site assessments. Use of these documents will help ensure minimal environmental and health impacts and will discourage use of less suitable sites. I suggest that the Agrément Certificates should not apply to the site suitability aspects of site selection. In particular the Site Characterisation Form in the EPA Manual should be used for all site suitability assessments. I would recommend that those local authorities who are not already doing so should use the Site Characterisation Form at the back of the EPA Manual as a means of collecting the relevant information. This is also available on the EPA website (http://www.epa.ie).

- Good information on the 'ground' conditions is necessary as a basis for good decision-making. Groundwater protection schemes (DoELG/EPA/GSI, 1999), which compile and make available relevant geological and hydrogeological information, can be of great assistance. Proper site assessment and selection requires a multidisciplinary knowledge. In my view, no one profession, whether hydrogeologists, engineers, planners, environmental scientists or environmental health officers, have sufficient knowledge currently. Site assessors require specific training. This is being provided by a FÁS Course 'Site Suitability Assessment for On-site Wastewater Management', which is run jointly by the GSI and EPA. In the near future when sufficient numbers have been trained, I believe that before a site is deemed suitable, it should be certified by a 'competent person'. Therefore, future site assessors may require certification by FÁS to be deemed a 'competent' person.

- On-site systems, both conventional septic tank systems and advanced systems, should be installed under the supervision of a 'competent person' and certified by that person. Both systems can give problems if not installed properly and maintained. All effort in evaluating a site is totally wasted if the system is not installed as designed.

- It has been argued that only advanced systems should be used in the future. I do **not** agree with this view. In a significant proportion of the country, where the subsoil is free draining ('T' values 1-50) and sufficiently thick (>3 m), I would recommend conventional septic tank systems, provided they are suitably located, installed properly and maintained (see Daly (2001) for discussion on this issue). However, there is still a large proportion of the country which would be deemed suitable using the EPA Manual – for instance, shallow rock areas and areas with 'T' >50, but with 'P' between 1-50 – where I personally would use, and my judgement would be to recommend, a reputable advanced system. Therefore, I feel that they have a vital role to play in the future.

- I do not see 'groundwater pollution' being an issue in itself that would prevent permission being given for a house with an on-site system, unless the groundwater in the area has high nitrate levels, provided all of the requirements of the EPA Manual and the Groundwater Protection Responses are followed. Essentially sites can be 'engineered' to minimise the likelihood of groundwater pollution by microbial pathogens, even though it may be difficult and relatively expensive in some circumstances, such as in areas of outcrop and shallow rock. However, I would not advocate dependence on disinfection of effluent as the solution to microbial contamination of groundwater, as it cannot be guaranteed that the disinfection unit will be maintained.

- In contrast, I believe that there are circumstances where the impact on surface water cannot be prevented in practice. These are as follows:
  - where both 'P' and 'T' values are >50 (a failed site according to the EPA manual);
  - where P is between 1-50 and 'T' is >~80 (this value may vary somewhat depending on

the circumstance, particularly the slope of the site). This circumstance is not explicitly deemed a failure in the EPA Manual – it is left to the expert judgement of the site assessor;
- outcrop and shallow bedrock where the bedrock has a low permeability (typically many of the 'poor' aquifers, for instance, in the west of Ireland).

In these situations, the effluent cannot migrate underground at a sufficient rate to prevent ponding. The only option then is to discharge to surface water with a licence from the local authority. However, in the vast majority of circumstances, this will not be a viable option as there are seldom streams nearby with a sufficient continuous flow (especially in summer) to dilute the effluent adequately. In most hydrogeological settings, these areas correspond with poor aquifers where summer baseflow is low and consequently small streams dry up or have very low flows in summer (not to mention the fact that there are seldom flow data available). I suspect that there are many houses (I have seen several!) where effluent is piped directly into seasonal drainage ditches and small streams. Clearly these situations pose a threat to human health as well as impacting on surface water quality.

♦ While (a) using the EPA Manual and the Groundwater Protection Responses, (b) installing conventional systems on readily suitable sites and advanced systems on less suitable sites, and (c) having trained personnel available, represents great progress for the future, much of this progress will be hindered unless there is a massive **increase in the level of enforcement and monitoring by local authorities**. It would be particularly important that advanced systems should be monitored, as these are usually used in areas that are not suitable for conventional septic tank systems. Ideally the installation, inspection and maintenance of such advanced systems should be tracked to a local authority-held database. This might be incorporated as a planning condition. As resources to enable this to happen are not readily available, perhaps local authorities should be allowed to charge a sufficient planning application fee to cover the costs?

Summary

In conclusion, the management of the risks to human health and the environment of effluent from houses in unsewered areas depends on the site hydrogeology, proper site evaluation and selection by trained staff, use of appropriate technology, use of the EPA Manual and the Groundwater Protection Responses, saying 'no' when justified and, above all, enforcement and monitoring by local authorities. For the sake of our rural environment and the future health of householders in rural areas, let us give this issue a high priority and let us get on as soon as possible with the required changes.

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Bypass Flow – Is it Relevant to Ireland?

Introduction

In a paper a few years ago on landspreading of organic wastes from activities licensed by the EPA (Daly, Power and Keegan, 1998), it was concluded that preferential flowpaths in soils and subsoils are likely to exist in Ireland and should be taken into account in considering pollutant movement to groundwater. Preferential flow is one of the most active research areas in hydrogeology and soil science in the last 10 years. The main mechanisms of bypass or preferential flow above the water table are flow via macropores or via 'fingering'. Macropores are pores formed by soil fauna (mainly earthworms), plant roots, weathering cracks, fractures and natural soil pipes. 'Fingering' can occur when instabilities develop at the wetting front, leading to the propagation of discrete fingers of infiltration rather than a uniform surface. Both types of preferential flow paths can potentially greatly decrease the time taken for solutes and microorganisms to migrate through the soil and subsoil relative to predictions based on Darcian principles.

In the last few years I have been conscious of this issue when examining soil and subsoil exposures and in the last year I have undertaken a literature review. As a contribution to discussion on this issue, a summary of my findings are given below.

