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THE GSI GROUNDWATER NEWSLETTER

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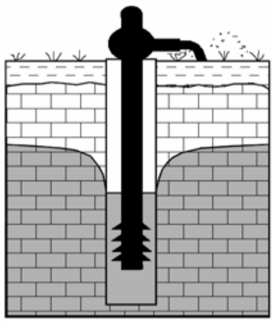

NUACHTÁN SCREAMHUISCE SGÉ

- Taiscéalaíocht
- Forbairt
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- Cáilíocht
- Truaillú
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In This Issue

Groundwater level monitoring has many uses, but few would expect that major **earthquakes** could be detected in our monitoring network in Ireland. The earthquake that caused the devastating **tsunami** in SE Asia on December 26th 2004 caused **abrupt water level fluctuations** in several wells in Ireland (see articles by Peter McConvey (page 14) and Geoff Wright (page 17)). In addition, Geoff Wright reviewed all the water level charts for four wells and found traces of over **100 seismic events** since 1980.

Water is a primary requirement for the well-being of society in every country – the combination of our rainfall and population density means that so far we haven't needed to worry about water availability in Ireland. This is not the situation in many parts of the world. In an interesting article (page 19), Henning Moe outlines the situation regarding **water supply in the West Bank and Gaza Strip**, which rely on groundwater for nearly 95% of their water supplies.

As I drove and walked around the midlands, west and south-west of Ireland on holidays this summer, the **increasing number of new houses in rural areas** was striking. Queries to the GSI emphasise the drive to get **planning permission** for these houses. Thanks to the **EPA Manual (2000)**, the **Groundwater Protection Responses (2001)** and the **FÁS Course on Site Suitability Assessments**, the standard of decision-making is improving. However, every possible argument is being used by some applicants to get permission. A favourite response to sites with poor soakage and a resulting high water table is "sure we will drain the site and that will solve the problem"!! But, will it? Some advice for local authorities on assessing difficult sites is given in the article starting on page 3.

Nitrate in groundwater is another topical issue at present. On page 2, Kirsty Hooker outlines the findings from a study of nitrate leaching from tillage land at the Teagasc Oakpark Research Centre in Carlow. Useful research undertaken by Anna Tooth at **Crag Cave** in Kerry (page 8) illustrates once again the potential role of **preferential flowpaths** in enabling pollutants to pass rapidly through soil and subsoil in shallow rock areas. An innovative use of **Cork's first waterworks**, established in 1768, is described by Úna Leader on page 26.

Donal Daly, Geological Survey of Ireland

Summary of Findings from a Study of Nitrate Leaching from Tillage Land

Nitrate contamination of ground and surface waters has consequences to both human and environmental health. In drinking water, high concentrations of nitrates are linked to methaemoglobinaemia (blue baby syndrome) and several different cancers. Excess nitrates in surface waters can lead to eutrophication, which can result in algal blooms and sometimes reduce light and oxygen enough to result in a toxic environment for fish. In the case of nitrate, eutrophication is mainly a concern in estuarine environments. Along with other chemical and biological parameters, various authorities have set limits for acceptable nitrate concentrations. The limit used in EU legislation is 11.3 mg/l NO_3-N, equivalent to 50 mg/l NO_3. The Nitrates Directive, drawn up in 1991, aims to reduce nitrate pollution and has several requirements with which all EU member states must comply.

This study was partially motivated by the requirements for compliance with the Nitrates Directive, given that there was a lack of Irish data on nitrate losses from tillage land. The aims of this project included quantification of nitrate leaching losses from the two most commonly grown cereal crops in Ireland. Additionally, potential methods of reducing losses from spring barley were assessed, that had been shown to reduce nitrate leaching losses in other studies. Using climate data and measurements of soil tension, the periods when leaching is likely to occur under Irish conditions were determined. The quality of groundwater in a tillage area was examined by monitoring throughout the study period.

Two sites at the Teagasc Oak Park Research Centre in Carlow were used to study nitrate leaching losses. On a clay loam soil at Knockbeg, nitrate losses from spring barley and winter wheat were quantified from systems with both high and low fertiliser inputs. Ceramic suction cups were used to collect soil solution for nitrate analysis throughout two seasons (2002-03 and 2003-04). Losses from spring barley were higher than those from winter wheat in both years. There was no clear relationship between fertiliser input and nitrate losses. High variability in the data was observed, both temporally throughout the season and spatially across the site. In general, nitrate concentrations were highest in the autumn and gradually decreased throughout the winter. The spatial variation, which occurred between plots in the same treatment, may be due to variability in soil water dynamics.

At the second site, the Road Field, losses from spring barley were studied on a sandy loam soil. The use of winter cover crops and reduced cultivation were evaluated as potential methods of reducing leaching losses over one year (2003-04). Again, ceramic suction cups were used to collect soil solution for chemical analysis, but soil samples were also collected for nitrate extraction. The use of a cover crop was found to significantly reduce nitrate leaching losses at this site. No effect of cultivation method on nitrate leaching losses was found on the plots with cover crop grown, although the fallow reduced cultivation plots had higher average nitrate concentrations than the fallow ploughed plots.

Nitrate is reaching the groundwater, and concentrations in the area exceed established limits and show a pattern of increasing over the past couple of decades.

Summary of findings from M.Sc. thesis "A Field Study of Nitrate Leaching from Tillage Land in South East Ireland", these do not necessarily reflect the opinions of Teagasc.

This project was supervised by Catherine Coxon, Trinity College Dublin, Karl Richards, Teagasc Johnstown Castle and Richard Hackett, Teagasc Oak Park and funded by the Teagasc Walsh Fellowship Programme.

Kirsty Hooker, Trinity College Dublin & Teagasc
(currently with O'Neill Ground Water Engineering)

Site Suitability for On-site Wastewater Treatment Systems
The Role of the Water Table

Background

The EPA Manual (2000) requires that 1.2 m unsaturated subsoil should be present beneath the invert of the percolation trench for conventional septic tank systems and 0.6 m for advanced systems (this depth may be increased in the next edition of the Manual). The Groundwater Protection Responses for On-site Systems (DELG/EPA/GSI, 2001) requires greater thicknesses in high risk areas.

There are areas of the country where the water table is within 2.0 m and sometimes within 1.0 m of the ground surface, particularly during and after wet weather. Many consultants and agents undertaking site suitability assessments on behalf of applicants for planning permission for unsewered houses are asserting that sites with a high water table can be made suitable by installing a drainage system to lower the water table. In some situations it appears that consultants and agents are stating this to avoid making the conclusion that a site is unsuitable. Consequently, local authority planning and environmental staff are left with the final decision on the site suitability, even though they are not likely to have visited the site nor undertaken any of the site characterisation. So, the issues arising are:

- ♦ What is the significance of the depth to the water table?
- ♦ Can the installation of a drainage system to lower the water table make a site suitable?
- ♦ What can consultants/agents do?
- ♦ How should local authority staff approach this issue?

Site Suitability – the 2 Critical Questions

In assessing the suitability of a site for the disposal of effluent from an on-site system, the site can be deemed suitable only if the answer is '**yes**' to the two following questions:

1. Will the effluent get away underground without ponding at the surface? (hydraulic issue)

2. Will the effluent be treated adequately before a relevant receptor is reached? (attenuation issue)

The Water Table

How does the depth to the water table or, rather, the thickness of the unsaturated zone, affect these questions in the context of Irish hydrogeological settings?

First of all, **unsaturated bedrock** is of little use in purifying effluent because flow is only via fissures and, in karst areas, in conduits. Therefore, only subsoils play a significant role in attenuating pollutants.

With regard to subsoils, it is the **permeability** and **thickness** that are usually the key factors, and not the unsaturated zone! There is sometimes an over emphasis on the water table as an issue and too little on the permeability of the subsoil. This is illustrated by considering the following four site scenarios:

1) A free draining site, with permeable subsoil (classed as SILT or SAND or GRAVEL (using BS5930 (BSI, 1999)) with 'T'[1] <~30);

2) A poorly draining site, with relatively low permeability subsoil (classed as CLAY or occasionally SILT/CLAY with 'T' >~90);

3) A free draining site but getting marginal, with permeable subsoil (classed as SILT or SILT/CLAY with T in the range 30-50); and

4) A poorly draining site, which might be made suitable (subsoil classed as SILT/CLAY or CLAY, with 'T' values in the range 50-~90.

Scenario 1: Free Draining Sites

By definition, the subsoil is permeable and, if bedrock is close to the surface, it also is probably relatively permeable. The water table will not be

[1] *'T' and 'P' values are a measure of the percolating capacity of soil and subsoil. They represent the average time in minutes for the water level in a percolation test hole to drop 25mm. For 'P' tests, the bottom of the test hole is 400mm below the ground surface, whereas 'T' tests are carried out at greater depths – 400mm below the invert of distribution pipes.*

close (<2.0 m) to the surface as water can move away easily underground thereby maintaining a low water table. The main exception is low lying areas on flood plains, where people usually avoid, or should avoid, building houses. Therefore, a thin unsaturated zone is not usually a limiting factor in site suitability assessment in this scenario.

Contaminant migration (Question 1)
As the subsoil is relatively permeable SILT or SAND or GRAVEL, the effluent will readily move vertically through the subsoil until the water table is reached; no ponding will arise provided the percolation area is installed properly. There is one possible exception – in shallow rock areas where the bedrock has a low permeability, thereby preventing the effluent from getting away.

Conclusion: the key factor is the permeability of the subsoil and, in certain situations, the bedrock. The depth to the water table is **not** a primary factor.

Contaminant attenuation (Question 2)
As the subsoil is permeable enough to allow migration of effluent downwards beneath the percolation area, the **key factor is the thickness of the subsoil above bedrock**. While the unsaturated zone helps to attenuate pollutants as they move downwards to the water table, it is not the key factor. Without a sufficient thickness of subsoil, there is a danger that pollutants, particularly microbial pathogens, will get into groundwater in the bedrock.

Conclusion: In this scenario, the key factors determining the treatment of effluent are: a) the presence of permeable, free draining subsoils; and b) the depth of subsoil above bedrock. The depth to the water table reflects the permeability of the geological materials and topography, and is **not** a primary factor.

Site suitability
Sites in this scenario are usually **suitable**, provided the depth to rock (or subsoil thickness) requirements are met. The main issue is achieving sufficient attenuation; there is seldom a hydraulic issue.

Scenario 2: Poorly Draining Sites

Sites in these areas will be underlain by relatively low permeability subsoil, classed as CLAY using BS5930 or occasionally SILT/CLAY, with 'T' values >~90. Usually, a gley soil will be present, there will be a high density of streams and drainage ditches, and rushes will often be present. The trial hole will invariably indicate a high water table, with water in the trial hole and/or the presence of mottling. However, the high water table reflects the permeability of the subsoil! In wet weather, water moving into the subsoil cannot get away underground readily, the subsoil therefore becomes saturated and is likely to remain like this for several months. Therefore, on a clayey subsoil ridge, such as a drumlin or moraine, a shallow piezometer in winter may show the 'water table' at 0.5 m bgl or even less for short periods, whereas a piezometer in the underlying bedock will show the water table many metres deeper during the same period.

The shallow 'water table' in the subsoil should be seen as reflecting a low permeability subsoil; the low permeability does not allow percolating rainfall to get away readily through the subsoil. The low permeability is caused by the clay content of the subsoil. Therefore, the water table in the subsoil is **not** a primary factor. In addition, the 'water table' is not the receptor at risk from the effluent, and in this sense should not be regarded as the 'true' water table.

Contaminant migration (Question 1)
Rainfall is unable to get away underground readily in this scenario. Consequently, effluent, which presents a hydraulic loading in addition to and at least as high as effective rainfall, will not migrate away and so ponding is inevitable.

Conclusion: Groundwater is not at significant risk as the permeability of the subsoil is too low and effluent cannot get through it. However, ponding will occur, particularly in wet weather, and surface water is at risk.

Contaminant attenuation (Question 2)
As a significant proportion of the effluent cannot move into the subsoil, effluent with high concentrations of contaminants will pond at the surface. Groundwater is well protected by the low permeability subsoil, even though that the 'water table' may be less than a metre bgl. This illustrates the danger of considering the water table in a simplistic way. In particular, it is worthwhile to distinguish between lower permeability and higher permeability situations in visualising its role, and by asking the question "what groundwater is the target/receptor?"

