ISSN 0790 - 7753

THE GSI GROUNDWATER NEWSLETTER

NUACHTÁN SCREAMHUISCE SGÉ

- *Exploration*
- *Management*
- *Pollution*
- *News from abroad*
- *Development*
- *Quality*
- *Reviews*
- *Opinion Forum*

- *Taiscéalaíocht*
- *Bainistíocht*
- *Truailliú*
- *Nuacht idirnáisiúnta*
- *Forbairt*
- *Cáilíocht*
- *Athbhreithniú*
- *Tuairimí*

Published by the Geological Survey of Ireland,
Beggars Bush, Haddington Rd.,
Dublin 4.
Tel: (01) 6707444 Fax: (01) 6681782

Edited by: Donal Daly

Foilsithe ag an Suirbhéireachta Gheolaíochta Éireann,
Tor an Bhacaigh, Bóthar Hadington,
Baile Átha Cliath 4.
Tel: (01) 6707444 Fax: (01) 6681782

No. 40 **May 2002**

In This Issue

The first article, by Donal O'Suilleabháin (page 2), deals with the basic human requirements of **potable water** and **adequate sanitation**. It highlights the value not only of the work of agencies such as **Concern** after natural disasters in developing countries, but also the value of the practical knowledge and commitment of hydrogeologists in helping communities in these countries.

The **EU Water Framework Directive** (WFD) will impinge on virtually every citizen in the coming years. **Implementation of the Directive** will be a journey that will influence and affect water and environmental engineers, and hydrogeologists to, at the very least, some degree. From a groundwater perspective, the **requirements of the WFD** provide a unique opportunity to:

- advance our understanding of groundwater in Ireland;
- improve our datasets;
- have groundwater considered and managed as a vital part of the hydrological cycle;
- improve our existing water level and water quality monitoring networks;
- enable our groundwater to be protected by providing an allied mechanism to Groundwater Protection Schemes; and
- provide intellectually stimulating work!!

As a means of introducing the **groundwater aspects of the Directive**, the main elements are summarised in diagrams on pages 5-7.

This Newsletter has a strong **karst** emphasis. Richard McGrath and David Drew highlight the value of **microgravity** in karst areas (pages 12-14); David Drew gives a practical and useful summary of the various elements of **water tracing** on pages 14-16; Gerry Baker describes the use of a **dispersion model for karstic aquifers** on pages 22-24; and Colin Bunce reviews a beautifully produced **booklet on the Burren Karst** on pages 18-19.

We have excellent contributions from two of our young Irish hydrogeologists: Amy Brennan describes **drilling results in a locally important aquifer** (page 8); and Orla Dwyer outlines the use of **soil vapour surveying** (pages 17-18). The value of the more experienced and, dare I say it, older hydrogeologist is illustrated by Geoff Wright's article on **pumping tests** on pages 9-11.

Editor

Water and Sanitation Project

Introduction

In the last week of October 1998, Hurricane Mitch, the worst natural disaster to hit the Central American region in decades, caused major loss of life and widespread infrastructural damage throughout the region. An estimated 70% of the national infrastructure was destroyed and approximately 3 million people were directly affected. Concern Worldwide responded initially by distributing emergency supplies (food, medicines, shelter materials and water and sanitation equipment) to over 100,000 people in some of the worst affected areas of northern Honduras.

From this initial response, it became apparent that greater assistance would have to be provided to rural communities as they began the slow process of rebuilding their homes, farms and livelihoods. Subsequent projects included housing, food security and agriculture. In addition to these a Water and Sanitation project was undertaken in two phases from July 1999 until September 2001. These two phases were co-funded by Ireland Aid/Department of Foreign Affairs and Concern Worldwide. A total of 48 communities were targeted over the two phases, involving approximately 13,900 beneficiaries.

The targeted communities were located in the Department of Yoro in Northern Honduras, approximately 35 km south of the Caribbean Coast. The terrain is difficult and predominantly rural with wide valleys and flood plains flanked by steep mountain ranges. The three municipalities targeted by Concern Worldwide were El Negrito, Morazan and Victoria. All lie in the west of the region and between them have an approximate population of 75,000.

Objectives

The overall objective of the project was to restore the levels of sanitation and potable water to the levels that existed within the target communities prior to Hurricane Mitch. This was to be achieved through:

- The construction and correct use of approximately 850 new family latrines.
- The construction and rehabilitation of 25 community potable water supplies.
- Improved knowledge of hygiene and sanitation within the community.
- Building local capacity.

Project Activities and Outputs

Prior to commencing any of the main project activities in the communities, surveys were undertaken to ascertain demographic information, existing sanitary conditions and access to potable water. In addition to this a one day workshop was undertaken in each community to explain the project objectives, outline Concern norms in latrine and water system construction and establish liaison committees.

Two types of latrines are commonly constructed in rural communities in Honduras. These are the pour/flush type and the dry type. The pour/flush type is constructed in communities where there is a permanent and abundant supply of water and are the preferred latrine type as they are more hygienic and there are less problems with odour. The dry type is constructed in communities where water supply is a problem as they are easier to use and maintain. Concern provided the manufactured materials required and the technical assistance and supervision while the communities provided the local materials (sand, wood and stones) as well as the manual labour.

During the course of the project a total of 1,282 latrines were constructed. This greatly exceeded the number of latrines originally planned as a greater contribution than expected was received from the participating communities and more of the cheaper, dry latrines were constructed than originally expected.

The most common forms of rural water systems in Honduras are gravity fed systems.

The advantage of these systems is that they are relatively cheap to construct and easy to maintain and operate. As there are no mechanical components to the systems and no fuel requirements, the actual costs in operating and maintaining the systems are minimal.

The inputs from Concern for the construction of the water systems were the initial topographic survey, materials (e.g. tubing, cement, accessories etc.), equipment, technical assistance and transport. The communities were required to provide the manual labour, local materials and skilled labour.

The criteria employed for constructing gravity fed systems were that the spring source had to:

1. Be at a higher elevation than the community.
2. Be within 3 km of the community.
3. Have a sufficient permanent yield to meet the community's needs.

In instances where the spring yields were not sufficient to provide domestic supplies to the communities, public taps were installed instead.

Upon completion of the systems the catchment areas of the sources were fenced off. Where possible these areas then became the property of the entire community and all agricultural activity was prohibited.

During the course of the project Concern constructed 19 new systems and repaired or extended 15 existing systems. Once again this exceeded the number originally planned, due to a greater contribution received from the participating communities and counterparts.

Before commencing the construction of the water systems a *Junta de Agua* was formed in each community. These committees then assumed responsibility for organizing the construction of the systems and their subsequent operation. Concern, in conjunction with local counterparts, conducted two to three day workshops with each *junta* in the operation, administration and maintenance of water systems. The juntas also had responsibility for collecting monthly rates from the community members, a very important factor in ensuring the communities had sufficient resources to operate and repair their systems and thereby ensuring project sustainability.

Two hand dug wells were constructed in communities where gravity fed systems were not a viable option due to the absence of a spring source. These wells were excavated to a depth of 5 to 7 m and lined with concrete rings. A hand pump was installed on each well and the surrounding area fenced off to protect the well.