Relevant Text from Daly, Power and Keegan (1998)

A substantial volume of research material, summarised by Abu-Ashour et al. (1994), Beven and Germann (1982), Thomas and Phillips (1979) and White (1985), indicates that it is an over-simplification to: (a) treat topsoils as a homogeneous medium conforming to Darcian principles of water flow, and (b) assume that the only recharge process is displacement (by piston-like flow) of all resident water and solutes by incoming water and solutes. The presence of macropores (e.g. pores formed by soil fauna (mainly earthworms), plant roots, weathering cracks and natural soil pipes) can greatly decrease the time taken for solutes and micro-organisms to migrate through the topsoil relative to predictions based on Darcian principles. As a consequence of preferential flow in macropores, gravitational flow of water can occur in soils that are well below 'field capacity' and water can move rapidly through unsaturated soil ahead of the wetting front in the soil matrix. Fleming et al. (1990) found rapid movement of faecal bacteria to tile drains and the presence of faecal bacteria at 0.5 m depth in underlying soil, following landspreading of liquid manure; they concluded that macropore flow was the most likely transport mechanism. Hallberg (1989), in a review of pesticide pollution of groundwater in the humid US, concluded that preferential flow may be making soils more susceptible to leaching of pesticides (and other land-applied compounds) to groundwater than evaluations based on traditional concepts of Darcian flux would suggest.

The role of preferential flow is likely to be less in Ireland than in some of the countries where they are shown to have a significant impact because Irish soils are relatively young (less than 16,000 years since the Ice Age ended) and climate variations (particularly temperature) are less than, for instance, the US and continental Europe. While little research has been carried out on this in Ireland, there is sufficient evidence to show that it is also an issue that is relevant to contaminant movement and groundwater protection here:

- *Ryan and Noonan (1995) showed the role of macropores in soils at Johnstown Castle with a field tracing experiment where dye, applied at the surface, moved to almost 0.9 m bgl in thirteen days.*
- *In their review of the soil associations in Ireland, Gardiner and Radford (1980) describe the presence of roots below 0.5 m in most soils and below 1.0 m in some soils. According to Gleeson (1998), grass roots may reach depths of 2.0 m during dry summers.*
- *Ball (1993) has reported summer cracks in fields of pasture land down to 2.0 m. In a situation with 3-5 m soil and subsoil over bedrock, and a water table 4.0 m bgl, he found a rise in the water table of 1-3 cm and a sudden increase in faecal bacteria in the groundwater following 24 hours of intense isolated showers in June and August. He concluded that summer rainfall can bypass the soils moisture deficit and recharge the groundwater system through macropores.*
- *Field observations by geologists and hydrogeologists in the GSI and consulting firms*

report the presence of preferential flowpaths as deep as 2.0 m bgl.

- *GSI automatic water level monitoring shows recharge occurring during the summer months after heavy rainfall in certain circumstances.*

Preferential flowpaths are likely to exist in virtually all soils down to about 0.4-0.5 m bgl. Below this their presence will reduce with depth, depending largely on the soil and subsoil texture. In some situations, particularly where (a) the bedrock is shallow and permeable, (b) the soil and subsoil have a high clay/silt content, and (c) the underlying subsoil is sand/gravel, they may be present to depths greater than 1.0 m.

Literature Review

In undertaking the literature review, I read over 50 papers; therefore due to pressure of time, the papers summarised and quoted below represent only a fraction of these. All the papers acknowledge or assume that preferential flowpaths exist. What is poorly known is how often these pathways act as actual flow conduits, particularly as preferential flow cannot be monitored using only suction cups in the unsaturated zone. Also the understanding of the mechanisms of flow initiation and the modelling of this flow are still at the early stages of development.

Abu-Ashour et al. (1994). They state '*Several laboratory and field studies showed that average velocity of microorganisms moving through soil was greater than that of a chemical tracer such as chloride or bromide or the flow of ambient groundwater without any tracer*.' They conclude '*Microorganisms migrating into and through soil from sources on the land surface may cause a serious threat to ground and surface waters. It has been estimated that microorganisms can migrate distances in the field. Results from various studies suggested that preferential flow through macropores, worm holes, cracks, and fractures is the main reason for such observations. However, a quantitative representation of this phenomenon has not been provided*.'

Ball (2002) based on experience and observation, argues that preferential flowpaths are present in Irish soils and subsoils and presents photographs of preferential flowpaths at a site in Wexford.

Beven & Germann (1982): '*The experimental evidence cited above strongly suggests that theories of soil water flow that treat the soil as a relatively homogeneous medium conforming to Darcian principles may not adequately describe the infiltration and redistribution of water where the soil contains macropores. Thus we may expect that predictions based on Darcy's law may be significantly in error when the macropores conduct significant amounts of water. However, any improved theoretical structure cannot reject traditional approaches, since models based on Darcy's law have been well proven in the past. This suggests the introduction of a domain concept to model combined macropore/matrix systems, with the matrix as one domain that can be described by hydraulic principles based on Darcy's law and the macropores as a second domain. A description of the interaction between the domains would then complete the model*.' They quote other research that found that '*rainfall intensities of 1-10 mm/hr may be sufficient to initiate macropore flows, depending on antecedent precipitation'*.

Coyne et al. (1996): In an experiment at the Kentucky Agricultural Experiment Station, water samples were collected at 0.9 m depth and the volume was measured after every rain that caused leaching. Faecal coliforms were found immediately after heavy rain. It was concluded that '*Macropore flow was probably the main factor contributing to the rapid fecal bacteria movement through soil'*.

Feyen et al. (1998): Concludes: '*From the beginning of the century, soil physicists have been trying to describe water flow and solute transport in porous media or soils based on physical laws using a mathematical framework. However most of their work was restricted to homogeneous soils. Although it provided many useful insights into the flow and transport phenomena, their solutions may not be adequate for describing transport processes in natural soils under field conditions. The major problem in many soils is the discrepancy between the assumption of a homogeneous porous medium and the observed heterogeneity, both at the micro- and macro-scale. Micro-heterogeneity, occurring in structured, cracked or microporous soils, and macro-heterogeneity, due to the inherent spatial variability of soil properties, have a distinct effect on the water flow and solute transport processes*.'