Conclusion: The subsoil permeability is the primary factor determining site suitability; the water table reflects the subsoil permeability.

Will installing drains in the subsoil near the proposed percolation area make the site suitable?

Drains, provided they are spaced sufficiently close by, will lower the water table and will increase the volume of unsaturated subsoil beneath the percolation area. However, they will not change the permeability. Therefore, the unsaturated zone created beneath the percolation area by the drains will fill up, and the effluent is likely to pond, particularly in wet weather. Consequently, drains should not be proposed as a solution. Once again, this illustrates the need to focus on the subsoil permeability rather than the water table.

The argument is sometimes made that advanced systems and raised percolation areas are a solution in this scenario. This is not correct: while they reduce the pollutant loading and help in dealing with Question 2, they do not decrease the hydraulic loading, which is the main difficulty in these areas.

Will removal of the clayey subsoil and backfilling with more permeable subsoil make the site suitable?

One potential solution in areas where the subsoil is <2-3 m thick is to remove the subsoil down to bedrock and backfill with suitable subsoil ('T' values preferably in range 10-30) – this is referred to as 'site improvement works' in the EPA Manual. Can this work? It will, from the point of view of contaminant treatment (Question 2), provided the subsoil requirements in the EPA Manual and the Groundwater Protection Responses are followed, but the hydraulic issue remains the principal one in this situation.

Two questions arise:

1. Could the bedrock provide a suitable pathway for effluent away from a site?
2. What investigation is needed to check the bedrock permeability and pathway?

Neither of these is dealt with explicitly in the EPA Manual or the Groundwater Protection Responses.

Provided the permeability (and transmissivity) is sufficiently high, both beneath the percolation area and down-gradient, the effluent will migrate away satisfactorily. The permeability is likely to be high enough in bedrock where the aquifer classification is Regionally Important (**R**) and Locally Important, where the bedrock is moderately productive (**Lm**). These underlie ~30% of the country. However, care needs to be taken in lowlying areas with a high winter water table as removal of the clayey subsoil, which may be confining the aquifer, may result in an artesian spring at the site!

In the remaining Locally Important aquifers (**Ll**), and particularly in the Poor (**P**) aquifers, it cannot be assumed that bedrock will always be sufficiently permeable. Therefore a site investigation involving the drilling of shallow boreholes, testing of the permeability and monitoring of the water table in winter would be required. At least three boreholes are recommended: two in the vicinity of the percolation area and one further down-gradient. In my view, this investigation would need to be supervised by either a hydrogeologist or an engineer with geotechnical expertise. As experience with this scenario improves, it may be possible in the future to relax these recommendations in **Ll** aquifers.

Site Suitability

Sites in this scenario where the bedrock is overlain by thick (>3 m) subsoil are **unsuitable** for discharge to groundwater (the effluent will **not** discharge to groundwater sufficiently!), and engineering measures or the use of advanced systems are not a solution.

On sites overlying **R** and **Lm** aquifers, where the clayey subsoil can be replaced by suitable subsoil, the existing tests (desk study, visual assessment and trial hole test) may be sufficient to assess site suitability. However, on **P** and **Ll** aquifers, a hydrogeological investigation should be undertaken in addition to the existing tests. On many sites on Poor (**P**) aquifers in particular, difficulties are likely to arise in wet weather.

Recommendation to Local Authority Staff

Sites in this hydrogeological setting will seldom be suitable, unless discharge to surface water is an option. If a planning application is made with a proposal to discharge to groundwater, I suggest that consideration of the application by Local Authority staff should only occur where:

- the drainage system is installed in advance;
- winter water levels have been measured in trial holes or piezometers;

- good scientific evidence is provided that the effluent will move away underground without ponding.

Furthermore, I would recommend that before granting permission, the site is visited by local authority staff during a wet period.

For sites where it is proposed to replace the existing subsoil down to bedrock, I recommend that they should be approved only after a hydrogeological investigation has been undertaken and evidence is provided that the effluent will be able to move away underground satisfactorily.

Scenario 3: Free Draining Sites, but Close to Permeability Limit

In these areas, sites are free draining but getting marginal, with permeable subsoil (classed as SILT or SILT/CLAY with 'T' in the range 30-50). In most areas, these sites are suitable for both conventional septic tank systems and advanced systems.

In general, the text for Scenario 1 applies here. However, there is one hydrogeological setting where the general EPA Manual requirements regarding suitable subsoil and 'T' value are met, but ponding may occur for short periods in exceptionally wet weather. In this setting, slope and landscape position determine site suitability. The following three paragraphs apply to this particular scenario only.

This situation arises in certain **flat areas** underlain by relatively low permeability bedrock – the Calp limestone for instance – and by tills that are permeable enough to be suitable but close to the suitability boundary; areas like this are present in the east midlands in particular – east Offaly and west Kildare, for instance. Groundwater gradients are, inevitably as the area is flat, low. Often, the 'T' value, while high, will be low enough that it does not provide a reason for failing the site. Yet there are periods in winter, particularly during exceptionally wet weather, when the water level in the ground rises to within a few tens of centimetres of the ground level. Inevitably, an on-site system cannot function properly during these periods, as there is no where for the effluent to go and so it inundates the percolation area and ponds at the surface. This occurs because the general permeability of the subsoils and/or bedrock in the area is too low, given the flat terrain and associated low hydraulic gradient, to enable all the available recharge to get away underground, consequently the water table rises close to ground level. Usually these areas have many open shallow drainage channels (dikes, sheughs), which are dry for most of the year. It may be possible to detect the occasional saturation of the subsoil by the presence of mottling.

A site with the same geology, hydrogeology and relatively high but adequate 'T' value is unlikely to have such problems in wet weather <u>if the site is on a slope.</u> Here the gradient of the water table is sufficient to enable the recharge to move away and so the water table, although it will rise, does not reach the surface. **This illustrates the importance of the visual assessment and trial hole test, and of not just depending on the 'T' value**.

Conclusion: In this hydrogeological setting, the subsoil permeability is sufficient for percolation, but the low hydraulic gradient causes a high water table on occasions.

Site Suitability

Site works and raised percolation areas can overcome the occasional high water table in most situations. It would usually be necessary to deepen the main outlet drain for the area; installing drains in the vicinity of the percolation area alone may not sufficient. In addition, raising the percolation pipes will reduce the likelihood of problems. (Keep in mind that drains should not be within 3 m of the percolation area.)

Scenario 4: Poorly Draining Sites but Close to Permeability Limit

In these areas, sites are poorly draining, but might be made suitable (subsoil classed as SILT/CLAY or CLAY, with 'T' values in the range 50-~90. Conventional septic tank systems discharging to groundwater are not allowed in these areas, whereas advanced systems are allowed provided the 'P' value is between 1-50.

Contaminant migration (Question 1)

While the subsoil has a relatively low permeability, when taken together with the topsoil, effluent from beneath the percolation area is likely to be able to move away satisfactorily (mostly horizontally in the topsoil, but partly in the subsoil), provided the site isn't too flat. In flat areas, drainage may succeed in lowering the water table provided that the main drain in the area can be deepened.

Conclusion: The key factors are the permeability of the subsoil and the topography or landscape position. A high water table may be present in wet weather in relatively flat or lowlying areas. Lowering of the water table by drains may be a solution.

Contaminant attenuation (Question 2)
As the soil and subsoil are permeable enough to allow migration of the effluent downwards beneath the percolation area and sideways away from the site, the **key factor is the thickness of the subsoil above bedrock**. However, this is usually not a serious limiting factor, as advanced systems and perhaps raised percolation areas can be used.

Conclusion: In this scenario, the key factors determining the treatment of effluent are a) the presence of permeable soil and subsoil capable of allowing some effluent to move away, and b) the depth of subsoil above bedrock.

Will installation of drains in the subsoil in the vicinity of the proposed percolation area make the site suitable?

The answer is 'sometimes'. On sloping sites, the permeability and hydraulic gradient may be sufficient to enable the effluent to get away satisfactorily, although care needs to be taken that it does not re-emerge as a seep further downslope. In these areas drains may be a solution where the water table is high on occasions. On flat sites, the water table will often be high in winter and drains are unlikely to lower the water table sufficiently.

Site suitability
Sites in this scenario may be either **suitable** or **unsuitable**, depending largely on the slope and the permeability of the soil and subsoil. Installation of drains may work in some circumstances, particularly on sloping sites.

Recommendation to Local Authority Staff
Sites in this hydrogeological setting may or may not be suitable for discharge to groundwater. If an applicant is proposing to drain a site to lower the water table, I would recommend the following:

- ♦ the drainage system is installed in advance;
- ♦ winter water levels are measured in trial holes or piezometers;
- ♦ the site is visited by local authority staff during a wet period prior to granting permission.

Summary & Recommendations

1) In conceptualizing the factors determining site suitability, the key primary factors are: a) subsoil permeability; b) depth of subsoil over bedrock; and in certain circumstances c) the topography or landscape position. These determine secondary factors such as the hydraulic gradient, the depth to the water table, attenuation capacity and the ability for effluent to move away underground.

2) Installation of drains as a solution to high water tables will not work in many circumstances, particularly where the subsoil has a high clay content.

3) On poorly permeable clayey sites, with a consequent high water table, provision of comprehensive evidence that installation of drains will enable effluent to move away underground, without ponding in wet weather, should be provided by consultants or agents before local authorities consider granting planning permission.

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Donal Daly, Geological Survey of Ireland

Karst Drip Water Studies in a Till-covered Cave System: Implications for Groundwater Vulnerability

Introduction

The study was performed at Crag Cave, Castleisland, Kerry, in southwest Ireland. The site comprises a shallow Lower Carboniferous limestone cave system (maximum depth ca. 20 m) (Figure 1). The near surface cave site was selected to minimise chemical complexity arising due to mixing of aquifer waters. The cave system is overlain by siliciclastic, clay-rich glacial till of 1 to >2 m thick that is thought to be of dual porosity comprising low permeability micropores along with a well-developed fracture network.

Fieldwork was performed over 20 days in August 1997 and 8 days in January 1998 and included daily monitoring of rainfall volume, till saturation, karst water drip rate and karst water chemistry. A total of 14 speleothem-forming karst drip water sites were sampled at subsurface depths ranging between 10 and 20 m below ground level, and at lateral distances of between approximately 5 and 110 m apart. The sites were selected to include a variety of flow regimes and included stalactite, soda straw and drapery apertures.

Effects of Rainfall on Karst Water Drip Rate

Temporal and spatial variations in karst water discharge were observed in response to rainfall. Drip rates at karst water sites were initially high during monitoring in August 1997 due to antecedent rainfall conditions. Subsequent rainfall events generated preferential flow through till and limestone fissure networks, causing drip rate variations at sites in receipt of a significant fracture flow component. Increases in till moisture content were observed but with a time lag of days, indicating that influx of soil matrix water to the aquifer was not responsible for changes in subsurface discharge rates.

Drip water site responses can be classified into four types (see figure 2):

1. Rapid response without time lag was seen at flashy, fast-flowing sites B, F and J where a fracture flow component, passing through well-connected apertures, dominated. Large peaks in discharge occurred with the maximum rainfall of 11.08.97, followed by a decrease, with storm water from subsequent smaller rainfall events then preventing any further reduction in flow rate.

2. Rapid response with time lag was seen at slower flow sites A, D, E and I. High initial antecedent drip rates remained high for a number of days followed by a gentle decrease. The maximum rainfall event stopped this trend, bringing about constant discharge after a 24 hour time lag, with subsequent rainfall events again stopping trends of gentle discharge decrease and maintaining constant flow for 1 – 3 days, after a similar time lag period.

3. Intermittent response was seen at sites C, G and H. Site G was subject to occasional flashy discharge whilst sites C and H exhibited typically lower flow rates. Discharge at site G only increased with the maximum rainfall event, indicating that the flow route to the site is through poorly connected fractures with high flow only being routed there once a particular threshold in storm flow input had been exceeded. In contrast, the response seen at sites C and H was of a decrease in discharge after maximum rainfall, indicating that the local aquifer pressure head had exceeded a threshold at which flow became diverted away from these sites along higher capacity routes.

4. No response was seen at slow seepage flow sites K, R, X and Z, all of which exhibited minimal variations in drip rate with no relationship to rainfall, being fed by long residence time aquifer reservoir waters.