Construction of two other wells was also attempted. However water was not encountered above 8 m and the wells had to be abandoned and sealed for safety reasons.

The education component of the project involved the distribution of teaching aids and children's workbooks to the schools in the communities. These materials dealt largely with waste, water, dengue fever and basic hygiene. Prior to the distribution of these materials the teachers were involved in a one day workshop to instruct them in the use of the materials.

Conclusions and Evaluation

During the course of the project a total of 1,282 latrines were constructed and 34 communities had their access to potable water improved. A subsequent evaluation of the project showed that access to a latrine increased from approximately 24% of the beneficiaries to 80% and access to a safe potable water supply increased from approximately 20% to 75%.

Donal O'Suilleabháin, Concern Worldwide

Water Framework Directive – Groundwater Aspects

The EU Water Framework Directive (WFD) will have a major impact on the groundwater and engineering communities in Ireland. Instead of trying to summarise the WFD into a short article, I have given below the abstract, introduction and figures from a paper (Daly, 2002) to give a flavour of the groundwater aspects and to give two relevant references.

Abstract

The future is bright for groundwater in Ireland. The Water Framework Directive (WFD) establishes a requirement for river basin planning based on the maintenance, improvement, protection and sustainable use of the Community's water. Groundwater is at the heart of this Directive. It is seen as an integral element in the understanding and protection of our water resources and the ecosystems dependent on water. The WFD provides an opportunity and a challenge to the groundwater community. By 2005, groundwater throughout the country will be allocated to groundwater bodies, which are the groundwater management units of the WFD. The hydrogeology of each body will be evaluated and described to a level appropriate to the importance of the groundwater as a source of drinking water, and for the needs of surface water and terrestrial ecosystem, in combination with the threats posed by human activities. By 2007, an upgraded groundwater monitoring programme, both of water levels and quality, will be in place. River Basin Management Plans, which will integrate groundwater with the other parts of the hydrological cycle for the first time in Ireland, will be published in 2009. Measures designed to achieve the objectives of the Directive will be drawn up and ultimately our groundwaters must achieve 'good status' by 2015. But achieving these requirements and deadlines will not be easy: the timescale is short; a multi-disciplinary and multi-organisational approach is essential; seeing groundwater in terms of ecologically oriented objectives will be new to many hydrogeologists; and the precise technical requirements are not contained in the Directive. However, the WFD provides a vision and opportunity to inspire and sustain us for the future.

Introduction

Water Framework Directive

The Water Framework Directive (WFD) (2000/60/EEC) is probably the most comprehensive piece of EU water legislation to date. It establishes a strategic framework for managing the water environment and sets out a common approach to protecting and setting environmental objectives for all groundwaters and surface waters within the European Union.

At the heart of the Directive is the requirement to produce a strategic management plan for each river basin, setting out how the objectives are to be achieved. The plans are based on the following:

- ♦ subdivision of the river basin into groundwater and surface water bodies;
- ♦ characterisation and risk assessment of the water bodies, including a description and an evaluation of the hydrogeology, a detailed analysis of the pressures on the water bodies within the river basin and an assessment of the impact of the pressures;
- ♦ monitoring, evaluation and presentation of the quantitative and qualitative status of groundwater and surface water bodies.

A comprehensive programme of measures can then be drawn up, tailored to the specific circumstances in each river basin, and in particular to target improvements and monitoring effort on those water bodies most **at risk** of failing to meet their environmental objectives. Characterisation and risk assessment must be completed by the end of 2004, which is a short time scale. The main emphasis subsequently from a hydrogeological perspective, is on monitoring. However, the tasks should be seen as following an iterative planning cycle (see Figure 1), and therefore improvement of the characterisation and risk assessment will continue after 2004.

The WFD introduces new approaches to considering groundwater:

- ♦ It sees groundwater mainly in terms of whether it is of significance to surface water ecosystems, terrestrial ecosystems or water supply;
- ♦ It concentrates largely on groundwater in 'groundwater bodies';
- ♦ It introduces the concept of the 'status of the groundwater body';
- ♦ It requires greater integration of qualitative and quantitative aspects of both surface waters and groundwater, taking into account the natural flow conditions of water within the hydrological cycle.

The Directive is intended to provide a 'framework'; consequently it does not detail all the technical requirements. Also, it is a complex Directive, partly because it encompasses all waters in an integrated way; therefore interpreting the requirements on the groundwater aspects is not easy. In addition, there is continuing discussion at EU level on the precise requirements, particularly in the monitoring area.

Groundwater Working Group

The Department of the Environment and Local Government has established a WFD Co-ordination Group to co-ordinate and promote, at national level, implementation of the Directive. Under the aegis of the WFD Co-ordination Group, a Groundwater Working Group has been established to assist in the technical interpretation of the groundwater aspects of the Directive, and to provide guidance for River Basin Projects in the delivery and implementation of groundwater work requirements. The Working Group on Groundwater consists of the following members: GSI – Donal Daly (convenor), Vincent Fitzsimons, and Geoff Wright; EPA – Conor Clenaghan, Margaret Keegan and Micheál MacCarthaigh; DoELG – Pat Duggan; Dúchas – Jim Ryan; Local Authorities – Billy Moore and Ray O'Dwyer; Third Level Institutions – Paul Johnston; Environment and Heritage Service (NI) and Geological Survey of Northern Ireland (GSNI) – Peter McConvey; SE RBD – Colin Byrne.