Fleming, Dean & Foran (1990): Liquid manure was spread on land in Ontario (recent glacial deposits). Samples were taken in drainage tiles at 70-90cm. At 3 out of 5 sites, elevated levels of chemicals and bacteria were found within hours of spreading. Most impact occurred within 72 hrs. Macropore flow was thought to be the most likely transport mechanism.

Flury et al. (1994): Research in Switzerland. Dye tracing experiments were carried out at 14 different sites applying 40 mm in 8 hrs (equivalent to a heavy rainstorm with a return period of 2yrs). The experiment was conducted on different soils. A trench was dug 1 day after the tracer was applied. The dye had moved 15-100 cm in that time, due to preferential flow. They concluded that it is likely that during heavy rainfall the sorbing soil matrix is bypassed in many, if not most, Swiss arable soils. They also concluded that '*The occurrence of preferential flow is the rule rather than the exception*.'

Foster (2000) in an overview paper presents a generalised compartmental scheme of groundwater flow and pollutant attenuation (Figure 1), contrasting velocities of 2 m/yr (matrix) compared to 1-10 m/d (preferential flow) in the unsaturated zone. In a section on preferential flow, he points out that it is difficult to prove, especially under natural rainfall conditions, and because of the '*pressure to model has almost certainly been underestimated in past models of nitrate transport in the vadose zone.*' He gives indirect evidence for preferential flow, such as intermittent groundwater contamination by bacteria in areas of deep water table, despite the fact that tritium concentrations indicate transport of <1.0 m/yr. He states that most transport of pesticide (in Hampshire) was via preferential flow. On Cryptospiridium he concludes that the role of preferential flow through the vadose zone is especially significant. He states '*Farming is an inherently 'leaky activity', particularly when practised on permeable sub-soils generating significant preferential vadose-zone flow'*.

Gachter et al. **(1998)**: Research was undertaken in Switzerland on transport of Phosphorus from soil to surface waters by preferential flow. Grassland area with dairy and pig production. Liquid manure applied at a sprinkling intensity of 6 mm/hr for 8 hours – regarded as '*high but not unusual as compared to naturally occurring precipitation'*. Half the plot was excavated the next day; it showed tracer going to 90 cm. On the basis of results from Br and dye tracers, the top 10 cm retained most of the sprinkled water. Only 65% of the Br and 69% of the dye were recovered in the soil profile. Thus, about 35% of the sprinkled water must have left the soil profile quickly along preferential flowpaths. They concluded that vertical macropores in combination with fast lateral water movement (mainly along drainage systems) contributed significantly to the eutrophication of Lake Sempach. They also concluded that '*worm burrows were the dominant structures leading to preferential flow down to a depth of about 0.8 m*.'

Hallberg (1989): A review paper on pesticides in groundwater in the humid USA. He states: '*Preferential flow also affects some common notions about the 'relative susceptibility' or vulnerability of various soils to pesticide leaching*.' … '*pesticide detections were more common in groundwater in fine-textured tills than in areas of coarser-textured soils overlying sand and sand and gravel aquifers. While displacement flux, which may occur with some of the mobile fumigants, will leach solutes more uniformly through the soil; preferential flow will generally deliver smaller amounts but very rapidly. In many medium to fine-textured soils in the humid grain belt, preferential flow may make these soils more susceptible to leaching of pesticides (and other land-applied compounds) to groundwater than generally considered.*' …… *'Conclusions based on current models that evaluate pesticide movement, based on traditional concepts of Darcian flux, must be used with caution, and with an understanding that they do not provide a complete understanding of the potential problems*.'

Jury & Fluhler (1992). They review numerous papers. They indicate how the results of preferential flow can be missed: '*It is possible that shallow preferential flow was not detected by the solution samplers used by Butters et al. (1989), but was detected by the soil coring method used by Ellsworth et al. (1991).'* They describe an example by Roth who studied solute transport through a layered and structured soil in Switzerland, finding that macropore movement accounted for about 56% of the total flow. The fast movement carried substantial solute mass below 2 m during the course of the study, whereas the matrix flow was centred at about 85 cm at the end of the experiment. They give examples of other studies showing the appearance of pesticides in groundwater/tile drains soon after rainfall. They conclude '*It is unfortunate that the theory of solute transport through soil was developed exclusively from studies conducted in the lab, because that theory has been transferred to the field regime without justification in many cases. The result of this action has been that models have entered the consulting, regulatory, and policy areas, where they are used routinely in applications for which their assumptions do not apply*." Also: "*The field evidence regarding preferential flow is quite consistent in one respect. Preferential flow can occur under a variety of circumstances, and is not restricted to clay-rich soils with significant structural voids. Rather, based on the evidence of the dye tracing studies of Kung and Ghodrati and Jury, it seems likely that structureless soils may be just as prone to developing preferential flows as their finer-textured structured ones, although clearly for different reasons. A defining characteristic of preferential flow is high matrix permeability. This ensures that any plume resulting from funnelling of flows by lateral migration around obstacles will be able to move downwards at the new higher flow rate. Such flows at the present time appear to be unpredictable, in the sense that they are triggered by small-scale features that cannot be characterised by conventional sampling methods in the unsaturated zone*.'

Jorgensen et al. (1998): Undertook research in Denmark and found fractures in clayey till to 1.5-2.0 m. They concluded that flow is controlled by fractures and by flow through a few root channels.

Natsch et al. (1996): In Switzerland, used genetically modified bacteria as tracer. They conclude '*the results of this study suggests that a heavy rainfall occurring after application of bacteria to field soils leads to the transport of a significant number of bacteria to depths of at least 150 cm*.'