Similar hydrogeological behaviours were observed in January 1998 when high antecedent rainfall conditions were followed by dry weather during monitoring with most sites showing a progressive decrease in drip rate over time, with the exception of underflow sites and H that showed a rising trend.

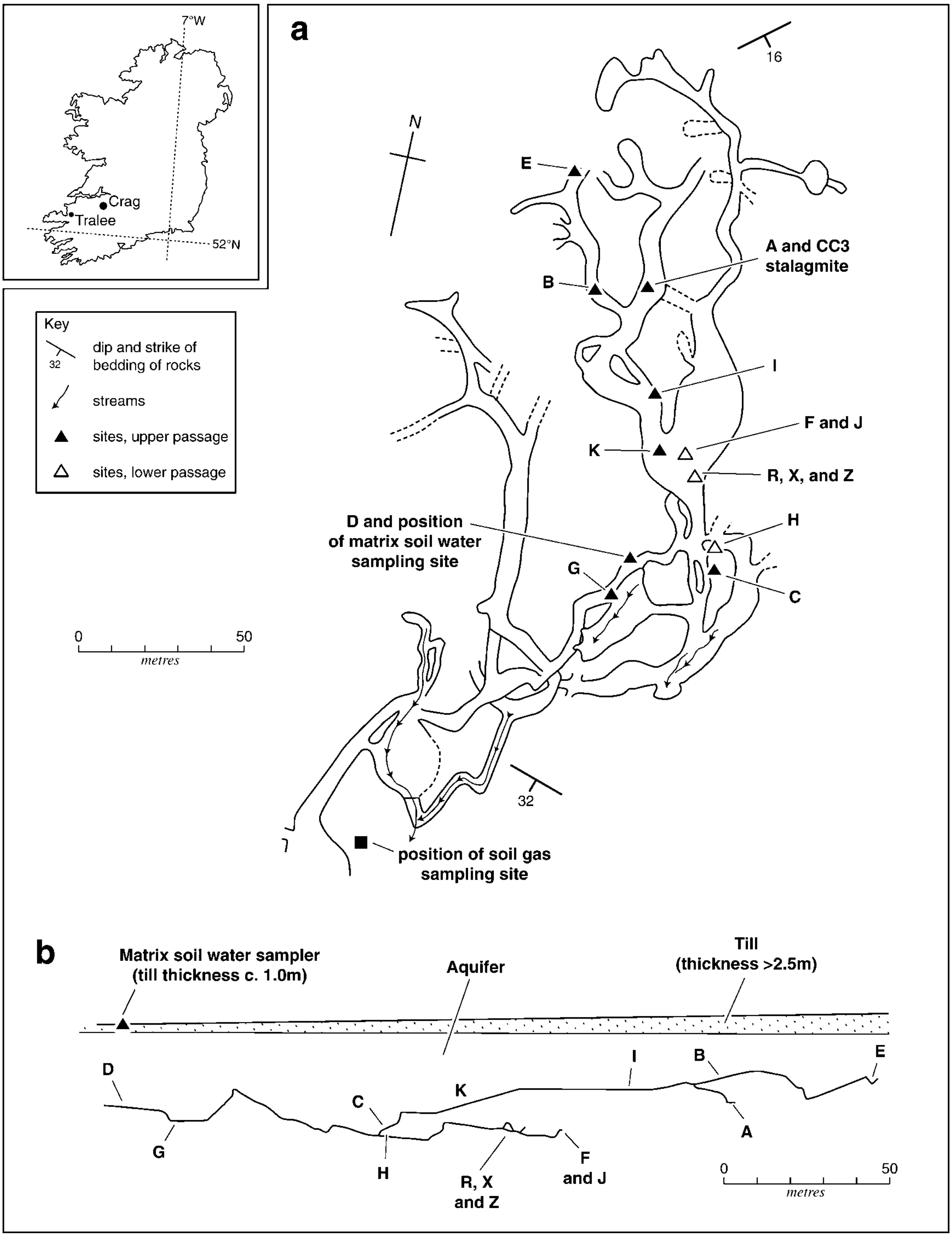


Figure 1. Crag Cave site map with a) plan view (modified from Gunn, 1983) and b) cross-section diagrams. The cross-section shows the location of surveyed floors of cave passageways that are typically 2 to 3 m in height.

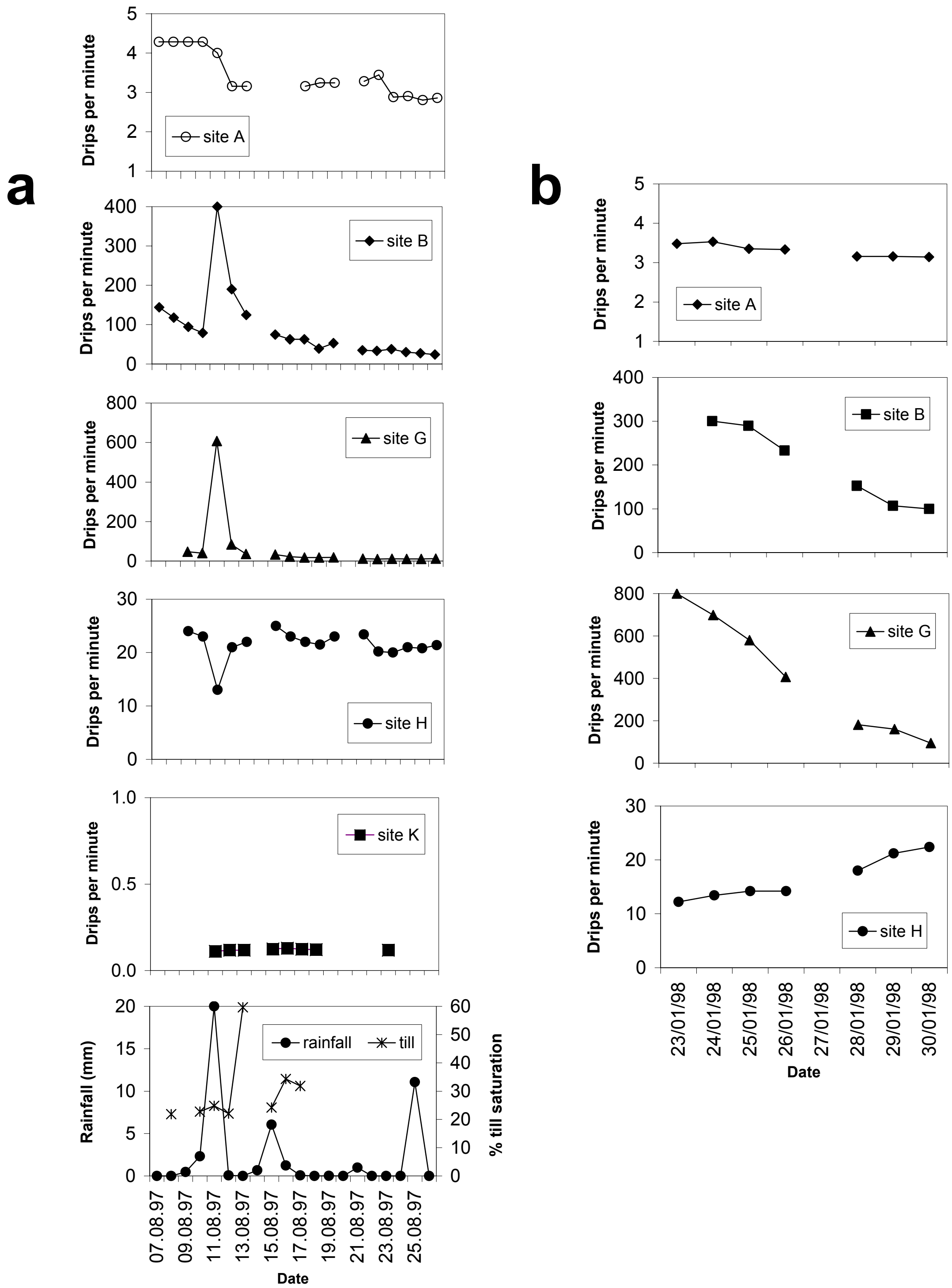


Figure 2. Temporal variation in (a) karst water drip rate, rainfall volumes and till saturation in August 1997, and b) karst water drip rate in January 1998. Percentage till saturation figures are averages of 10, 20 and 30cm depth measurements (the till was waterlogged below ca. 40cm). No discharge data are available for site K in January 1998.

Effects of Varying Drip Rate on Karst Water Geochemistry

The variations in chemistry caused by changes in drip rate were determined largely by the relative dominance of storm water to aquifer storage water feeding each drip site. Four trends in hydrogeochemical behaviour were observed with sites generally exhibiting similar patterns in both August 1997 and in January 1998 (see figure 3):

1. Dilution. Decreases in levels of SO_4^{2-}, which is not involved in carbonate system processes, accompanied by decreases in Ca^{2+} and trace element concentrations indicate the occurrence of dilution during increased discharge. Sites B, F and J were all subject to dilution at times of high flow indicating influx of storm water along fracture flow routes. However, decreases in SO_4^{2-} concentrations were at a maximum of 50%, suggesting that there was still a large component of seepage flow from aquifer storage in the flow.

2. Prior calcite precipitation (PCP). PCP can occur during slow flow via the degassing of CO_2 from carbonate solutions into aquifer air pockets, driving precipitation of relatively pure calcite along the flow route prior to the point of issue in the cave. This process therefore depletes the water of Ca^{2+} and brings about relative enrichment in Mg^{2+} and Sr^{2+} and commensurately higher Mg/Ca and Sr/Ca ratios. PCP was observed at sites K, R, X and Z where changes in ion concentrations and Mg/Ca and Sr/Ca ratios continually occurred in the absence of variations in discharge. This chemical behaviour confirms a seepage flow origin for the sites from long residence time aquifer storage reservoirs, and an absence of a storm flow component.

3. Source change. Changes in the source of the aquifer storage feeding waters were responsible for variations in elemental chemistry with discharge at sites where dilution or PCP did not occur. At sites A, D and I rainfall induced piston flow through the karst system that entrained storage waters from secondary feeding reservoirs, leading to changes in major and trace element concentrations and ratios at higher drip rates. This indicates that the sites were fed by longer residence time seepage flow waters rather than surface water influx. However, behaviour at site I changed to a dilution trend in January 1998, indicating that storm water input became important when the aquifer system contained a greater overall volume of water in the winter.

4. Stable chemistry. At underflow sites C and H, ion concentrations and Mg/Ca and Sr/Ca ratios remained constant despite changes in discharge. This indicates that the sites were fed from storage reservoirs without any storm water input or source change during rainfall events, with drip rate changing purely due to less flow being received.

5. Complex behaviours. A combination of hydrogeochemical behaviours was seen at sites G and E. When the sites were subject to a low flow regime, Ca^{2+} increased with increasing drip rate and Mg/Ca and Sr/Ca decreased, indicating PCP occurring at times of lowest flow and ceasing at slightly elevated drip rates, once the flow threshold at which PCP can occur had been exceeded. When the sites were subject to higher flow regimes, site E drip water geochemistry was controlled by dilution with storm water input causing a decrease in concentrations, whilst the variations in site G geochemistry were a result of source change. However, as with site I, site G drip water became subject to dilution effects in January 1998 under conditions of greater aquifer water volume.