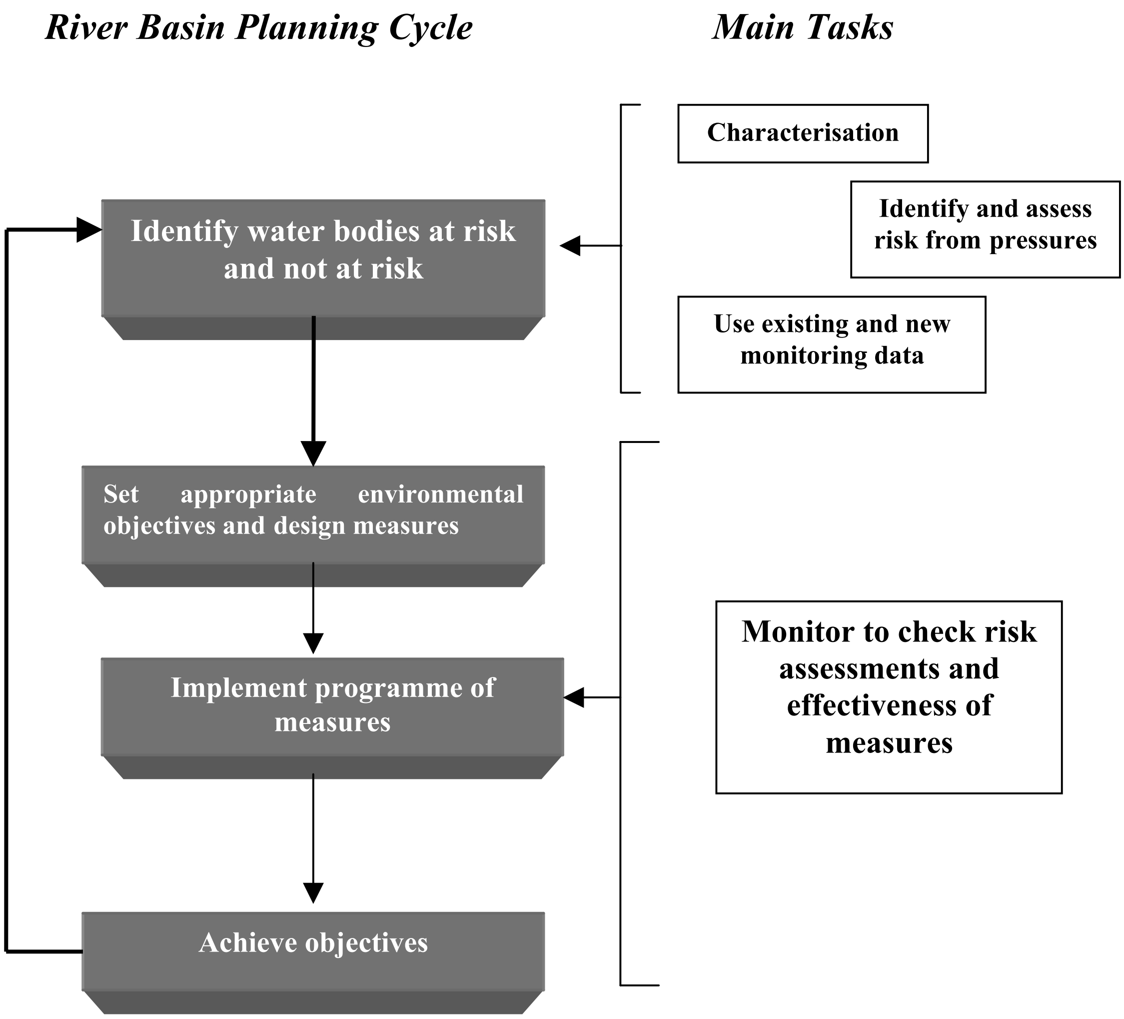

Figure 1 **River basin planning cycle and main tasks**

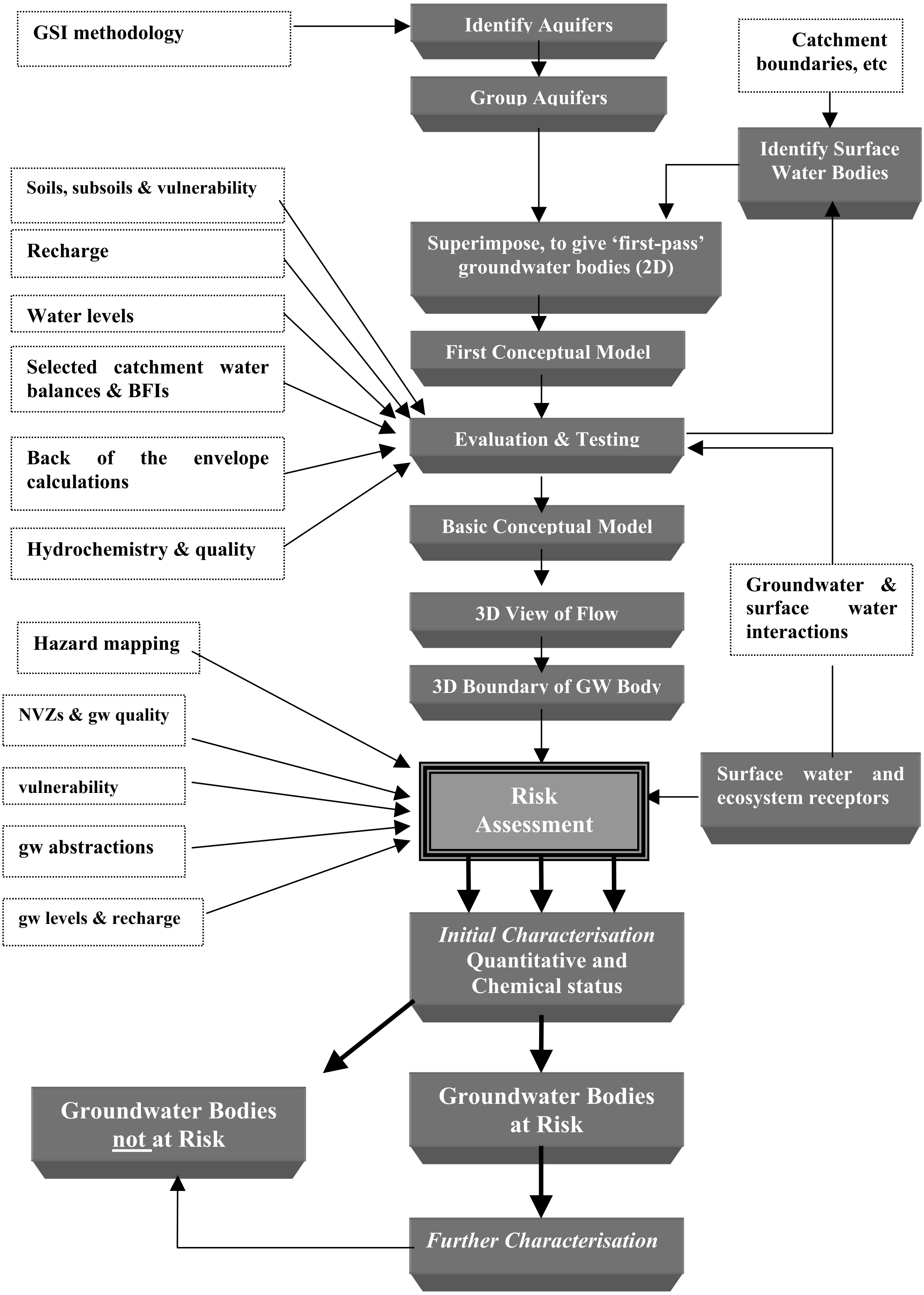

Figure 2 **Summary of approach leading to the delineation of groundwater bodies**