Posner at al. (1992):Research in Wisconsin. A leaching study using Bromide concluded that macropore flow was the dominant mechanism of downward movement. Piston-type simulation predicted Br would move to 60cm by Nov; Br was detected at 80cm by August 13th under all crops.

Ryan (1998) quotes the results of a study by Simmonds and Northcliff (1998) on rainfed monolith lysimeters, having 1 m freely drained sandy loam overlying gravel at 1.5 m with clay lenses occasionally present between 1 and 1.5 m, showed high velocity flow via macropores, triggered by rainfall intensities exceeding ~5 mm per hour.

According to this paper, '*Intense rainfall (>5 mm per hour) resulted in bypass flow in this soil even though it was a deep sandy loam with poorly developed structure which was as likely to come as close as field soils ever do to 'text book ideal' of one-dimensional (piston) flow that can be described by flow equations in which the soil is regarded as a quasi-amorphous medium'*. He quotes Jarvis (1992) who states that '*much UK grassland is based on well structured soils that contain pockets of relatively immobile water and (NO_3^-) and have preferential flow through macropores. Because of this, NO_3^- concentrations may be lower than in poorly structured soils where water movement is by displacement or piston flow*'.

In his own research, Ryan carried out dye studies by loading a cylindrical area with 180 mm of dyed water, and field infiltration studies. He concludes '*It seems reasonable to infer that the preliminary dye and infiltration studies both indicate preferential flow in the profile of the Johnstown Castle soil'*.

Sililo & Tellam (2000) undertook research on fingering in unsaturated zone flow. Fingering is a class of preferential flow where the pathways occur in macroporeless soils and may be caused by an instability of the wetting front or changes in the permeability structure of a soil. *'These pathways are transient in nature and highly dependent on the porous medium properties (grain size and structure), and infiltration flux, and the initial and boundary conditions. Evidence abounds in the literature that suggests nonuniform transport and rapid transfer of water from the surface to aquifers in macroporeless soils. The evidence includes rapid changes in water levels and chemistry in aquifers after rainfall events (Steenhuis et al. 1996); recharge even when evapotranspiration is high (Berkman et al. 1996); marked lateral heterogeneity in moisture content in the unsaturated zone (Starr et al. 1978, 1986: Glass et al. 1988; van Ommen et al. 1988; Allison, et al. 1994); and marked discrepancies between simulation model results and actual field measurements (Jury and Fluhler 1992)*.' Other research is summarised in the paper, which then concludes '*Despite all of the work in this area, the understanding of field-scale fingering is still limited*'.

Under '*Discussion and Conclusions'* on the experiments undertaken by the researchers, the paper states:

"These experiments have shown that:

1. *Stratification will not get rid of fingering; on the contrary, it will enhance the process.*
2. *In a discontinuous layered system, both fingering and funnelling will occur.*
3. *In a dipping multilayered system, lateral flow on top of the fine grained layers will increase flux in the down-dip direction. The latter will dominate flow in the system because water will be received from both the lateral and vertical directions.*
4. *In systems where the top fine-grained layer has a variable thickness, finger density and amount of flow will be greatest at zones where the fine layer is thinner.*
5. *Surface depressions will concentrate water flow, and fingers forming below such areas will dominate the flow in the system,*
6. *Once formed, fingers can persist in the same location for a long time. Fingers may be viewed as semi-permanent preferential flow structures that may transport water rapidly both in time and in space.*
7. *In systems where the upper fine-grained layer has macropores, the latter will concentrate water flow and fingers will form directly below these zones.*
8. *In moist sands, fingers will be broader and less distinct.*

Several studies have already demonstrated that fingering does occur in field systems (van Ommen et al. 1998, 1989; Glass et al. 1988; Ritsema et al. 1996; Glass and Nicholl 1996). However, no general quantitative representations of fingering are as yet widely available, and although empirical equations and numerical solutions have been proposed, the presence of heterogeneities would seem to make their validity less certain. This is especially so in field systems where nonuniform conditions in soil structure and moisture content are the rule rather than the exception. In situations where fingering is significant, current approaches based on an assumption of uniform flow are likely to give erroneous results. Hydrogeological applications that may be affected include recharge estimations, interpretation of hydrochemical data, and the monitoring transport, and fate of contaminants in the unsaturated zone. Fingering has important implications for monitoring of flow and contaminants within the unsaturated zone and some means of determining flow patterns is necessary. ..... "

Simard et al. (2000). Describes research on phosphorus and preferential flow. Three experiments were conducted: in Quebec (2) & Devon (1). The studies suggested that coarse- and fine-textured soils may be particularly prone to P transfer by preferential flow through artificial tile drainage and the natural pore network. Studies present provisional findings that form indirect evidence on the presence of preferential flowpaths for P transport.

Stamm et al. 1998. Dye sprinkling experiments were conducted. Worm burrows were found to be the dominant penetration pathway. Infiltration rate along preferential flow paths was 5-10mm/hr. The dye infiltrated 2-5 cm into the general bulk of soil, and penetrated rapidly to 80cm along preferential flowpaths. The authors concluded that in agricultural soils, vertical preferential flow is the normal case and not the exception.

White (1985) reviews numerous papers that indicate that macropores affect the transport of dissolved and suspended matter through soil. He concludes that **'***A general conclusion to be drawn from studies on undisturbed soils is that macropores can greatly decrease the time taken for dissolved and suspended matter applied to the surface to reach subsurface drains or groundwater'***.** He goes on conclude that further research is needed.

Examination of Soil and Subsoil Exposures

I will describe only one recent experience. As part of the FÁS training course 'Site Suitability Assessments for On-site Wastewater Management', a trial hole test was undertaken on Teagasc lands at Johnstown Castle in November 2002. In a trial hole in a gley topsoil and a sandy CLAY subsoil, I measured (in the presence of 72 course participants) one tubular macropore 6 mm in diameter at 0.6 m bgl and several macropores 1-2 mm in diameter. Also, at a point where a drainage pipe was cut through by the mechanical digger, a clear preferential flowpath was present above the pipe with evidence of flow shown by the rusty colour of the soils and subsoil in the vicinity of the macropore contrasting with the surrounding grey subsoil. In a trial pit in fine SAND subsoil on a second site, macropores up to 5 mm in diameter (interpreted as worm burrows) were present in the A and B horizons of the soil and there were several hair line macropores (probably formed by roots from a woodland that had been felled) shown by discolouration, running vertically to the bottom of the pit (>1.2 m).