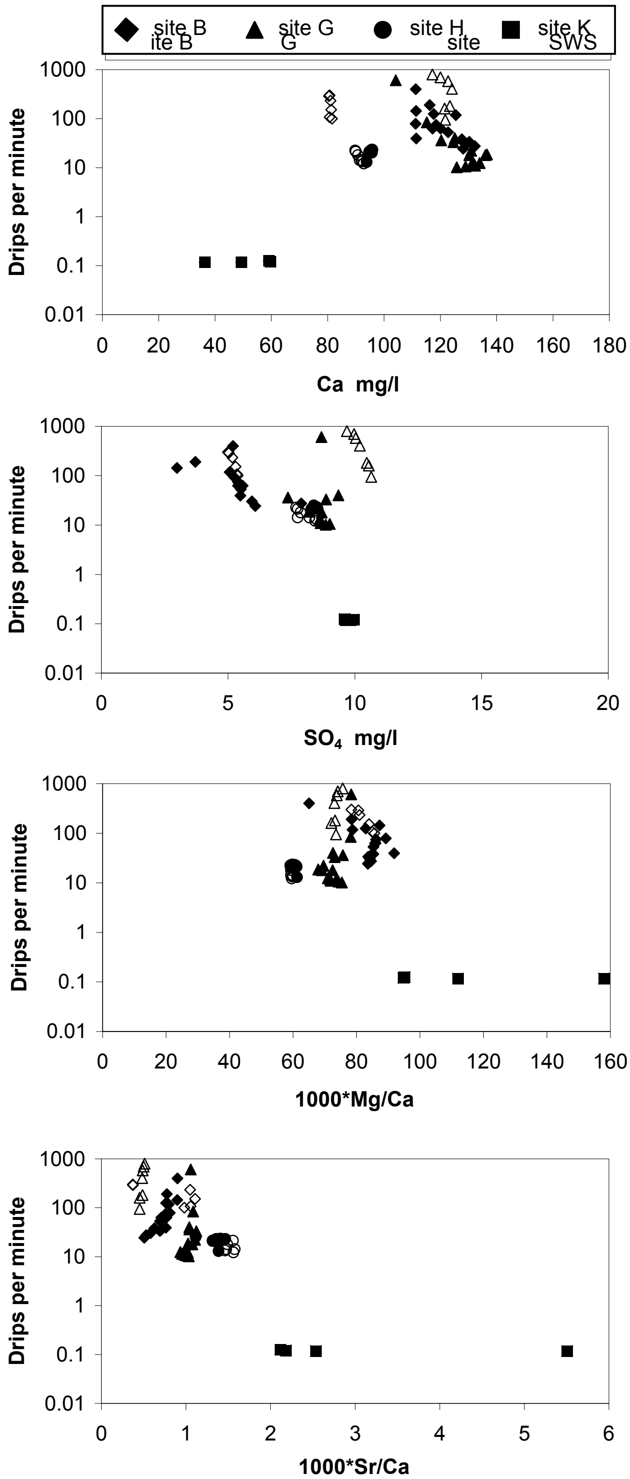


Figure 3. Variation in karst water Ca^{2+} and SO_4^{2-} concentrations and Mg/Ca and Sr/Ca ratios with drip rate in August 1997 (filled symbols) and January 1998 (open symbols).

Implications for Limestone Groundwater Vulnerability

This study illustrates that groundwater may be vulnerable to pollution even where it is overlain by a 1 to >2 m thick clay layer of low permeability. Secondary porosity fracture networks are highly efficient at delivering storm waters to the subsurface aquifer, meaning that any readily soluble pollutants at the ground surface or lining till fracture walls will enter the aquifer. Limestone aquifers are particularly vulnerable to pollution by storm waters since they are frequently of high secondary porosity. For example, a storm water component was detected at depths of 10 to 20 m below the ground surface less than 24 hours after rainfall events. Widespread lateral dispersal of incoming flow is also commonplace, often along well-connected poorly known, unmapped fracture systems, meaning that there is the potential to transport contaminants over large distances.

Storm water inflow will also feed into long residence aquifer storage reservoirs where pollutants may gradually build up over time. This study shows that changes in discharge rates at individual drip water sites are frequently accompanied by a source change of feeding aquifer storage waters. This illustrates that contaminants within storage waters may be further mixed throughout the aquifer even in shallow cave systems.

Groundwater will be most at risk in areas where the unsaturated zone is shallow and the water table is close to the surface, often coinciding with valley settings. Rural villages may be particular areas of concern in locations where there is an absence of mains sewerage or gas provision and a high density of domestic oil tanks and septic tanks. Such locations may also support a number of private water supplies that may be at risk. Diffuse pollution from pesticides and fertilisers, in particular from nitrate, may also be an issue in agricultural areas.

Conclusions

Fracture systems in clay-rich till deposits can be very efficient at transporting storm waters to depth in subsurface limestone aquifers and have the potential to transport readily soluble pollutants. Once in the aquifer, pollutants may become widely dispersed via both fracture and seepage flow pathways. This heightened vulnerability should be borne in mind during the planning process when development is being considered.

Limestone aquifers in Ireland may be particularly vulnerable due to the action of glacial and periglacial processes that have produced contraction cracking in till deposits (in addition to macropores systems developed by general soil processes). The influx of contaminants via rapid flow through till zones to aquifers may lead to slow build up of pollutants with aquifer storage reservoirs that may go unnoticed for some time. The potential therefore exists for the pollution of private and public water supply sources and costly remediation.

Acknowledgements

This study was performed with kind permission of the site owner, Mrs. Geaney and with funding from a Keele University studentship and support from NERC grant GR3/10801 awarded to I. J. Fairchild.

Reference

Gunn, J., 1983. Crag Cave '83 extension. Caves and Caving, 22, 2-3.

Further details of this study along with hydrogeochemical models can be found in:

Tooth and Fairchild, 2003. Soil and karst aquifer hydrological controls on the geochemical evolution of speleothem-forming drip waters, Crag Cave, southwest Ireland. Journal of Hydrology, 273, 51-68

Anna F. Tooth, Principal Officer (Groundwater Protection), Strategic Environmental Planning, The Environment Agency - Southern Region, England.

Northern Ireland Groundwater Monitoring Detects Tsunami Earthquake

Continuous monitoring of groundwater levels is currently undertaken at two sites within Northern Ireland. The sites form part of the United Kingdom National Groundwater Level Archive.

One site (Dunmurry) is located in the greater Belfast area and monitors water levels in the Permo-Triassic Sherwood Sandstone, the most significant aquifer resource within Northern Ireland. The sandstone operates as a dual porosity system with both fracture and intergranular flow. The other site (Killyglen) is located along the coast near Larne, approximately 25 km northeast of Belfast. This borehole is constructed into the Cretaceous Ulster White Limestone Formation (Chalk). This aquifer has negligible intergranular porosity with fracture flow dominant and karstic conditions developed in places.

The water level in the boreholes is measured using a float connected to two recording systems. A digital data logger collects measurements at 15-minute intervals. In addition a chart recorder connected to the float provides a continuous record of water levels. The monitoring stations are maintained by the Rivers Agency and managed by the Water Management Unit of Environment and Heritage Service.

Examination of the chart from the Killyglen borehole identified a short-lived disturbance where the water level rose and fell over a range of 26 cm (Figures 1 and 2). The recording of this event on the chart occurs in the early hours of Boxing (St Stephens) Day 2004.

The initial earthquake in the Indian Ocean, which generated the terribly destructive Tsunami occurred at 00:58 GMT on 26th December 2004. The earthquake occurred at a convergence zone between the Indian and Asian tectonic plates and registered a magnitude of 9 on the Richter scale.

The chart recorder for the Dunmurry site had failed prior to this date. However it is interesting to note that, from examination of past records, such responses to major earthquakes e.g. Izmit, Turkey on 17th August 1999, were not recorded at this site but were observed at the Killyglen site (Figures 3 and 4).

The disturbance noted in the monitoring at Killyglen is believed to be a response to the dissipation of the earthquakes energy through the earth’s crust temporarily altering the dynamic strain. The lack of response at the Dunmurry site could potentially be explained by the much higher storage within the sandstone rock which dampens out the response in water levels. In addition the majority of the sandstone aquifer is at most, only semi-confined by overlying glacial deposits. The Killyglen borehole is located on the margin of an extensive area of low storage chalk which ,for the most part, is confined by overlying Palaeogene (mainly basalt) strata.

The distance between the monitoring site and the epicentre of the earthquake is approximately 10500 km. Chart records for the Killyglen site have recorded a number of major earthquakes and aftershocks over the past decade. This phenomenon, along with surges in stream flow closer to epicentres has been reported elsewhere in the world for other earthquakes and had been previously noted in Northern Ireland by Peter Bennett.

Peter McConvey, Geological Survey of Northern Ireland and Colin Gibney, Water Management Unit, EHS

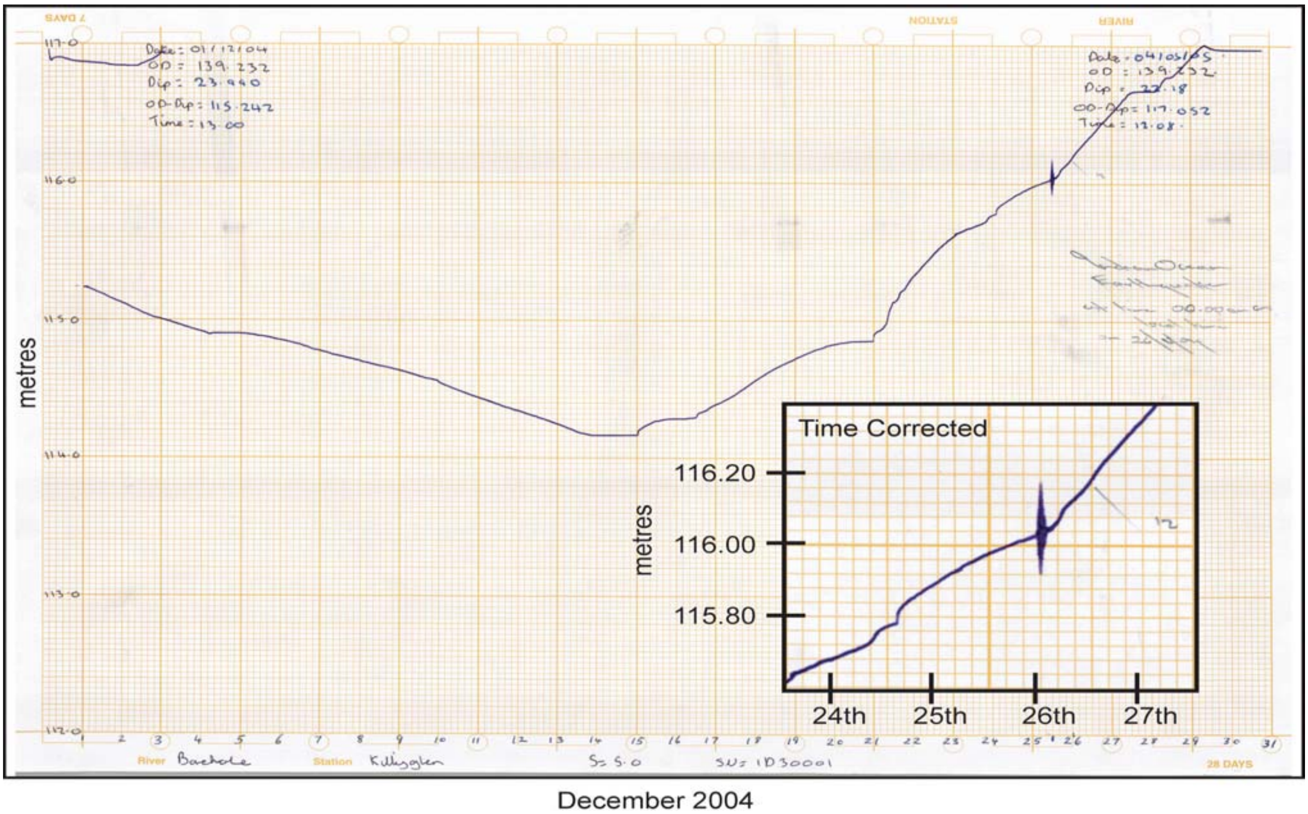


Figure 1. Killyglen Observation Borehole 2004

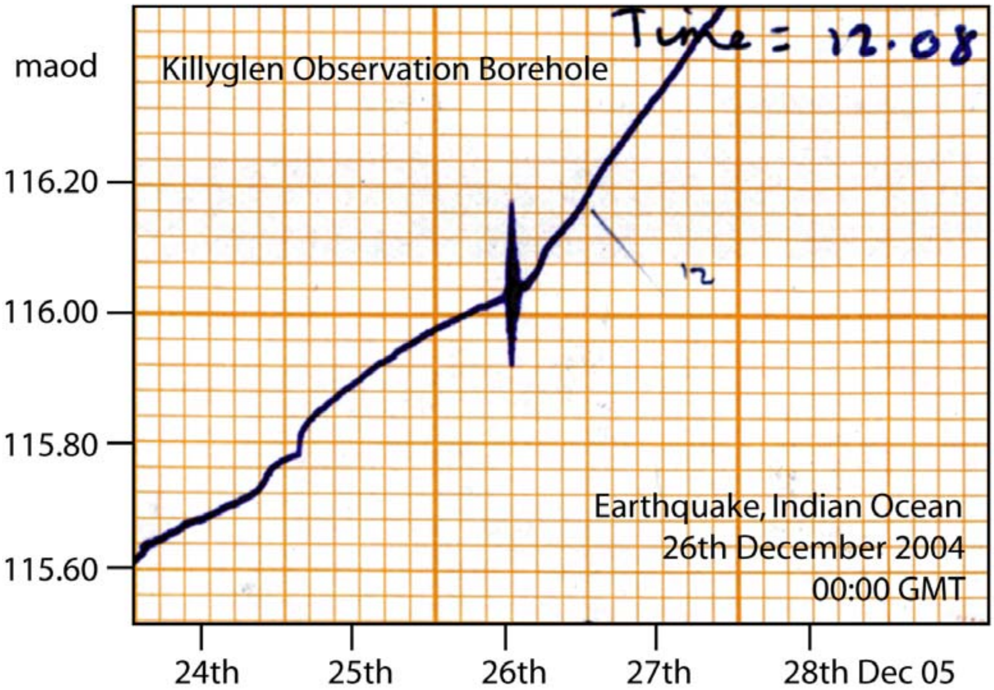


Figure 2. Killyglen Observation Borehole 2004

(These charts can be viewed in colour on the GSI website www.gsi.ie)