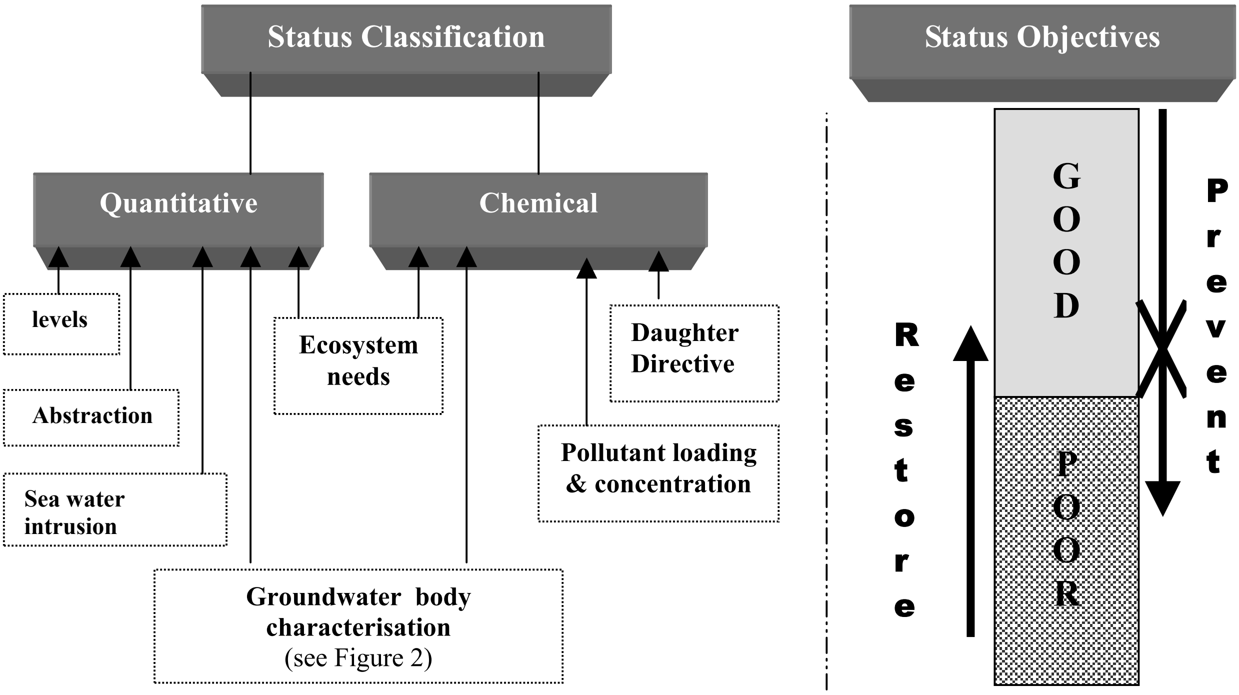

Figure 3 Groundwater status classification and status objectives

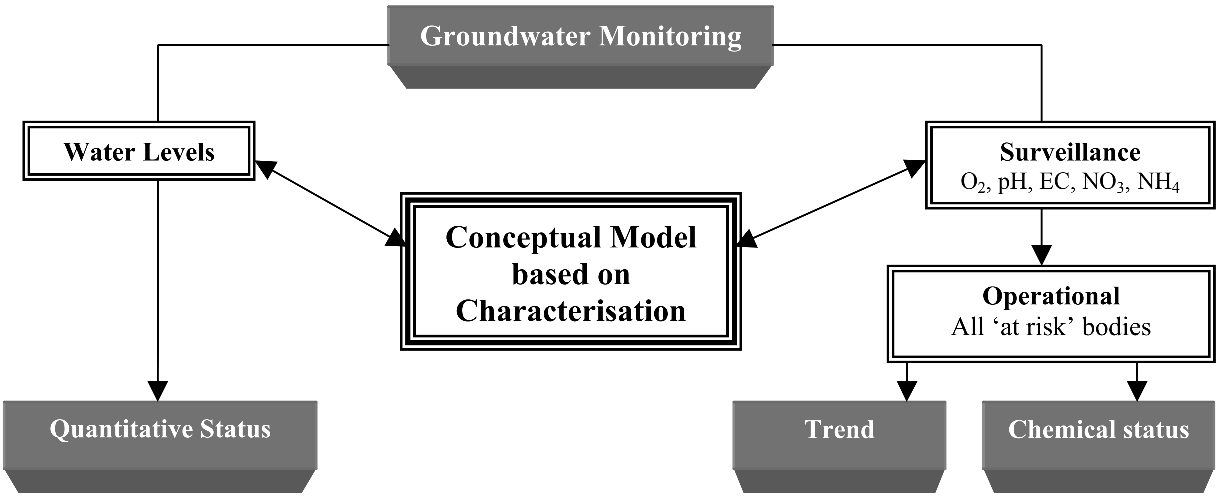

Figure 4 WFD Groundwater Monitoring

References

Daly, D. 2002. Water Framework Directive: An Overview of Groundwater Aspects. Proceedings of Annual IAH (Irish Group) seminar 'Groundwater Quality', Tullamore.

Groundwater Working Group, 2001. WFD River Basin Management Systems : Technical Requirements for Groundwater and Related Aspects. Interim Report. 31pp. Also on website: http://193.178.1.105/euwfd.htm

Both paper and report can be obtained from Groundwater Section, GSI.

Donal Daly, Geological Survey of Ireland and WFD Groundwater Working Group

Developing Groundwater in Locally Important Aquifers

The following article is a summary of a presentation given at the March IAH (Irish Group) Technical Discussion Meeting.

The potential for large groundwater volumes in locally important aquifers and the variation in well yields to be found in a limestone aquifer were highlighted last summer at the K-Club, Straffan, County Kildare.

The K-Club is the premier parkland golf course in the country and has the honour of hosting the 2006 Ryder Cup. As it is playing host to an event of this magnitude, a second 18-hole golf course is under construction, located to the south of the River Liffey (K-South). The requirement was to locate and develop a groundwater supply to meet the irrigation needs of the new course and to provide water for the planned water features, especially a cascading waterfall type feature located at the south of the site. The maximum peak demand was estimated to be 910 m^3/day.

A stream flows onto the site at the southern boundary, is channelled into the lakes and provides throughflow in the interconnected lake system with an overflow to the Liffey. The groundwater supply is intended to augment and possibly replace the surface water source in the drier Summer months in order to maintain flow through the lake system and prevent stagnation.

The initial well was drilled at the preferred site for a single well and least cost option. However, the results of this drilling exercise (TW1) were disappointing with an output of less than 5 m^3/day. In view of the fact that the least cost option had been ruled out, two alternatives were then possible; to drill a significantly deeper well at the pump house or to complete a multiple well–field.

As there is little experience of deep inflows in the Calp aquifer, the multiple well field option provided the more secure approach. seven No. wells were finally installed in the well field, all in close proximity to the planned water features on the course. Each successive drilling location was selected on the basis of the previous drilling results. Of the seven wells installed, the first and last wells drilled (TW1 & TW8) had very poor yields of <5 m^3/day, and the other five had good yields, averaging at approximately 220 m^3/day. The five good wells in the southern part of the site had a combined yield of 1105 m^3/day. The specific capacities varied from 7.5 to 14.8 m^3/day/meter (see Table 1).

The proposed demand of 910 m^3/day will only be needed during daylight hours and only when the surface water input to the lakes is very low. Therefore the demand will be considerably lower for at least half the year. The full requirement will be needed only during the Summer months, and as Table 1 shows, can be comfortably provided by the well-field.

In conclusion, the results of the exercise show that even in a relatively low yielding aquifer such as the Calp, large volumes of groundwater can be abstracted when a multiple well-field approach is adopted. Drilling in limestone is speculative, but, where sufficient land is available for investigation, then large yields are possible by adopting a well-field approach. In this case, an area of approximately 36 hectares out of a total site area of 85 hectares was investigated. Of this 36 hectares, two thirds have been shown to be productive, and one third unproductive.