Implications for Ireland

It is clear from the published literature firstly, that macropores in soils are a widespread phenomenon and secondly that, while flow mechanisms may not be fully understood, bypass flow occurs in many circumstances. Does the same situation arise in Ireland? Views on this must be based largely on judgement and, in particular, applying international research to Ireland. It can be argued that we must not make a judgement until we have definitive proof from research undertaken here. However, this is a difficult research area, requiring significant resources and probably several test sites, and several years of research. In any case, any research undertaken in Ireland will, presumably, build on the research undertaken elsewhere. In the meantime, decision-makers cannot wait until definitive proof is available; it is their responsibility to make decisions based on the best expert judgement available.

- It would be simpler and easier if preferential flowpaths were not an issue in Ireland. Unfortunately the balance of evidence is that they are.
- Even in the absence of detailed research on preferential flow in Ireland, it is highly unlikely that Ireland is completely different to the rest of Europe and North America. However, the role of preferential flowpaths may be less in Ireland as our soils and subsoils are relatively young and our climatic variations are less than many other countries.
- It is likely that macropores are present in most if not all topsoils in Ireland.
- Macropores are also likely to be present in the upper 0.5 m of some subsoils, particularly in those that are clayey or sandy. Macropores may occasionally be present to greater depths, particularly in areas of shallow permeable bedrock.
- A critical question is whether water and pollutants will flow through the macropores and bypass the protection provided by the soils and subsoils. The facts are that bypass flow occurs in macropores in other countries under natural conditions. In my own direct experience on a research project steering group in Britain, the judgement has been made that bypass flow (of herbicides, for instance) through soils is an important issue. Therefore, we must assume that, in certain circumstances at least, it occurs in Ireland.
- What could those circumstances be? This is a question that could be answered more definitively following a more detailed examination of the literature and applying the results to Ireland. I have not undertaken this examination for this article. My initial response would be say that initiation of flow in macropores under most natural conditions will occur more readily in structured soils and in the top of low permeability clayey subsoils and high permeability sandy/gravelly subsoils. However, in areas of very shallow bedrock (<1.0 m), particularly where the bedrock is permeable and/or karstified, bypass flow is likely to occur in certain circumstances (e.g. depending on the microtopography of field surfaces and initial soil moisture content) after heavy rainfall. In circumstances where the hydraulic loading is higher than from rainfall alone, beneath percolation areas for instance, bypass flow is likely to occur in all soil types.
- How significant is this for Ireland? For groundwater it could be highly significant where the thickness of soil and subsoil is shallow (<2 m). In many of these areas, pollutants may penetrate to 1.0 m within hours or days of heavy rainfall, in certain circumstances, thus bypassing the protection provided by the topsoil and the upper part of the subsoil. In areas underlain by thicker subsoil, the lower subsoil will generally not contain macropores and good protection will be provided. For surface water it may be significant where rapid flow through macropores enables pollutants (phosphorus and herbicides, for instance) to enter field drainage pipes and nearby drainage ditches.
- In conclusion, until there is evidence to the contrary, I would recommend decision-makers to assume that bypass flow is likely to occur in Ireland.

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Royal Irish Academy Scientific Statement on Climate Change and Ireland

A number of important research studies have now reported growing concerns regarding the potential impacts of future climate changes at global, national and regional scales. These reflect a consensus among atmospheric scientists that human induced modification of the atmosphere is now likely to provide the main driver for climate changes over the coming decades. Ultimately climate change is a global problem that requires a global solution. The impacts will be determined by a number of factors including the magnitude and rate of climate changes, the political response of the global community and national governments in terms of policies and legislation, and the adaptive capabilities of individuals, industrial, agricultural and ecological systems. Given the great uncertainty associated with each of these factors, many of which are interrelated, future climate scenarios are expressed in terms of degrees of confidence based on observed trends and the predictions of sophisticated computer models. The Irish Committee on Climate Change believes it is appropriate to indicate where confidence does and does not exist in relation to future climate predictions, and also where precautionary measures should be taken, and adaptation to climate change promoted, to ensure that social, economic and environmental activities in Ireland do not suffer undue adverse impacts.

1. Future Climate Scenarios for Ireland

Predicted climate changes for Ireland are dominated by a warming trend. This committee considers that there exists ***a high degree of confidence*** *that Ireland will warm by approximately 0.25°C per decade over the present century. By mid-century typical spring temperatures are likely to be occurring approximately 2 weeks earlier than at present, and the onset of typical winter temperatures is likely to be later by a similar amount. Individually hot summer months are likely to become more frequent. A hot August, such as occurred in 1995, may be experienced in 1 out of 5 years by mid-century.*

This committee considers that there exists a ***medium degree of confidence*** *that precipitation in Ireland will increase widely during the winter months, and decrease extensively during the summer months. Summer reductions in precipitation are, we believe, the principal climatic indicator of concern from an Irish perspective. By mid-century, reductions in summer rainfall of up to 30% are possible, most marked in southern and eastern areas of Ireland. The frequency of very dry summers, such as experienced in 1995, may increase substantially, perhaps approaching 1 in 3 by the 2050s. Summer soil moisture deficits will increase substantially in severity and spatial extent.*

This committee considers there is a ***low degree of confidence*** *at present concerning future changes in wind speed and direction, and in the frequency of gales and extreme storms. Similarly, the long-term behaviour of the North Atlantic Drift is not known with any certainty, though major changes in this current are considered unlikely in the first half of the present century.*