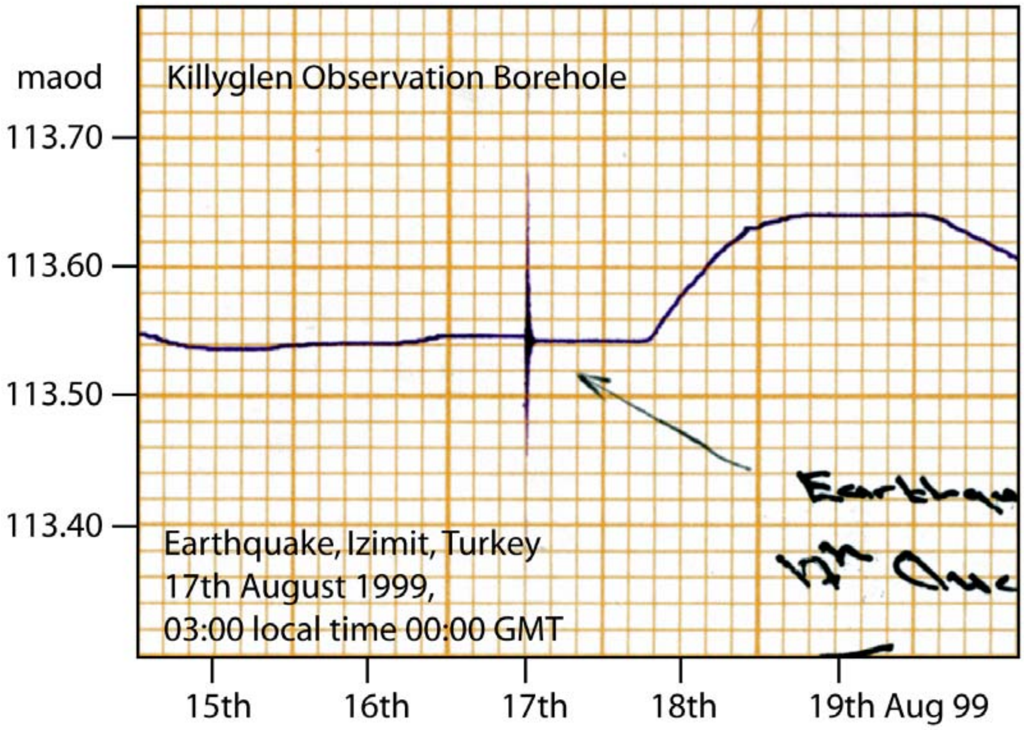


Figure 3. *Killyglen Observation Borehole 1999*

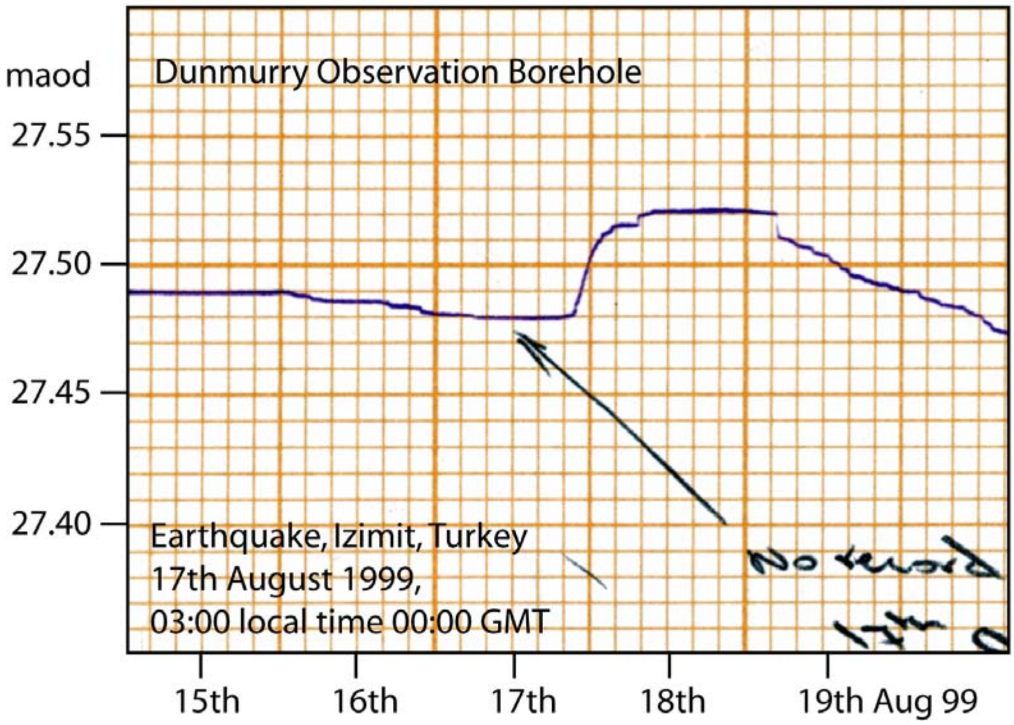


Figure 4. Dunmurry Observation Borehole 1999

(These charts can be viewed in colour on the GSI website www.gsi.ie)

Earthquakes and Groundwater Level Records in Ireland

As reported in GSI News, Issue No. 2 (Winter 2005, available on the GSI website at www.gsi.ie), three GSI groundwater level monitoring wells (operated by OPW) in Co. Kilkenny showed significant fluctuations of water levels due to the 26 December 2004 earthquake off Sumatra.

The three wells have been monitored (using Ott R16 recorders) since the early 1980s. The fluctuations of water level are recorded by a pen on a chart on a clockwork-driven rotating drum. The recording ratio (movement of pen:change in water level) is normally 1:10 or 1:20. The three wells penetrate different aquifers:

- KNY 18/92 (2315SWW233): 20 m deep, depth to bedrock 18.5 m, screened in Quaternary gravel.
- KNY 27/58 (2313NEW118): 62.1 m deep in Dolomitic Limestone, depth to bedrock 15.8 m.
- KNY 31/72 (2313SEW061): 40.2 m deep in Kiltorcan Sandstone, depth to bedrock 6.1 m.

The three wells simultaneously registered abrupt water level fluctuations in the early hours of 26 December 2004. The maximum fluctuations ranged from about 50 mm in 18/92, to 240 mm in 25/78, to 280 mm in 31/72. The differences probably relate to the differing storage coefficients in the three aquifers. Similar effects were seen in wells monitored by GSNI/EHS in Northern Ireland.

We have also found similar events registered by another borehole in Carboniferous limestone in Co. Roscommon:

- ROS 14/91 (1427NEW062): 74.6 m deep in Oakport (Limestone) Formation, depth to bedrock 14.3 m.

A review of all the water level charts from the four wells has now found traces of over 100 seismic events since 1980. Comparison of the event dates and times with earthquake records on the USGS website (www.usgs.gov) indicates that the event magnitudes range from 5.7 upwards, most of them being above 7.

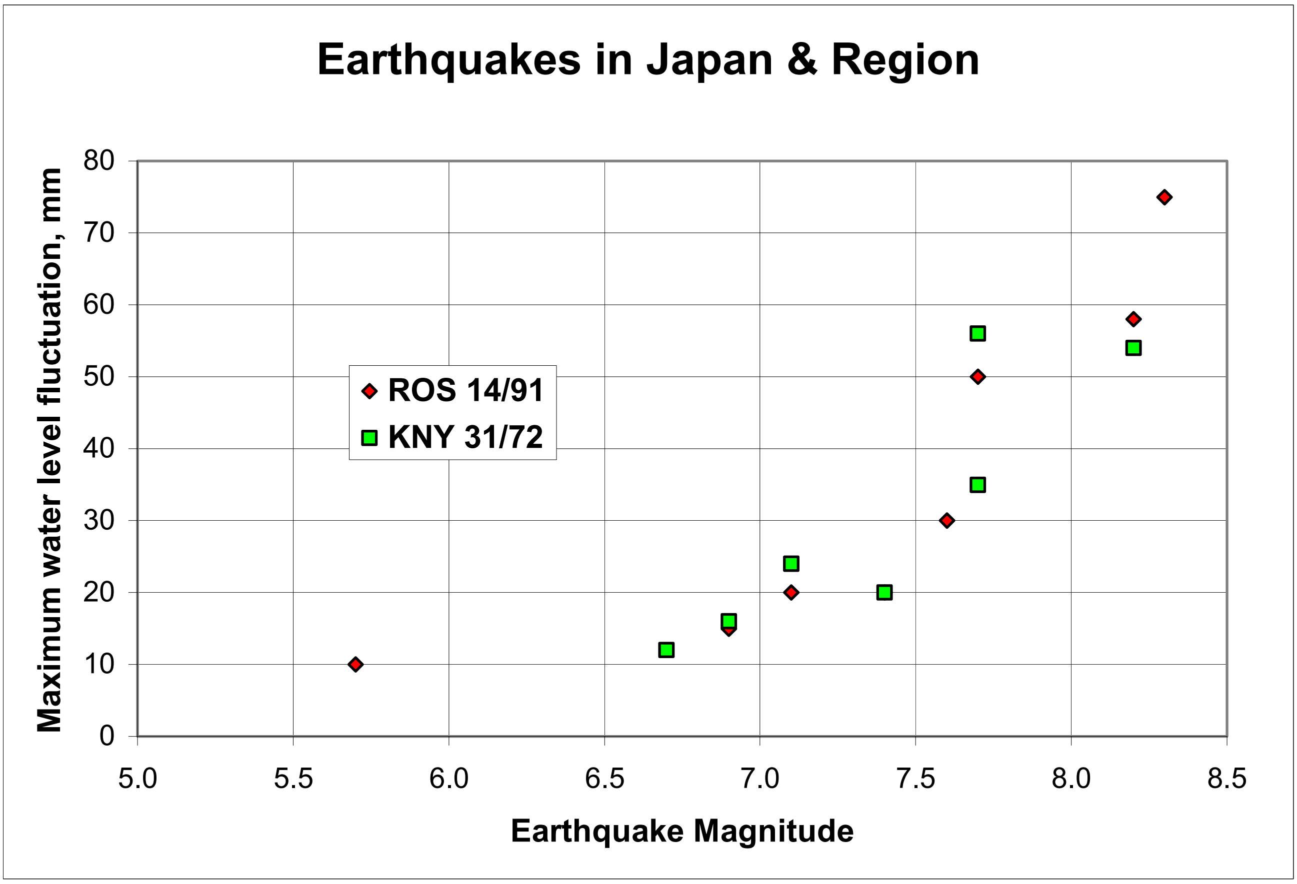
The large water level fluctuation (280 mm) generated in KNY 31/72 by the 26th December earthquake (Magnitude 9.0) was, in fact, exceeded by that produced (304 mm) by the smaller (Magnitude 7.7), but nearer, Algerian earthquake of 10th October 1980, just a few weeks after the recorder was installed.