A locally important aquifer doesn't automatically imply a small resource but rather that the resource has the potential to be managed to provide significant groundwater supplies.

Table 1

Well no.	Duration of test (hours)	Yield (m^3/d)	Specific capacity (m^3/d/m)
2	72	342	12
3	48	110	7.5
4	96	331	14.8
6	24	102	7.5
7	72	220	9.8
Total		**1105**	

Amy Brennan, White Young Green Ireland

TIPS on TESTS

What they didn't tell you about Pumping Tests on the MSc Course…………

This note was written in response to reading many pumping test analyses/evaluations in several countries over the past thirty-odd years.

Pumping test evaluation is covered (sometimes to excess) on taught Hydrogeology courses. It may or may not be covered on other taught courses, and if you obtained a postgraduate degree by research you may have missed out completely. In any case, coursework and textbook examples almost only deal with ideal situations, where the numerous conditions required by the various formulae (isotropy, homogeneity, horizontal flow, near-infinite aquifer, constant discharge rate, etc., etc.,) apply.

The real world of Irish hydrogeology is a long way from fulfilling most of these conditions. In fact, the temptation is often to throw in the towel and assume that pumping tests cannot be analysed at all. However, despair is not the only option (though sometimes it may be the best!).

The objectives of pumping tests normally comprise some or all of the following:

- to estimate the sustainable yield of a well;
- to estimate aquifer properties including T and S and identify the presence of lateral or vertical boundaries to the aquifer system;
- to estimate any interference effects with other wells, springs or surface water bodies;
- to detect short-term variations in water quality during testing and to provide water samples for analysis;
- to investigate any changes in well performance over time due to, for example, silting up, clogging of well screen, or reductions in regional or local water levels.

The tips below deal with some of the commonest problems in evaluating pumping tests (particularly in Ireland) as well as some of the commonest mistakes made.

1. Uses of Pumping Tests

Keep in mind that pumping tests are not only used (and useful) for estimating aquifer properties (T & S, etc.). In fact, values for T & S are not often required, or are required only as approximations. In Ireland, pumping test results are more often needed for estimating the sustainable pumping rate of a well or group of wells.

The principal hydrogeological use of pumping test data is, in fact, to assist in understanding the behaviour of the well and the aquifer. Before you dive into the procedures for deriving aquifer parameters, look at the graphs to try to understand what is going on in the well. It can often be helpful to have a graphical log of the well (strata and construction) alongside the drawdown curve (at the same scale).

2. Transmissivity (T)

There are now many more equations and methods available for estimating T and S than when I first learned Hydrogeology in the mid-sixties, when we were basically limited to the methods of Thiem, Theis, Jacob, Walton and Boulton. However, it remains the case that the main methods used by most people remain the 'Straight-Line' methods, using semi-log graphs of time-drawdown and recovery data. The reason is easy to see – they are simple and they seem to work. However, in their very simplicity lies their pitfall, and I have seen these methods abused wherever I have worked.

- For a reliable T value, measurements in a suitably located and constructed observation well are almost essential.

- The Jacob method is derived directly from the Theis formula, and there is a ***vital*** proviso: the value of the function 'u' MUST be small. Textbooks differ on how small it must be – Davis & De Wiest (1966), Krusemann & de Ridder (1970), Bouwer (1978) and Reeves (1986) say less than 0.01, while Driscoll (1986) and Fetter (1994) say less than 0.05. This happens when 't' is large and/or 'r' is small. For example, where 'r' is 20m, 'T' is $100m^2/d$ and 'S' is 0.2, 't' must be about 12 hours or more. Although 'u' will almost always ***appear*** to be small enough in a pumping well (because 'r' is very small, 0.1m) in practice the early time data will usually be hugely influenced by well losses. Therefore, ONLY use later time data for Jacob analyses, and work out the 'u' value threshold for ***your*** particular test.

- Don't try to draw straight lines through all parts of the drawdown graph which appear to approach a straight line, often leading to multiple estimates of 'T'. Multiple gradients can only be justified where there are clear hydrogeological grounds – where boundary conditions (Barrier or Recharge) are suspected, or a clear horizontal variation, e.g. gravels above a poorer bedrock aquifer. In these conditions, be careful – the apparent 'T' value after a barrier has been reached will not be correct, while a gravel layer will probably have a different 'T' value from that of the underlying rock.

- Beware of jumping to the conclusion of a barrier boundary – sharp increases in the drawdown curve are much more likely to result from horizontal layering, or a gradual reduction in permeability with depth, than from vertical barriers.

- If different methods of analysis produce markedly different 'T' values, don't just attempt to average them. Think about why you are getting different values. What assumptions are being made? Where are errors most likely to be introduced? Why might one or another method be inappropriate?

3. Recharge

Irish aquifers are normally unconfined. This means that (a) extended pumping will tend to reduce the (saturated) aquifer thickness and thereby reduce the Transmissivity, and (b) many pumping tests are affected by recharge, especially if they take place in a wet period. Recharge is most likely to exhibit itself towards the end of the test, when the incremental drawdown is small compared with recharge rates. Look out for flattening or reversal of the drawdown curve, and for a recovery curve which extends back to a level above that of the initial static water level (before pumping). Recharge can be allowed for if you have water level monitoring data for a well in the same aquifer, outside the cone of depression, and the test drawdown data can be corrected. A possible alternative approach is to apply a linear correction for all drawdown data over the period of recharge, i.e. take the amount of 'excess recovery' and distribute the error over the recharge period. Recharge will particularly affect any estimates of aquifer properties derived from the recovery curve.

4. Pumping Rate (Q)

Classical pumping test analysis assumes that the pumping rate remains constant throughout a test. In practice, this rarely happens. Positive-displacement pumps (i.e. piston pumps or Mono-type pumps) can maintain a constant rate (and for this reason their pumping rate must be controlled through their engine speed and not through a gate valve on the outlet) but most tests in Ireland use a submersible pump. Submersibles operate on the suction principle and their pumping rates decrease as the head (i.e. drawdown) increases. Different pumps have different head-discharge relationships which can be examined in the manufacturer's literature. Fortunately, the reduction in pumping rate is normally small after the early part of the test.

In addition, many tests are carried out without hydrogeological supervision and the supervisor often 'plays around' with the pumping rate during the test, perhaps because it is clear that the initial rate is unsustainable, or alternatively because it becomes clear that the well can yield more than expected. Making hydrogeological sense of such a test may be difficult, but is often not impossible.

For Recovery analysis, the pumping rate over the entire period of the test should be averaged. This should be done on a time basis, i.e. calculate the total volume of water pumped and divide it by the total time.

For any other analyses, don't attempt to average the pumping rate over the test. Look for periods of relatively constant pumping rate, e.g. estimate a Jacob straight-line gradient over a single period when the rate was constant. In deriving a specific capacity, use the discharge rate and drawdown at the end of a period where the rate was relatively constant.

5. Storativity (S)

Classical pumping test analysis includes formulae for deriving 'S' values, using observation well data only. In practice, this is much more difficult than deriving reasonable 'T' values, particularly because 'S' is much more sensitive to deviations from ideal conditions. Storativity values from pumping tests need to be regarded sceptically.