2. Impacts on Sea Level

A sea-level change of 10-70cm can be expected by the 2080s irrespective of any mitigating measures taken in the intervening period. For some locations (soft, low lying exposed coasts) rates of coastal erosion will increase. Extreme high water levels will become more frequent, possibly by a factor of up to tenfold. Wetland and very low-lying coastal areas, including some fish feeding and breeding grounds, will be particularly susceptible to these changes and a focus of pressure will exist at the coastal zone. We believe 'hard' engineering defences against such changes will not be cost effective other than in high-value land in urban areas, or where *transport infrastructure is at risk. Studies are urgently required to quantify this exposure and review planning policies for the coastal zone.*

3. Impacts on Agriculture

Agricultural and forestry changes will accompany climate changes. Many crops will grow more vigorously in a CO_2-enriched atmosphere and generally less fertiliser application will be required in Irish soils. Increases in weed growth and in some pest types will, however, compromise agriculture and forestry productivity. We believe that the temperature changes will generally be more beneficial for Irish agriculture, than the expected precipitation changes. We believe that the viability of some existing crops will be compromised by summer droughts and that though grass production will remain Ireland's main crop, it will be accompanied by greater diversity in agricultural production. Soybean, maize, sunflower and oilseed rape are likely to become increasingly common crops, with new areas for soft fruits also emerging west of the Shannon. We urge the agricultural community to consider the implication of climate change including the need for irrigation during the summer months.

4. Impacts on Water Resources

Greater seasonality in water availability will result from the changes in precipitation projected. Increases in runoff during the winter months will occur widely by mid-century with marked reductions in summer runoff, in excess of 25% in places. This would create problems of water supply where competition for water resources exists. We believe that greater application of the precautionary principle is required in calculating the likely availability of water for domestic, industrial or agricultural use. We recommend that similar principles should be applied for the purposes of effluent and waste-water management where lower summer flow poses a threat to the maintenance of water quality objectives in rivers. Freshwater ecosystems in some parts of the country are likely to suffer from the combined impacts of summer draw-down and increased loading of nutrients (and other pollutants). Such a combination would have an adverse effect on water quality, such as increased eutrophication, unless the appropriate actions are taken. We urge medium term planning strategies such as the National Spatial Strategy, and the Strategic Planning Guidelines for the Greater Dublin Area and the Water Strategy for Northern Ireland to explicitly incorporate climate change perspectives in their considerations.

Conversely, it is likely that higher winter rainfall will increase both the number and magnitude of river flood flows. We urge greater study into the need for improved river flooding defences in critical locations, and mandatory incorporation of potential changes in flood frequency into land use planning and in the requirements of environmental impact assessment.

5. Impacts on Health

Little awareness of potential health impacts of climate change exists in Ireland. Potential changes exist on both positive and negative scales. Further studies are however necessary to establish details in these areas, in particular the likelihood of changes occurring in water-borne diseases and in the incidence of diseases such as malaria, tick-borne encephalitis and Lime disease in a warmer climate. Indirect effects such as increased photochemical air pollution also would have health consequences requiring quantification.

6. Other Areas of Concern

A number of other areas require further research before authoritative statements concerning the impact of climate change can be made. These include the built environment, the construction and transport sectors, sports and recreation, and the insurance industry. The Irish Committee on Climate Change will issue further comments on these sectors when specific impacts on Ireland become clearer. This statement is merely a summary of the current position in selected areas and one that is designed to reinforce the need for careful planning and informed vigilance (a 'no regrets' policy) in many sectors of Irish life.

Acknowledgement: This is reproduced with permission from the Royal Irish Academy. The statement was drawn up by the RIA Irish Committee on Climate Change, which is chaired by Dr. John Sweeney. Further information on the Committee can be obtained on their website: http://www.ria.ie/ICCC/home.html

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EPA-Funded Research Projects
ERTDI Programme 2000 – 2006. Phase 3: Water Framework Directive (WFD)

Four groundwater related research projects have been awarded funding or are the subject of contract negotiations with the EPA under the Phase 3 call for research proposals to meet the priority needs of the Water Framework Directive.

2002-W-DS/7: Development of a Methodology for the Characterisation of Unpolluted Groundwater.

This is a desk study, which is scheduled to run for 12 months commencing November 2002. The contract has been awarded to TMS Environment Ltd. and Environmental Simulations International (ESI) as a collaborative venture.

Research objectives

- Review international groundwater characterisation methodologies with a focus on methodologies proposed by other EU member states.
- Develop a methodology for an approach to characterising groundwater bodies in Ireland. The methodology should consider a number of aspects including the following; groundwater bodies related to aquifer lithology, hydrogeochemistry, rainfall chemistry, hydrogeological parameters (e.g. hydrological throughput), and geographical location (e.g. coastal).
- Test the developed methodology using available monitoring data. Any data gaps in the existing monitoring system should be identified.

Expected results

A final report should be published presenting a review of other European approaches, a recommended approach to groundwater characterisation and results of the initial methodological testing.

2002-W-MS/16: Recharge and Groundwater Vulnerability.

This is a medium scale study, which is scheduled to run for 36 months commencing December 2002. The contract has been awarded to Department of Civil, Structural and Environmental Engineering, Dublin University (TCD). Through its work on groundwater vulnerability mapping, the Geological Survey of Ireland (GSI) has developed expertise on techniques and requirements for areal mapping of recharge indicators. The GSI will participate in the project steering group, provide vulnerability mapping for the experimental sub-catchments, and assist with data analyses and with the assessment of data analysis techniques.

Research Objectives

Overall objective:

- To develop a quantified link between groundwater recharge, and permeability/vulnerability as mapped using Geological Survey of Ireland guidelines.

Milestone objectives:

- Review and evaluate current methods for the estimation of groundwater recharge at the sub-catchment level.
- Review current data availability and identify suitable sub-catchments, which will form the basis of the experimental studies. These would preferably comprise areas where vulnerability mapping and relevant, long-term, monitoring data already exist.
- Examine relationships between information from detailed instrumented sites with sub-catchment scale maps of groundwater vulnerability and aquifer potential.
- Develop a preliminary GIS based assessment tool for the estimation of groundwater recharge (recharge acceptance).