A brief examination shows that, as might be expected, the amplitude of the water level fluctuation depends largely on the magnitude of the seismic event, the distance from Ireland, and the aquifer storage coefficient. For a given part of the world, an approximate relationship can be derived between the earthquake magnitude and the response in a given well (see graph). The list to date includes earthquakes in Indonesia, Philippines, Japan, Alaska and NW Canada, Oregon, California, Siberia, Mexico, Peru, Chile, Colombia, Bolivia, Iceland and other parts of the Mid-Atlantic Ridge, Macquarie Islands, Taiwan, China, Central Asia, Iran, Pakistan, India, Turkey, Greece, Cyprus and Romania.

Apart from the intrinsic interest in recording such events at such a distance, there should be practical benefits from analysing the data - helping us to understand the nature of our aquifers, and perhaps to derive actual storage coefficients in the affected aquifers.

ROS 14/91 is also influenced by earth tides (small semi-diurnal changes in gravity produced by the changing relative alignments of Earth, Moon and Sun), which produce water level fluctuations of a few centimetres. KNY 31/72, although its response to earthquakes is similar to that of the Roscommon well, has a much smaller (barely detectable) response to earth tides, while KNY 27/58 and KNY 18/92 have no detectable response to earth tides.

Water level fluctuations in response to earthquakes and earth tides are normally only detectable (at least with this type of instrument) in confined aquifers, where the very low storage coefficient transforms the minute pressure changes into observable water level fluctuations. It is somewhat surprising, therefore, that the effects of earth tides and earthquakes can be found in a relatively shallow well in gravel such as KNY 18/92. We have also found that three monitored wells in SE Cork, which exhibit tidal responses (typical of confined aquifers) show no sign whatever of responding to earthquakes.



Geoff Wright, assisted by Jane Coll, Groundwater Section, GSI

Groundwater and Water Supply in Palestine

Introduction

The conflict in Israel-Palestine has its roots in complex issues that involve land rights, refugees, and the status of Jerusalem. A vital topic that rarely receives mention in media is water rights. Water is a primary requirement for a viable future Palestinian state. The present sharing of water resources between Israelis and Palestinians do not meet this requirement.

Palestinians in the West Bank and Gaza Strip rely on groundwater for nearly 95% of their water supplies. In the West Bank, demands on groundwater resources far exceed supplies, and in the Gaza Strip, poor groundwater quality is as much of a problem as quantity. This article summarizes the hydrogeology and natural groundwater resources available in Palestine, outlines the challenges faced by water managers, and briefly touches upon Palestinian options to address the water crisis. The situations in the West Bank and Gaza Strip are described separately, as the hydrogeological characteristics of each are very different.

The West Bank

Groundwater in the West Bank flows through a regional aquifer system commonly referred to as the Mountain Aquifer System (MAS). The MAS is subdivided into three aquifer basins called the "Western", "Northeastern", and "Eastern" Aquifer Basins, as depicted in **Figure 1**. The name of each basin indicates the principal groundwater flow directions within each. The groundwater resources of the West Bank are shared between Israel and Palestine. **Table 1** shows the estimated natural annual replenishment rates for each aquifer basin, as well as annual quantities utilized by Palestinians and Israelis, respectively.

Based on Article 40 of the Oslo peace accords, Israel retains control of nearly 75% of all groundwater resources in the West Bank. Only the Eastern Aquifer Basin is deemed to have additional production capacity for Palestinians. Groundwater from the MAS represents about 30% of Israel's total water supplies, and nearly 95% of the Palestinian water supply in the West Bank. In contrast, only about 25% of the MAS groundwater resources would be available to Palestinians. Israel presently augments its national water supply with water from Lake Tiberias (Sea of Galilea), the Coastal Aquifer, desalination, and reclaimed treated wastewater. Palestinians presently augment their water supply by household-scale rainwater harvesting and small-scale capture of runoff during the wet winter season.

Structurally, the MAS is largely a regional N-S trending anticline with gentle dips (up to 15%) along its eastern flanks and steeper dips (up to 40-50%) along its western flanks. The rocks of the MAS consist primarily of mid- to late-Cretaceous carbonates – marls, limestones, dolomites, and chalks, occasionally inter-layered with thin muds. While the carbonate sequence of the MAS may reach thicknesses of more than 700 m within the West Bank, water is transmitted through numerous, thin (<1 m), individual horizons. Some formations are karstic, although large-scale cave systems do not exist. The karst is commonly considered to be a paleo-karst.

Groundwater flow directions are strongly influenced by geological structures, and hydraulic properties are spatially highly variable. This poses a particular challenge to well siting for production purposes and monitoring.

Recharge to the MAS takes place primarily along the central highland areas of the West Bank. Westerly storms coming off the Mediterranean Sea lose most of their moisture on the western flank and central parts of the MAS, with little or no effective rainfall to the east. This classic "rainshadow" effect explains the significant difference in estimated natural replenishment rate between the Western and Eastern Aquifer Basins (see **Table 1)**.

Recharge primarily takes place over a short, 4-month winter season (December- March). Average annual precipitation rates vary from about 700 mm/yr near Ramallah in the central part of the West Bank, to less than 50 mm/yr in Jericho, located on the Dead Sea to the east. There is considerable variability in average annual and monthly mean rainfall.

Figure 1: Plan Map of Mountain Aquifer System

Source: modified from Palestinian Academic Society for the Study of International Affairs

(This map can be viewed in colour on the GSI website www.gsi.ie)

Table 1: Estimated Aquifer Replenishment and Groundwater Utilization from the Mountain Aquifer System

Aquifer Basin	Estimated Annual Natural Replenishment Rate (Mm^3/yr)[1]	Estimated Recent Utilization[2] Mm^3/yr	
		Palestinian	Israeli
Western	362	23	343
Northeastern	145	40	105
Eastern	172	60	46
	679	123	494

[1] - per Article 40 of the Oslo Accords. Numbers in million cubic meters per year.

[2] - numbers are recent averages, and will fluctuate slightly from year to year.

Groundwater is accessed through deep wells and shallow springs. The bulk of Palestine's water supply is accessed through pumping of wells that range in depth from 100 - 900 m. Individual sustainable well yields vary significantly, from 1,000 – 7,200 m^3/hr. Drawdowns vary equally, from less than 1 m (in the case of some wells producing water from karstic aquifers) to more than 100 m. These variable combinations of yield and drawdown mean that water production in the West Bank is a technically difficult and expensive endeavour. Deep, highly producing wells require specially designed well pumps, with motor sizes upward of 500 Hp. Production costs are therefore high, and are compounded by high water transmission costs (to demand centers) as the topography of the West Bank often demands special and costly engineering solutions.

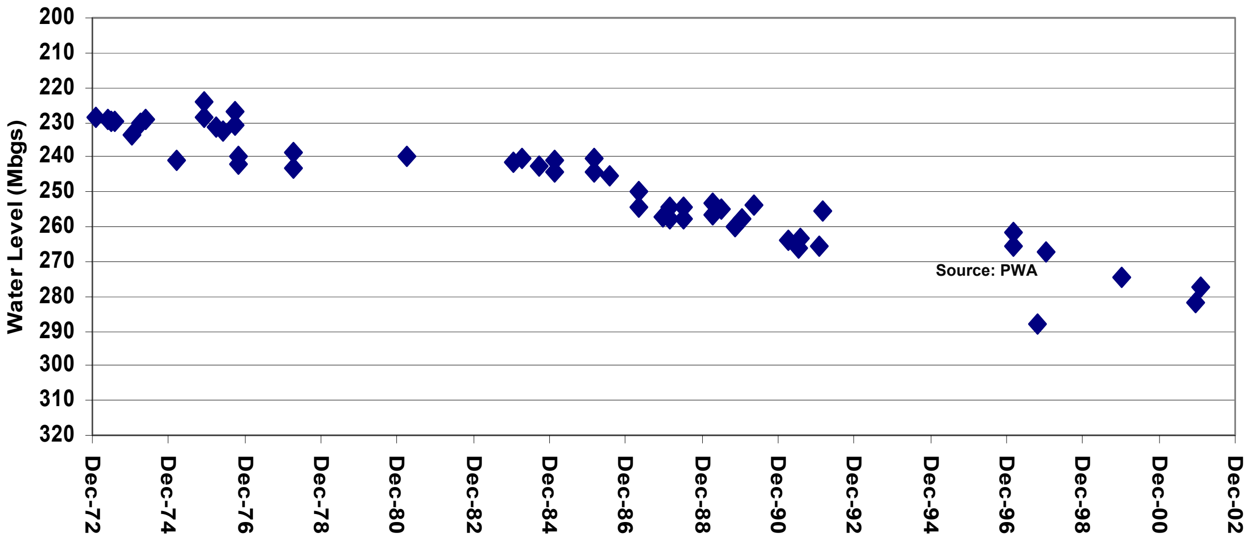
Palestinian groundwater production is managed by the Palestinian Water Authority (PWA). The PWA is also responsible for strategic planning, water and wastewater infrastructure development, monitoring, policy implementation, regulation, and water rights negotiations. Its main goal is to ensure the equitable utilization and sustainable management and development of Palestinian water resources.

An estimated 60 million cubic meters per year (Mm^3/yr) of water are presently being pumped by Palestinians, and an estimated 63 Mm^3/yr is sourced at springs. The largest user of water is the agricultural sector, the mainstay of the Palestinian economy. The industrial sector in the West Bank is small and remains a small water user. Domestic consumption is also very low, with an estimated average consumption rate of less than 50 liters per capita per day (lpcd), well below the minimum of 100 lpcd recommended by the World Health Organization (WHO). The situation is particularly bad in rural areas where communities rarely have access to water distribution networks. In such cases, domestic water is mostly derived from rainwater harvesting (in the winter months) and/or obtained from tanker trucks. Factors that influence the accessibility and availability of water in rural areas for domestic uses include affordability and the ability of tanker trucks to reach communities. In the past few years, with a deteriorating political situation in the West Bank, water supply has become especially costly, mainly because the ability of trucks to deliver water has been severely curtailed due to Israeli road closures, curfews, and checkpoints. It is estimated that an average rural household in the West Bank spends between 10-20% of its monthly household incomes on water. Water in rural communities may also be sourced at unprotected and polluted springs.

Groundwater quality deterioration is a growing concern for all water supplies. The absence and/or degradation of urban sewer systems, as well as a common reliance on open cesspits in both urban and rural areas, means that significant quantities of untreated wastewater are infiltrating back into the aquifer systems. Monitoring by the PWA of physico-chemical parameters such as chloride and nitrate suggest gradual and slow sewage impacts on groundwater quality. With the exception of shallow, small springs located within or near unsewered rural communities, groundwater quality in most parts of the West Bank remains fairly high, but warning signs of a worsening situation exist. Overabstraction represents another threat to available Palestinian groundwater resources. While there is broad and general acceptance over quantities replenished by rainfall to each aquifer basin, there is less agreement over the "sustainable yields" of each aquifer basin. As shown in **Figure 2**, water levels are dropping steadily in some areas as a direct consequence of overabstraction.

While both Israeli and Palestinian water managers are aware of the situation, there is presently limited direct coordination of pumping rates and regimes, and no common understanding of the sustainable yields of the total resources. The topic of sustainable yields has been studied by several parties, including external water supply specialists, and while all appear to agree that sustainable yields are different (smaller) than the numbers presented in **Table 1**, overabstraction has not been seriously acted upon until now. In the case of Palestine, this is mainly because significant alternative sources of water do not exist and available water for domestic consumption is already at critically low levels.