6. Permeability (k)

In theory, a value for permeability or hydraulic conductivity ('k') can be derived by dividing the 'T' value by the aquifer thickness (D). In practice, however, the permeability can vary hugely with depth, and it is likely that the permeability of the most critical layers (e.g. in estimating a maximum groundwater velocity) will be significantly higher than the value derived from T = k.D.

7. Specific Capacity (SC or Q/s)

SC is a very useful parameter, particularly because it can be derived from a test even when the lack of a constant pumping rate precludes deriving any reliable T or S data. And from a decent SC value you can derive an approximate T value via the Logan approximation (Logan, 1964; Misstear, 2001). It can also be used to derive 'Productivity' categories (Wright, 2000). However, remember that:

- SC is supposed to represent the well at equilibrium, i.e. when drawdown has stabilised.
- If you have a relatively smooth drawdown curve (which should fit a Jacob straight line) you can extrapolate it (to a reasonable degree) to, say, 10,000 minutes (about one week) and estimate the likely drawdown at that time.
- However, if drawdown is showing signs of continuously increasing, then any such extrapolation is best avoided. This situation is quite common in Irish aquifers.
- In unconfined aquifers (which includes the great majority of Irish aquifers) the specific capacity will vary seasonally, being highest in winter/spring when the water table is high and the saturated zone at its maximum, and lowest in summer/autumn, when the opposite is true. This difference will vary most where the water table fluctuates most.
- SC will also vary with the pumping rate. However, in confined aquifers the gradient is much less (theoretically there should be no gradient at all, but well losses complicate the picture).

Finally, remember that a single pumping test, even with the benefit of observation wells, still represents only a relatively small part of an aquifer. If there is a choice to be made between carrying out an extensive test on one well or simpler tests on a number of wells, the latter will usually give you a more representative picture of the nature of the aquifer. For more details of how pumping tests should be carried out you could do worse than read our GSI Information Circular (Wright, 1985).

References

Bouwer, H. (1978). Ground Water Hydrology. McGraw-Hill.

Davis, S.N. & De Wiest, R.J.M. (1966). Hydrogeology. John Wiley & Sons.

Driscoll, F.G. (1986). Ground Water and Wells, 2nd Edition, Johnson Filtration Systems Inc.

Fetter, C.W. (1994). Applied Hydrogeology, 3rd Edition. Prentice Hall.

Krusemann & De Ridder (1970). Analysis and evaluation of pumping test data. Bulletin 11, International Institute for Land Reclamation and Improvement, Wageningen, Netherlands.

Logan, J. (1964). Estimating transmissibility from routine production tests of water wells. Ground Water 2:35-37.

Misstear, B.D.R. (2001). The value of simple equilibrium approximations for analysing pumping test data. Hydrogeology Journal 9:125-126.

Reeves, M.J. (1986). Well Tests. *In: Brandon, T.W. (Ed.) Groundwater: Occurrence, Development and Protection.* Water Practice Manual, No.5, Institution of Water Engineers & Scientists, London.

Wright, G.R. 1985. Pumping Tests. Geological Survey of Ireland, Information Circular 85/2.

Wright, G.R. 2000. QSC graphs: an aid to classification of data-poor aquifers in Ireland. *In: Robins, N.S. & Misstear, B.D.R. (Eds.) Groundwater in the Celtic Regions: Studies in Hard Rock and Quaternary Hydrogeology.* Geological Society Special Publication No. 182.

Bruce Misstear (TCD) is thanked for helpful comments in reviewing my initial draft.

Geoff Wright, Groundwater Section, GSI

Geophysics as a Tool for Karst Groundwater Mapping

1. Introduction

The limestone lowlands to the west of the Shannon are known to be highly karstified but comparatively little is known about the nature of the groundwater flow systems. In particular it is uncertain whether flow is localised in major conduits, is epikarst dominated or is a distributed flow network. Evidence from water tracing suggests that conduit flow does occur and there is direct evidence of major conduits in the Gort area where cave divers have explored some 2.1 km of flooded passages.

Karst aquifers can be particularly vulnerable to both pollution from surface activities and large scale dewatering from mineral winning operations. This is due to the enhanced vertical and lateral flow paths, resulting from the dissolution of carbonate species by rainfall. Often this process results in the development of voids that can range in size from several centimetres to several tens of metres.

2. Technique

The Geological Survey of Ireland, the Department of Environment and Local Government and the Environmental Protection Agency have jointly developed a methodology for the preparation of groundwater protection schemes. Each scheme involves a county-wide map of groundwater protection zones, based on an aquifer map and a map of the natural vulnerability of the groundwater to pollution.

In order for any mapping technique to provide an acceptable assessment of vulnerability the location and spatial distribution of high permeability flow paths needs to be established. Of the available geophysical techniques that may allow for the identification of such features, microgravity is likely to be the most successful. Microgravity surveying has the potential to identify the presence and location of such voids and subsurface flow paths and thus clarify water tracing information which suggest conduit flow to potable springs used for public water supply within a catchment area.

Gravity surveying involves the measurement of subsurface geology on the basis of minute variations in the earth's gravitational field generated by differences of density between subsurface rocks. Gravity anomalies arising from voids and cavities are superimposed upon much larger variations and are virtually undetectable by conventional gravity investigations. Microgravity surveying has developed considerably over the last ten years however, and with the development of modern high resolution techniques and sophisticated reduction and analysis, these anomalies can be detected and interpreted. Not only do the isolated anomalies reveal the location of voids and conduits, but they also provide information on their depths and shapes.

Figure 1 Gravimeter used for surveying

The microgravity survey technique is a powerful cavity and conduit location method. The principle of the technique is to locate areas of contrasting density in the subsurface by collecting surface measurements of the variation in the Earth's gravitational field with an instrument called a gravimeter (Fig. 1). Because a cavity represents a mass deficiency a small reduction in the pull of the Earth's gravity is observed over the cavity. This is called a negative gravity anomaly.

3. Microgravity Mapping

Microgravity studies were made at two locations in western Ireland: in the Gort-Kinvara area of Co. Galway and in the vicinity of three public supply springs in Co. Roscommon.

Seven sites were proposed for the microgravity work in the Gort area. The sites were divided into four categories depending on the certainty of the conduit passing beneath them. At Morans and Poulaloughabo for example it was already known that conduits passed beneath the site. The sites at Moy and Poulnadirk were only suspected of overlying a large conduit and later the microgravity results proved this. Interestingly a profile conducted on a road adjacent to Caherglassaun Turlough indicated the presence of two large deep conduits possibly feeding the Turlough. A grid of data collected near to Gort at Poulaloughabo is shown in Fig. 2. The darker contours represent areas of relatively low gravity (negative anomalies) and conversely with the lighter contours. The grid clearly indicates the presence of a conduit path running from left to right across the area.