Expected Results

- A review of current methods for the estimation of groundwater recharge in temperate climates.
- A preliminary GIS tool for the assessment of groundwater recharge. The tool would be structured so as to allow scope for the incorporation of other relevant factors not included in this study.
- A database of groundwater acceptance related data.
- Formulation of a quantified linkage between groundwater recharge, and permeability/vulnerability as mapped using Geological Survey of Ireland guidelines. It is

intended that this linkage would be applicable to a selected generic combination of aquifer type and topographic setting (e.g. regionally important fractured aquifers in the central plains).

– A final report examining recharge acceptance on a sub-catchment scale and comparison with catchment characteristics.

2002-W-DS/8: Development of a Methodology for the Characterisation of a Karstic Groundwater Body with particular emphasis on the linkage with associated ecosystems, such as turlough ecosystems.

This is a desk study, which is scheduled to run for 12 months commencing November 2002. The contract has been awarded to Dublin University (TCD) and NUI Galway as a collaborative venture.

Research Objectives

- Develop a risk assessment framework for groundwater dependent habitats in Ireland. Identify and assess the qualitative and quantitative pressures leading to identification of risk of impact of such pressures (e.g. nutrients). High risk areas should require more in depth investigation. A wide range of major pressures should be included, such as abstraction, and chemical status especially nutrients. Designated protected areas should be considered as a priority.
- Examine the response of turlough ecosystems to hydrological inputs using appropriate methodologies to enable potential impacts to be assessed. This should involve hydrogeologists, ecologists and hydrologists.

Expected results

A final report should be published which presents a review of other European approaches and a proposed risk assessment framework developed for groundwater dependent habitats in Ireland.

2002-W-DS/11: An Assessment of the Role of Mathematical Modelling in the implementation of the Water Framework Directive in Ireland.

This is a desk study, which is scheduled to run for 6 months commencing November 2002. The contract has been awarded to Dublin University (TCD).

Research Objectives

The project should take account of all categories of models including: models of: anthropogenic pressures and impacts; diffuse pollution sources from land; hydrology/**hydrogeology**/hydrodynamics; dispersion and mass transfer; water quality; nutrient dynamics; eutrophication processes and aquatic ecosystems. Both inland and tidal waters should be covered. The following tasks are to be undertaken:

- Identify the main categories of mathematical models that have potential to play a role in guiding and implementing the WFD in Ireland (for example based on experience in other comparable countries).
- Outline the current availability of models relevant to the Irish aquatic environment.
- Recommend priorities for model application and development. Concerning the latter, there should be a particular focus on the requirements for deliverables in the early phase of implementation of the Directive (up to 2004).
- The strengths and weaknesses of each category of model should be assessed and presented, for example in relation to data needs for calibration and verification, and taking account of the main categories of hydromorphological conditions in Ireland.
- Test pilot the most applicable models for WFD identified during the assessment.

Expected Results

The project should be completed by preparing a report setting out the results of the assessment. The report should focus in particular on the strengths and weaknesses of each category of model as applied to Irish conditions and make clear recommendations on suitable approaches. The conclusions in the report should focus on how each modelling approach can contribute to meeting specific needs of the Directive with cross reference to the Articles/Annexes in question.

Further information on these research projects may be obtained from Margaret Keegan or Frank Clinton, EPA, Wexford.

Margaret Keegan, EPA

Research on Karst at TCD

Two groundwater related research studies have begun, based in the Geography Department of TCD. They address two previously neglected but significant aspect of karst hydrogeology related to Ireland: the functioning of groundwater systems in the lowland karst of Ireland and the distribution and characteristics of springs (dominantly karstic) in Ireland.

Brief summaries of the proposed investigations are given below.

Conceptualising the hydrogeology of lowland karst in Western Ireland

Researcher: Caoimhe Hickey

The lowland limestones of Ireland are the most important aquifers economically but the least known about. In these areas, the karst landforms are not as obvious as in areas like the Burren because they are often covered with a thin layer of Quaternary deposits. Consequently, little research has been carried out and they are often not protected sufficiently from pollution. The aim of the research is to improve this knowledge and to attempt to conceptualise and provide a model of the workings of lowland karst hydrologeology in Ireland. In fact, few studies of lowland karsts exist anywhere in the world and it is hoped that the model can be applied outside Ireland also.

To do this the focus of the research is on County Roscommon, as a representation of lowland limestones. Roscommon was chosen as an example of lowland karst due to its abundance of unmapped karst features and high dependency on groundwater (which makes up 89% of water usage). No studies have been carried out to date on the karst hydrology of Roscommon and there is very little known about it.

The research is divided into two main areas: deskwork and fieldwork. The deskwork involves producing a detailed spreadsheet/database of Roscommon showing various themes such as drainage density, mean altitude, geology, soil and subsoil type, density, size and behaviour of springs, swallow holes and dolines. From this work, highly karstic areas can be easily identified and any relations between the various themes will be highlighted.

The fieldwork will then focus on these highlighted areas to understand how they work. This will be achieved by:

1) locating and quantifying all karst landforms.
2) A detailed study of the karst springs in different weather conditions and times of the year by installing continuous monitoring recorders of discharge, conductivity, pH and temperature. This will provide invaluable information about the different types of karst aquifers. This information will then be used to characterise lowland karst springs by distribution, size, hydrochemistry and flow regime.
3) Water tracing experiments to trace or tag sinking streams. This information not only proves connections, and helps to delineate catchment boundaries, but also reveals knowledge about the workings of the underground flow routes, such as the rate of flow and responsiveness to rainfall.
4) Geophysical methods for the determination of underground conduits principally using micro-gravity surveying techniques.
5) Study of borehole logs.
6) Speleological investigations.

The office and fieldwork combined will enable the delineation of catchment boundaries for both the springs and surface rivers. From this and the interaction between the two types of water bodies aquifer boundaries will be constructed and a conceptual model of the flow regime for lowland karst areas will be produced.
This information can then be used as a basis for understanding and managing the hydrology of lowland karst environments.