Figure 2: Decreasing Water Levels in a Well near Bethlehem



The Gaza Strip

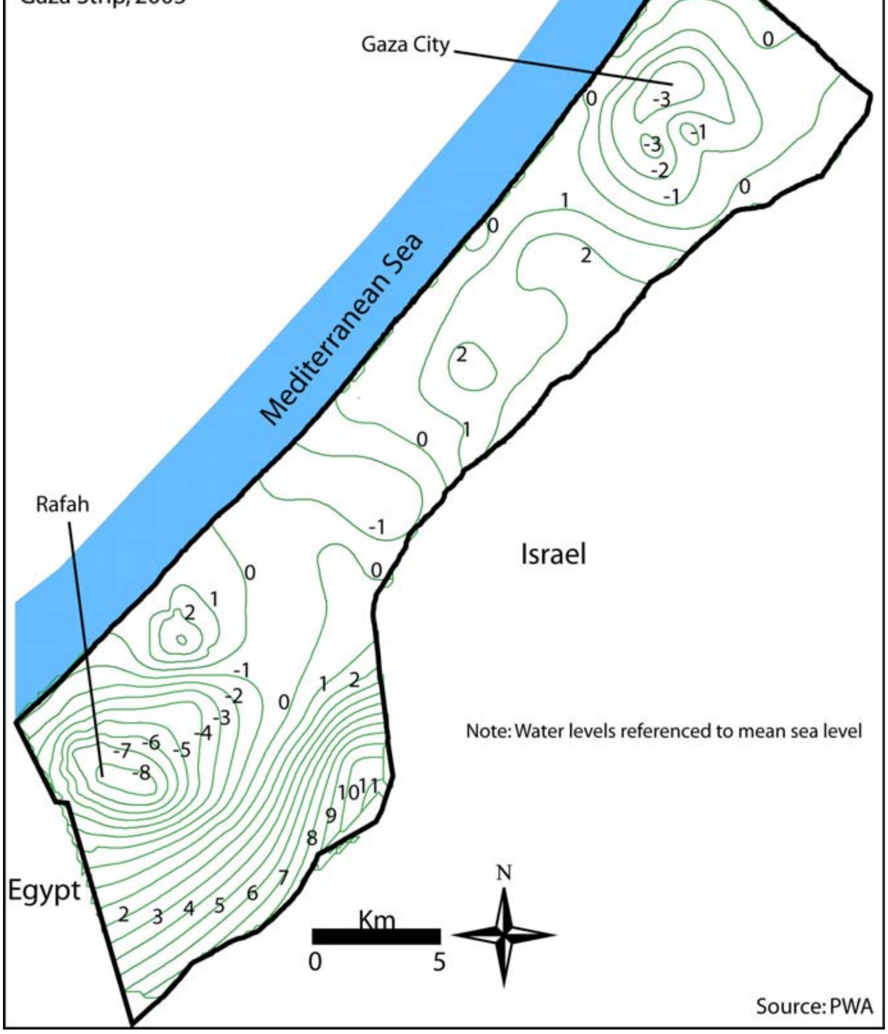
The Gaza Strip is hydrogeologically very different from the West Bank. The Gaza Strip is situated on, and obtains its water from, the Coastal Aquifer, which runs along the Mediterranean Sea from Egypt in the south to Lebanon in the north. It comprises a sequence of Pleistocene and Holocene age calcareous sandstones, shell beds, and clays. While the stratigraphy and thickness of the sedimentary sequence varies across the Gaza Strip, it generally slopes and thickens seaward, reaching a maximum thickness of about 150 m at the coast line. The sedimentary wedge thins to the east, and pinches out against Eocene chalks about 10 kilometers east of the border between Israel and the Gaza Strip. Notable geological features of the sedimentary sequence are buried, consolidated, and calcareous former sand dunes known as "kurkar", which are also found along the northern coast of Egypt. Kurkar formations pose a particular challenge to well drillers due to their unpredictable geometry and hardness.

Table 2 represents an estimated water balance of the Gaza Strip from recent groundwater modeling work carried out to study saltwater intrusion problems in the Coastal Aquifer. The elements of the water balance are numerous and complex, but in short, total abstractions exceed total replenishment. The largest volume of abstraction takes place from an estimated 4,000+ agricultural wells. These wells are only drilled (or hand dug) to a few meters below the water table, and therefore pump water from the shallow parts of the aquifer. Municipal wells are far fewer in number (about 100), but pump at higher individual rates and from deeper parts of the aquifer. Replenishment takes many forms, including natural recharge from rainfall and return flows from irrigation water and sewage. Natural recharge from rainfall decreases from north to south in the Gaza Strip, in line with a decreasing rainfall gradient from more than 400 mm/yr in the north to less than 200 mm/yr in the south (a gradient of more than 200 mm over 40 kms).

The water balance in **Table 2** represents a model-calibrated balance for the year 1998, when the quality and quantity of available data were especially good. In that year, there is an estimated imbalance of about 30 Mm^3/yr between aquifer inflows and outflows.

Table 2: Summary 1998 Water Balance (from Model Calibration)	
Units: Mm^3/yr	**Gaza Strip**
Inflows	
Recharge from Precipitation	35.0
Return Flows in Gaza[1]	51.6
Lateral Inflow [2]	36.6
Total Inflow	**123.1**
Outflows	
Municipal Abstraction	50.3
Agricultural Abstraction	90.3
Settlement Abstraction	5.0
Natural Groundwater Discharge	8.5
Total Outflows	**154.1**
Net Balance (Deficit)	-31.0
Inferred Seawater Intrusion	**31.0**

Figure 3: Average Measured Water Levels, Gaza Strip, 2003



(This map can be viewed in colour on the GSI website www.gsi.ie)

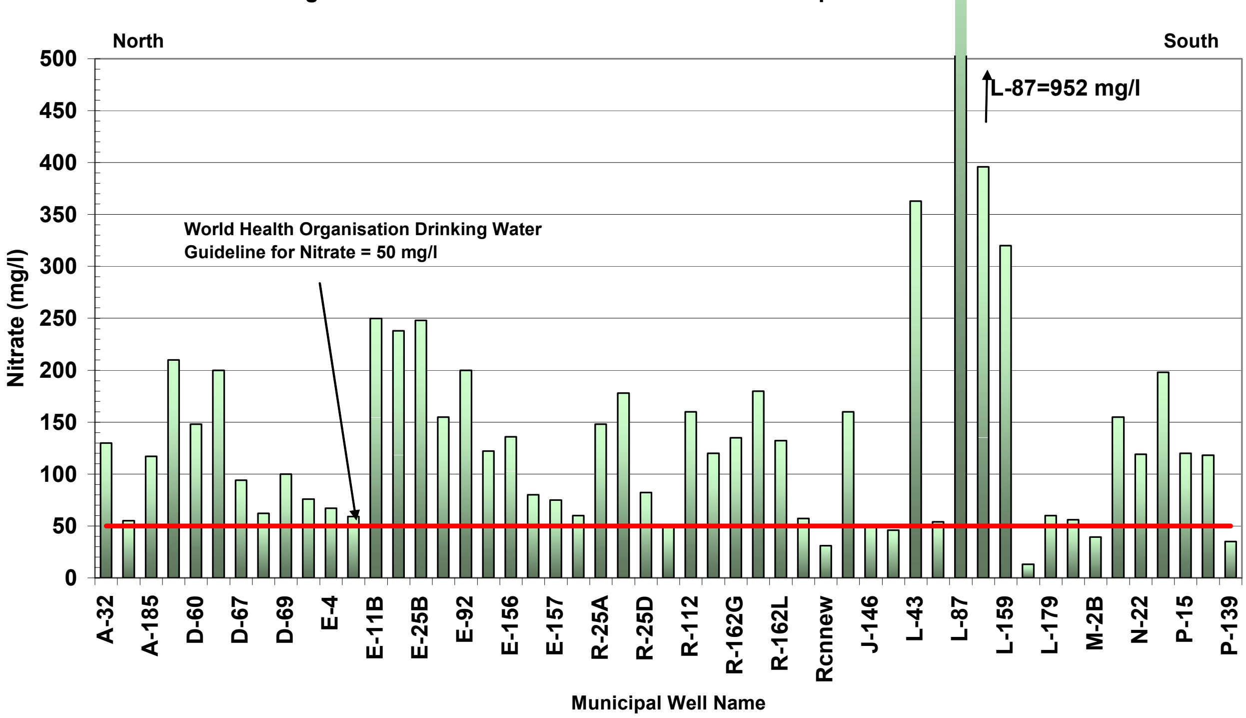
In several areas of the Gaza Strip, measured water levels (uncorrected for chloride concentrations and density effects) are decreasing and/or below sea level, notably near the larger urban centers of Gaza City, Khan Younis, and Rafah. **Figure 3** represents the estimated "average" water level distribution across the Gaza Strip in 2003. Water levels are measured below mean sea level across much of Gaza, especially within the pumping centers of Rafah and Gaza City. In Rafah, a landward hydraulic gradient has developed directly from the coast. Water levels, combined with the net water balance deficit, provide proof that seawater intrusion is taking place. Proof is also provided by municipal wells at the coast, many of which have experienced sudden breakthroughs of chloride concentrations to non-potable levels.

Modeling studies suggest that seawater intrusion occurs at rates up to 50-100 m/yr in some of the shallow confined subaquifers in the southern parts of the Gaza Strip.

The water quality situation is more complex than merely distinguishing fresh groundwater resources from seawater intrusion. Lateral inflow to Gaza from the east contains chloride concentrations between 1,000 to 5,000 mg/L. Deeper subaquifers (between coastal clay layers) in the southern part of the Gaza Strip contain syndepositional brines, with chloride concentrations up to 60,000 mg/L. The sediments also comprise evaporites. The deep sedimentary sequence in southern Gaza is believed to have evolved in manners similar to the back-lagoons presently observed in Bardawil on the north coast of Egypt. Finally, the best quality groundwater, with chloride concentrations less than 250 mg/L, occurs shallow in northern Gaza where rainfall is highest, as well as in permeable sand dune areas along the coast where recharge rates are higher.
Groundwater in Gaza is also affected by other anthropogenic sources of pollution, notably return flows associated with untreated sewage and irrigation, which carries fertilizers. This is reflected in high concentrations of nitrates throughout the Gaza Strip, as shown in **Figure 4**.

Some municipal wells presently supply water containing hundreds of mg/L of nitrate, which has prompted numerous public health studies. Other pollutants may be present in groundwater, but have not been systematically or routinely monitored.

Figure 4: Recent Nitrate Concentrations in Municipal Wells

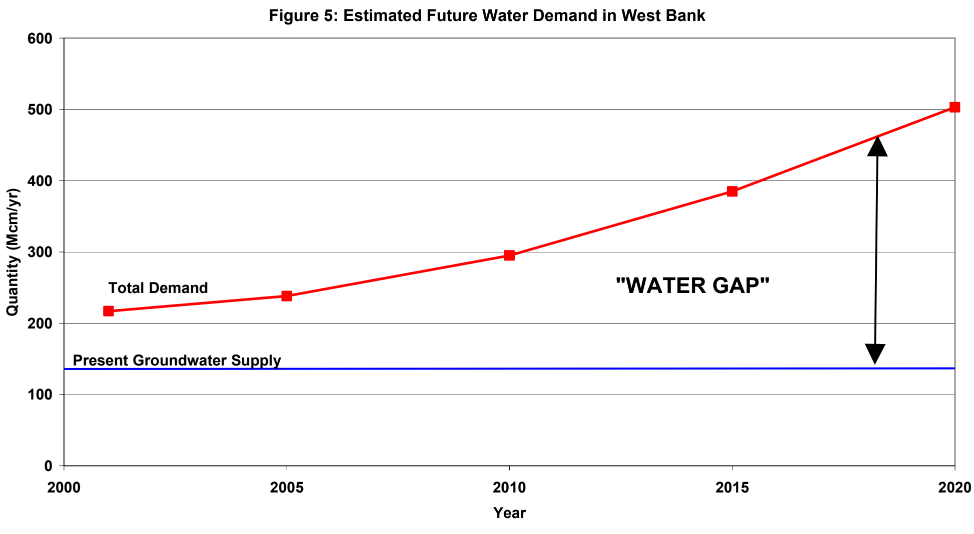


Addressing Future Water Demands and Quality Issues

The future total estimated water demand in the West Bank is shown for illustrative purposes in **Figure 5**. There is a significant and growing water gap between presently available (ground)water and future total water demands. Without significant new sources of water, Palestine cannot meet the "water gap". The increasing demand is a function of two primary factors: a high natural birth rate and a goal to increase per capita consumption from today's very low numbers (less than 50 lpcd) to around 150 lpcd (still below Israel, Europe, and the United States). Numerous studies have investigated options for sourcing new Palestinian water, and consensus has formed around the following major alternatives:

- Increased Palestinian water rights and pumping from the MAS, an option that would require reduced Israeli pumping;
- Demand management – both in domestic and agricultural sectors;
- Wastewater collection, treatment, and reuse;
- Increased harvesting of rainfall and runoff;
- Importation of desalinated water; and
- Reduction in agricultural pumping (Gaza).