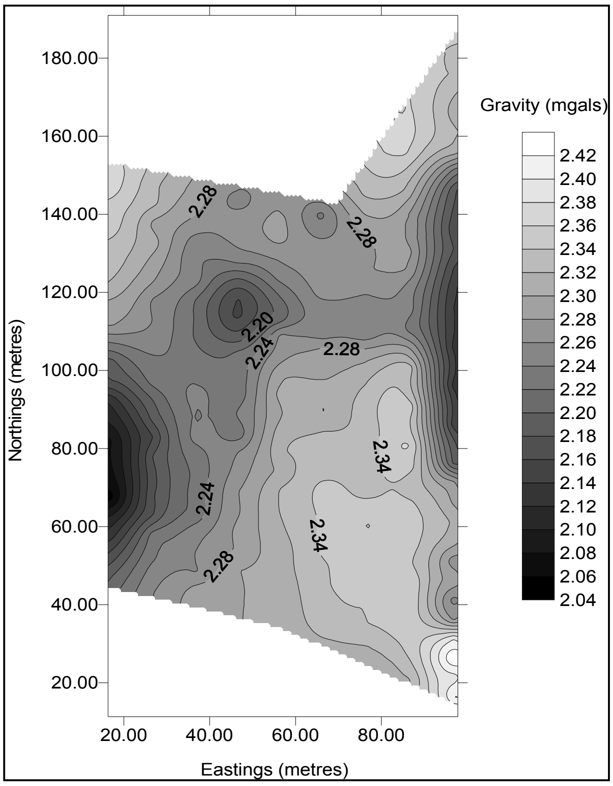

Figure 2 Gravity data collected at Poulaloughabo

Five surveys were conducted near to Castlerea in Co. Roscommon. Data acquired immediately adjacent to the public supply springs at Longford and Silver Island convincingly proved that the springs are conduit fed. A profile acquired 3km to the east at Mewlaghmore, adjacent to a sink (proven by water tracing experiments to link with the two springs), also indicated subsurface conduits.

Rockingham spring is a large public supply spring 5km east of Boyle. Microgravity carried out here confirmed the findings of earlier water tracing work. The microgravity suggested two conduits feed the spring.

4. Mathematical Modelling

With a technique that uses forward modelling this potential field data can be converted into what is called a thickness plot. The method works iteratively by comparing observed gravity to calculated gravity by at first assuming a density contrast between the cause of the anomaly and the host rock(Figure 3).

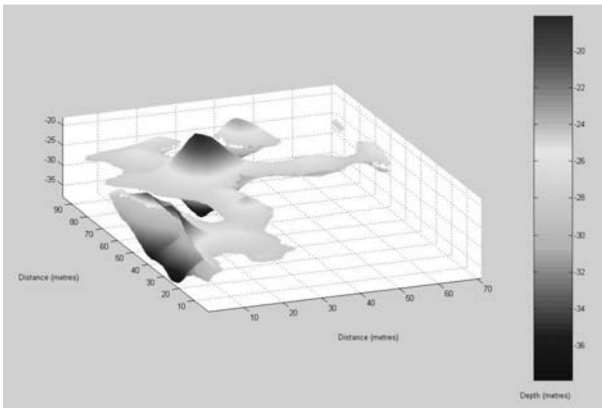

Figure 3 Thickness plot of data collected in Figure 2

Fig. 3 illustrates one analytical method of how microgravity surveying can be used to delineate the shape, size and depth of a causative body, in this case, a large karst conduit 25 metres deep.

A profile of microgravity data can also relay information about a subsurface conduit. The calculated gravity from a simple shape with a density in contrast to its surrounding rock can be compared with the observed gravity seen from the measured field data. Fig. 4 shows a subsurface model of a profile collected adjacent to Longford spring in County Roscommon. The model suggests that two equal sized conduits 12 metres deep feed the spring.

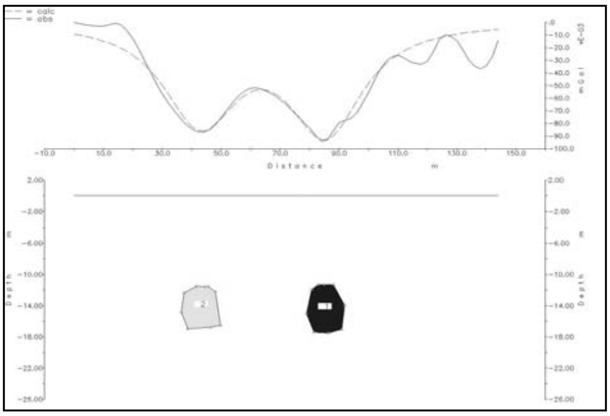

Figure 4 Subsurface model from Longford spring gravity profile

5. Conclusions

The microgravity investigations described above in western Ireland have helped to clarify the situation, for example, by strongly suggesting that the Gort conduit extends well to the east and west of its presently explored and mapped limits. Likewise in County Roscommon there is now evidence for the existence of significant conduits at some locations. In the case of County Roscommon with its extensive till cover, the information from microgravity surveys has been of great value in expanding upon the findings of recent water tracing experiments.

Richard McGrath, School of Earth Sciences and Geography, Keele University, UK.
David Drew, Department of Geography, TCD.

Water Tracing

The following article is a summary of a lecture given to the IAH (Irish Group) in December 2001 and is intended to provide a critical appraisal of the value of water tracing in hydrogeological investigations.

1. The value of water tracing

In theory Darcy's Law allows for the prediction of flow rates and directions but in practice it is of little use in fissured or conduit flow systems. Tracing can provide such information to some extent, especially with point recharge and conduit flow. However, tracing was developed for, and is still most applicable to, karst aquifers. Tracing matrix flow and flow through soil remains difficult.

Questions concerning underground flows that may be posed (and answered) by water tracing include:

- Where to? (destination of an input)
- Where from? (the origin of waters at a spring or borehole)
- Whether? (does A go to B?)
- How? (route, time, diffusion = aquifer hydraulics)

2. Aspects of Tracing

- The Tracer
  Matter or energy carried by the water and which distinctively marks a batch of water
- The Method of Detection
  Must effectively and unambiguously identify and isolate the tracer

3. Definitions

- Compound tracing (more than one sampling site).
- Multi-tracing (more than one input site).
- Replicate tracing (same site but under different hydrological conditions).
- Breakthrough curve (tracer concentrations through time at a site).

4. Criteria for a useful tracer method

A. Essential

- Tracer must be non-toxic and inoffensive.
- Must be detectable at very low concentrations.
- Must yield clear and unambiguous results.

B. Desirable

- Tracer should not be lost in the aquifer.
- Tracer should not be present naturally in significant quantities.
- Tracer should not be affected by water physics or chemistry.
- Method should be cheap and foolproof.
- Automatic sampling should be possible.

C. Ideal

- Multi-tracing should be possible.
- A negative result at a site should be valid.
- Subsidiary quantitative or qualitative data should be obtainable.

5. The main tracing techniques

- Fluorescent Dyes
- Biological Tracers
- Particulate Tracers
- Chemical Tracers
- Stable Isotopes/Water Hydrochemistry and Radio-Isotopes, are or were also used, but are not discussed in this paper as they are peripheral to 'main-stream' tracing.