The Hydrogeology of Springs in the Republic of Ireland

Researcher: Honor Chance

In Ireland, an unusually high proportion of rainfall becomes recharge to groundwater, which is becoming an increasingly important water resource, not only for public supply but also for other uses such as bottled mineral water and fish hatcheries. Because of the fissured and karstified nature of the major aquifers in Ireland, much groundwater discharge is from springs. Many of these springs are used extensively for water supply whilst others are of great ecological importance, for example the springs feeding Pollardstown Fen in Kildare and the springs associated with many of the turloughs of western Ireland. Despite their importance, very little work has been undertaken in terms of systematic investigations of springs in Ireland.

It is desirable that a basic understanding be developed of springs in Ireland with respect to their locations, hydrological and hydrochemical behaviour and reasons for their occurrence:

1) As a part of a database of natural resources in Ireland
2) In order to evaluate the significance of springs in Ireland in both water resource and ecological terms.
3) To improve understanding of the functioning of groundwater systems in Ireland.

This study comes at a time when new data, relating to springs and commonly in digitized form, is becoming available. The Geological Survey of Ireland is completing county Groundwater Protection Schemes, while new geological and Quaternary deposit maps are being produced. These environmental databases will be of great value in combining with spring data in a GIS framework. In addition a holistic understanding of surface and groundwater is a requirement of the EU Water Framework Directive, which is currently being implemented.

The project is funded by Embark.

David Drew, Department of Geography, Trinity College Dublin

Karst Seminar Proceedings

The Karst Working Group held a seminar entitled 'Geotechnical and Hydrogeological Aspects of Karst in Ireland' in Tullamore in October. Proceedings of the seminar are available for €25 (plus postage €3) by application to the Groundwater Section, GSI. The following papers are published in the Proceedings:

The Karst Environment and Karst Hydrogeology : An Overview by David Drew, Department of Geography, TCD

The Irish Geological Heritage Programme Karst Theme, and geological conservation issues in engineering projects in Ireland by Matthew Parkes, Geological Survey of Ireland

The Role of Karst in the National Groundwater Protection scheme by Donal Daly, Groundwater Section, Geological Survey of Ireland

Drilling and Construction of Wells in Karst Areas by David Ball, Consulting Hydrogeologist

Remedial Measures Applied to the Engineering Solution of Karst Problems by Michael Creed, Department of Civil Engineering, UCC

Road Construction and the Outflow from a Turlough by Kevin Cullen, White Young and Green Ireland Limited

Case History – Site investigations for roads with potential Karst – Case histories from the N3, N7/N8 and the N9/N10 site investigations by Patrick Casey, Arup Consulting Engineers

Flooding Problems in the Gort-Ardrahan Area of South Galway : Engineering Options and Modelling by Conor McCarthy, Jennings O'Donovan

Donal Daly, Karst Working Group Secretary

Springs on Sugar Loaf????

Micheál MacCartaigh (EPA), a person with a wide knowledge and many interests, passed on the following excerpt from the "Annals of the Kingdom of Ireland"

A stream of strange water burst forth from the side of Sliabh-Cualann[w] , in which were fish and coal-black trouts, which were a great wonder to all.

[w] Slíabh-Cualann.— This was the old name of the Sugar-loaf mountain, near Bray, in the county of Wicklow. The year 866 of the Four Masters corresponds with 867 of the Annals of Ulster, which notice the events of that year briefly as follows:

" A. D. 867. Cellach, mac Cumascaich, Abbas Fovair, juvenis sapiens et ingeniosissimus, periit. Convach, Abbot of Clonmicnois, in nocte Kal. Januarii in Christo dormivit. Daniel Abbot of Glingaloch and Taulachta. Caeven, mac Daly, Abbot of Doimliag, mortuus est. A battle by Hugh, mac Nell, at Killonairi, upon the O'Nells of Bregh, upon Leinster, and a greate army of forreners, wherein fell 900, or more. Flann, mac Conaing, King of all Bregh; Diarmaid, mac Edirsceoil, and many Gentiles, were killed in that battle; Diarmaid being king of Lochgavar. Fachtna, mac Maeilduin, died of a wound gotton in the battle, being heir apparent of the Fochla, that part of Ulster"{so called}."Congal, mac Feai, Abbot of Killdelga, scriba, quievit. Eruptio ignota aque de Monte Cualann cum piscibus atris. Ventus magnus in feria martini. Rechtavra, mac Murcha, abbot of Corca-mor, dormivit"—Cod. Clarend., tom. 49

However, streams bursting forth from the side of either Great or Little Sugar Loaf doesn't make sense hydrogeologically. Both consist of Cambrian quartzites, which have a relatively low permeability and contain little groundwater. Also I am not aware of any springs in that part of Wicklow. Is there another Sliabh Cualann, particularly in a karst area, which this description might apply to?

Donal Daly, Geological Survey of Ireland

IAH (Irish Group) News

The Annual Tullamore Seminar – 'Groundwater - its stakeholders' : 29th & 30th April 2003
Venue: Tullamore Court Hotel

This conference will devote the first day to groundwater issues in Ireland and the USA and a hydrogeology education status report, and the second day to international developing world issues. Many overseas speakers. The big names too...

Malcolm Doak, IAH (Irish Group)

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IAH Technical Discussion Meetings
7th January. **The Hydrogeology of the Curragh Gravel Aquifer** by Kevin Cullen, White Young Green, Ireland. This is the annual joint Geotechnical Society of Ireland/IAH (Irish Group) meeting.

4th March. **The Younger Hydrogeologists Forum**.

The meetings will take place at the GSI Lecture Theatre, Haddington Road, Dublin 4. They start at 18:00hrs, with tea/coffee served at 17:30hrs. For further information, please contact either Donal Daly (01- 6041490) or Kevin Cullen (01 – 294 1717).

CONTRIBUTIONS FOR THE NEXT ISSUE OF THE NEWSLETTER

Contributions for the next issue should arrive before 1st May 2003 to:

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