Of these options, only increased water rights and desalinated water can provide the quantities of new water required, but at significant economic and financial cost, and with a need for bilateral and multilateral negotiated agreements. The long-term challenge for Palestinian water resource managers is to increase water supply while managing the growing water demand of the Palestinian population. In Gaza, desalination is not an option but a requirement, while wastewater reuse would significantly reduce the overall agricultural abstraction. Across the West Bank and Gaza, the capital costs and investments required to implement necessary interventions would run into billions of Euros. Of course, the issues surrounding each of the options are complex and can not be captured meaningfully here. Further study and discussion – uch of it involving key political stakeholders from Israel, Palestine, and other states – will no doubt continue.



Henning Moe, CDM, Dublin

<u>About the Author</u>

Henning Moe is a hydrogeologist with CDM based in Dublin. He has worked extensively in Palestine and in Jordan on international aid projects associated with water supply and aquifer protection measures. He first became involved in Palestine in 1997 as part of a water resources assessment to fact-check Article 40 of the Oslo peace agreement between Israel and the Palestine Liberation Organization. Prior to his current work on the Eastern River Basin District project in Ireland, and his engagement in the Middle East, Henning worked primarily on aquifer remedial investigations at US EPA Superfund sites.

Cork's First Waterworks Gets New Lease of Life as Lifetime Lab

The Old Lee Road Waterworks in Cork was the first waterworks established in the city in 1768. Now more than 200 years later the site has been redeveloped to become an educational, heritage and tourist attraction. The redevelopment has been funded by Cork City Council and University College Cork with the aid of a substantial grant (€5.525 million) from the European Free Trade Association.

The Waterworks is located on the western side of the city, on the north bank of the River Lee, opposite the County Hall (Figure 1) and is the best-preserved Victorian water pumping station in Ireland. The site houses two boilers and three steam driven pumps, dating back to 1905, which have survived undamaged since the Waterworks closed in the 1930s. Surviving buildings include the beam engine house of 1863, the main stack, 1858 and the turbine house of 1888, all of which have been sensitively restored. They will house a visitor centre, an information centre for Sustainable Development, a science educational laboratory for primary school students and a theatrette with 'state of the art' audiovisual equipment available for conference use. The site will be known as the 'Lifetime Lab' to highlight its focus on sustainable living.

The visitor centre showcases the environmental themes of energy, water, waste and the natural environment. Using interactive display units children and adults alike can enjoy learning about renewable energy, the water cycle, the difficulties associated with the waste we generate and the importance of the natural environment. The hands-on displays are great. You can push buttons, pull handles and lift flaps as you learn. There are built in video displays and changing sound and lighting effects as you work your way through the interactive units. With displays, which allow you to turn a wheel to explore the water cycle and lift a flap to smell a landfill, the visitor centre is likely to be a big hit with school groups.

The site will also host an Information Centre for the provision of information to visitors on issues such as Sustainable Lifestyle and Sustainable Transport, Energy, Waste Management, and Air and Water Quality. The site itself is intended to champion sustainability and energy conservation. The buildings make use of heat pumps, space heating and solar power and have been insulated. Up to 80% of the energy needs are generated locally from renewable sources. Energy use on the site will be monitored and information on performance of the various heating systems made available as a working example of the use of renewable energy.

The Schools Resource Centre is a very exciting development for primary school children in Cork. The aim is to develop modules, in association with the Department of Education, which will follow the new Social, Environmental and Scientific (SESE) Curriculum in Primary Schools. School groups will be able to visit the centre and its purpose built laboratory and work through a series of science modules delivered by the Centre's Education Officer. This development will be a welcome support for Primary Schools who due to lack of space, equipment and facilities, may be finding it difficult to partially or fully deliver the new Science Curriculum.

The Lifetime Lab provides a unique amenity within Cork City, of interest in terms of industrial heritage, environmental education and as a tourist attraction and is another welcome addition to the city in its year as Capital of Culture.

Further information on Cork's Lifetime Lab can be obtained from Project Co-ordinator, Michael O'Brien (Tel: 021-4924119; e-mail: michael_obrien@corkcity.ie) or from Michaél Lyons, Manager of Centre for Sustainable Development at the Lifetime Lab (Tel: 021 4251104; email: michael_lyons@corkcity.ie

Ùna Leader, Coláiste an Phiarsaigh, Glanmire, Cork

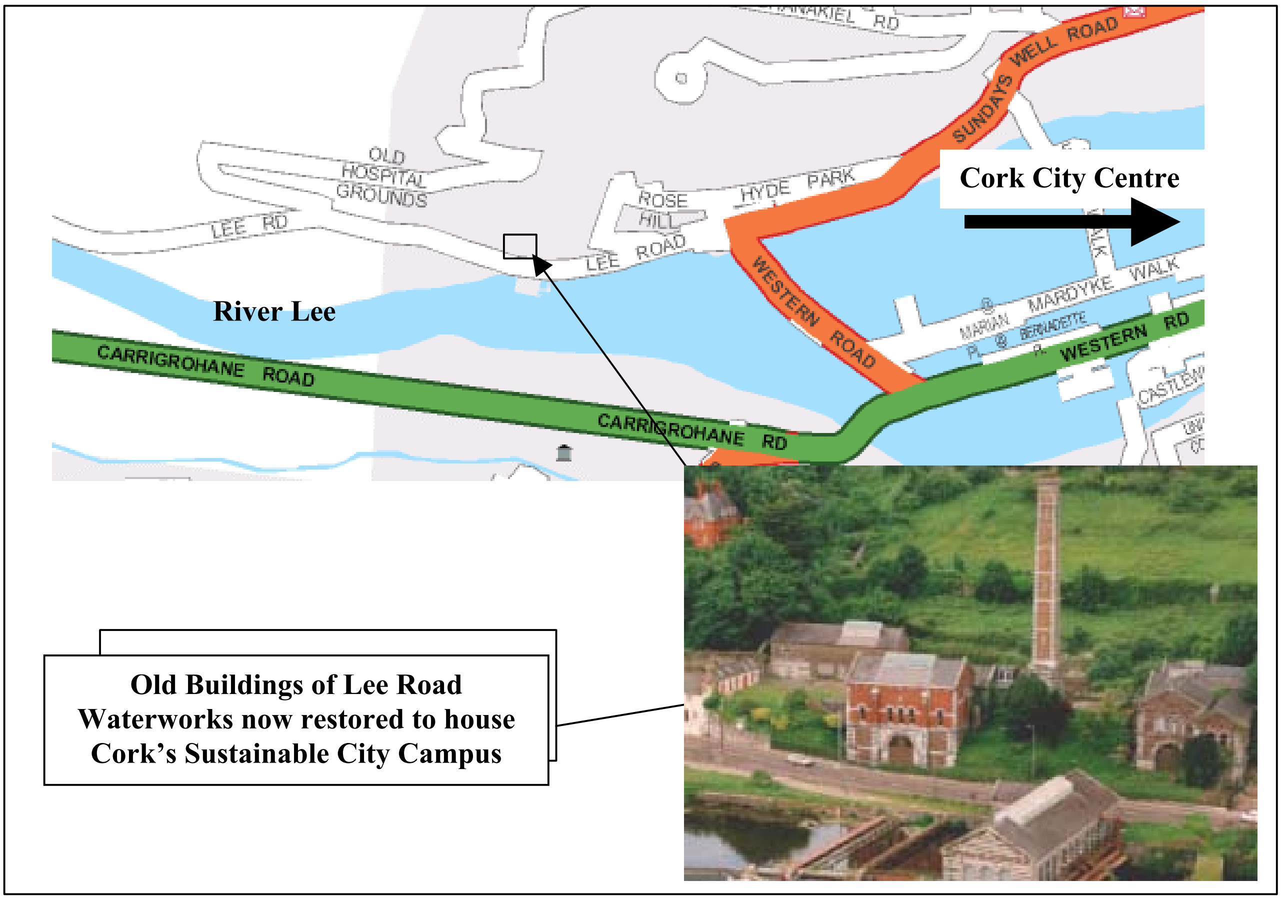


Figure 1. Location of Sustainable City Campus

(This figure can be viewed in colour on the GSI website www.gsi.ie)

What Groundwater Maps and Information are Free on the GSI Website?

The Groundwater subsection of the GSI's corporate website (www.gsi.ie) can be reached by via two routes:

1. clicking on the "Services" link under the Groundwater heading in the centre of the homepage (adjacent to the image), or
2. clicking on the "Work of the Survey" link on the left hand side of the homepage and selecting ***Groundwater*** from the list of "Survey Programme Areas" on the left hand side.

To navigate to specific areas, such as the Groundwater Protection Schemes, Response Matrices, FAQ's, Groundwater Newsletter, click on the links along the left or at the top of the screen.

Web Maps
Groundwater map data are available on either a national or county basis. The national maps comprise:

- National Draft Gravel Aquifer Map
- National Draft Bedrock Aquifer Map
- National Draft Generalised Bedrock Map

Data for county maps comprises:

- Groundwater Protection Zones
- Vulnerability
- Groundwater Protection Responses for Landfills
- Groundwater Protection Responses for Landspreading
- Groundwater Protection Responses for On-site Wastewater Systems for Single Houses

and are presently available for counties Clare, Kildare, Kilkenny, Laois, Meath, Monaghan, Tipperary North, Roscommon, South Cork and Wicklow.

"Groundwater Maps Now Online" (Una Leader, Groundwater Newsletter No. 43, October 2004) details how to access and make best use of these data.

The databases involved in the web-mapping initiative remain the property and responsibility of the Geological Survey of Ireland, unless otherwise stated. Web-mapping is no different from any other form of mapping. It therefore requires consultation of the map disclaimers and any queries should include the date and time at which the data were retrieved from the site.

Groundwater Information

The Groundwater subsection of the GSI website also includes other information:

- *Groundwater Protection Schemes* – information on methodologies, principles, aims and policies.
- *Responses Matrices* – responses and information for various activities (specifically relates to Groundwater Protection Scheme zones).
- *GWPS Status* – national status (none, draft or published) of the county schemes, and the sources reports available for each county.
- *Enquiries* – some of the data available and enquiry times and contact details.
- *The Karst Booklet* – digital copy of the introductory booklet about karst in Ireland (prepared by the Karst Working Group).
- *Groundwater Newsletters* – present and back issues.
- *FAQ's* – a list of the most popular questions and their answers.
- *Karst Field Trip* – overview of a karst fieldtrip in Roscommon (2000).

Other Groundwater related resources on the GSI website includes Conor MacDermot's pages (http://www.gsi.ie/staffhome/macdermc/index.html). This looks at Roscommon's hidden landscapes for an enthusiastic whistle stop tour of some of the county's interesting hydrogeological features.

Introductions to other interesting geological features and topics can be found by clicking on "Geology for Everyone" (left hand menu of the homepage (http://www.gsi.ie). For quick overviews of updates, check the "Site Updates" link.

Finally, we would like to encourage people, who have the facility, to access the newsletter through the website (in line with the philosophy of "reduce, reuse and recycle"), but we are still able to post printed copies to members.

Michael Sheehy and Monica Lee, Geological Survey of Ireland

IAH (Irish Group) Technical Discussion Meetings: Programme for late 2005

4th October **Aerial and ground-based photography systems for river and general environment management and mapping** by Gearóid Ó Riain, Compass Informatics
Use of satellite imagery (exact title not yet decided) by Martin Critchley, ERA Maptec

1st November **The EPA Soil and Subsoil Mapping Project - a final overview** by Spatial Analysis Group, Teagasc

6th December **Climate Change** (exact title not yet decided) by John Sweeney & colleagues, NUI, Maynooth.

The lectures take place in the GSI Lecture Theatre. They start at 18:00 hrs, with tea/coffee served at 17:30 hrs. For further information contact either Donal Daly (01-6041490) or Kevin Cullen (01-2954798).

CONTRIBUTIONS FOR THE NEXT ISSUE OF THE NEWSLETTER

Contributions for the next issue should arrive before 28th October 2005 to:

The Editor, GSI Groundwater Newsletter,
Geological Survey of Ireland,
Beggars Bush, Haddington Road, Dublin 4.

The contributors are responsible for the content of the material in this Newsletter. The views expressed are not necessarily those of the Geological Survey of Ireland.