6. Optimal tracing procedures

- Do not assume an outcome, and trace only to confirm that outcome.
- Monitor **<u>all</u>** possible outlets.
- Try to ensure a negative means a negative.
- Minimise the risk of contamination of samples.
- Check for background levels of tracer for at least a week prior to the test.
- Inject tracer at natural point recharge sites if practicable.
- With borehole injection carry out Specific Capacity tests first to find the best site.
- For diffuse input sites:
  - saturate the soils prior to input;
  - flush the tracer using >10m^3 of water.
- Only accept as positive samples in which:
  - tracer levels are more than 10x the detection limits;
  - tracer levels are more than 10x background levels.

7. Fluorescent dyes (Fluorescein, Rhodamine, Eosin, Pyranine etc)

A. Detection

- Water (grab) samples 20-50ml.
- Separate dyes using a non-linear curve filtering program.
- Coconut charcoal detectors (also known as bugs or fluocapteurs).
  - 10g samples washed and dried.
  - Eluted with 1-Propanol – Distilled Water – Ammonium Hydroxide (5:3:2).
  - Analyse after 30mins.

B. Problems with the use of dyes

- Losses via photo-decay, adsorption and water pH.
- Separating multi-trace dyes.
- Estimating quantities to use.
- Coping with high and variable background concentrations.

C. Problems with charcoal detectors

- False positives and negatives are common.
- Background fluorescence is enhanced disproportionately.
- Fresh charcoal adsorbs a wide range of organic molecules.
- Cannot generate a breakthrough curve.
- Fluorescein easily sorbed and desorbed.
- Rhodamine not easily sorbed or eluted.

8. Optical Brighteners

- Similar to dyes but invisible at dilutions >1:10,000.
- Adsorbed on to cotton or on P.E.S. filters.
- Tinopal LPW or 4BM seems to be the best (detection at 0.01 ppm).
- Good for qualitative A to B traces.
- Problems:
  - Much natural fluorescence at its emission wavelength.
  - Optical brighteners common in urban-industrial waters.
  - Cotton detectors often give equivocal results.

9. Phage as tracers

- The only credible biological tracer.
- Highly specific viral forms.
- Very host-bacteria specific.
- Density 1.0, diameter 0.1 microns.
- Multi-tracing possible.
- e.g. Aerobacter aerogenes
  - E.coli host
  - Half life 1000 hours.

10. Particulate tracers

- As suspended load, therefore there are potential problems with size and density.
- Lycopodium spores originally used (30 microns), caught and concentrated on plankton nets.
- Now polystyrene latex micro-spheres with customised density, colour, size, charge.
- Multi-tracing possible.

11. Chemical tracers

- Soluble and harmless chemicals.
- Detection of the element or via conductivity of the waters.
- Lithium commonest, also bromide, aluminium, etc.
- Disadvantages:
  - Often present naturally
  - Modifies water chemistry and biology.

12. How much tracer to use?

(The aim, with dyes, is to keep outlet concentrations at or below 1-2 mg/l.)

The amount required depends on:

- Residence time.
- Transport distances.
- Number of discharge outlets.
- Sorption decay and retardation coefficients.
- Diluting volume of water.

Estimates that have been made of the dye mass needed for a tracer test include:

Dienert	**M = Q . L. k** (k = tracer coeff. e.g. Fl 0.25, NaCl 250)
UNESCO	**M = L . k** (k = an aquifer coefficient)
Liebundgut	**M = Q . L. Cmax . A . 0.0018** (A = absorption coeff >1)
Quinlan	**300g per kilometre**
Aley	**M = 1.478 .** √ L . Q / v (v = estimated flow velocity)
Kass	**M = L . k . B** (k = tracer coeff Fl = 1; R = 4, Spores = 1.5)
Worthington	**M = 17 (L . Q .c) . 0.93**
Field	**EHTD Method**

Of these, Worthington's method has worked to some extent for the author

13. Guidelines for successful tracing

- Use fluorescent dyes or phage.
- Beware of optical brighteners and charcoal detectors.
- Plan the test carefully.
- Develop a strict protocol for field and laboratory aspects of the tracing test.
- Many tracings fail because:
  - Wrong outlets monitored.
  - Wrong amount and/or type of tracer used.
  - Sites not monitored for long enough.

David Drew, Department of Geography, TCD

Soil Vapour Surveying – A Useful Preliminary Site Assessment Tool

The following article is a summary of a presentation given at the March IAH (Irish Group) Technical Discussion Meeting.

Introduction

Soil Vapour Surveying (SVS) is a cost-effective tool for identifying hydrocarbon source areas and locating hydrocarbon vapour plumes in the subsurface. Depending on ground conditions, 6 to 12 vapour probes can be undertaken in one day. This survey can be carried out before, at the same time as, or following on from, other site investigation work. In the right geological and hydrogeological environment, it is therefore most effectively used in the following situations:

1. To provide a relatively inexpensive preliminary delineation of a free phase hydrocarbon plume over a large area, prior to installation of permanent groundwater monitoring wells;
2. To characterise a soil vapour plume (chemical type and concentration) as part of a source-pathway-receptor risk assessment, e.g. it could be used along a site boundary to determine if soil vapours are migrating off site towards a sensitive receptor.

When to Use SVS?

It is important to point out that there are limitations to SVS, and that it is useful under certain conditions only. In general, prior to undertaking any intrusive investigation, it is imperative to understand the environmental setting of a site, such that the optimum strategy for monitoring the site can be decided upon. This is generally achieved through undertaking a desk study (or Phase I) review of relevant historical data (e.g. chemicals likely to be present), geological, hydrogeological and hydrological records, and field reconnaissance.

The soil vapour surveying technique is most commonly applied to spills/leaks of lighter end hydrocarbons such as petrol and diesel (e.g. underground storage tanks at petrol stations). It is also used in the investigation of spills/leaks of heating oil, leaks from underground tanks holding liquors with a large fraction of lighter end hydrocarbons (e.g. gas works/benzole works).

SVS is most effectively used in granular soil types or fractured clay/bedrock environments. Samples cannot be taken too close to ground surface due to the possibility of drawing in atmospheric air. This minimum depth varies with surface/near-surface ground conditions. Depth to water table is also important, as water may be drawn into the equipment, giving erroneous results or damaging the equipment.

Soil Vapour Receptors, Pathways and Assessment

Humans are typically at risk when vapours collect in confined spaces such as buildings or basements. Vapours may preferentially move into a building through the floor/basement, due to its construction method or differences in pressure.

Vapours can migrate through the subsurface via granular soil deposits, through fractured media or along service conduits. The vapours themselves can be generated from a free phase organic plume (e.g. petrol), where high dissolved phase organic concentrations exist in groundwater or soil stained with organic contaminants (e.g. residual smear zone).

An understanding of the composition of the vapour, and the current and future receptors at the site will allow a preliminary assessment of whether the concentrations are likely to be posing a risk. If it is assessed that the vapours are likely to be posing a risk, permanent monitoring of vapours may be required. Vapour concentrations can fluctuate greatly with temperature and barometric changes; therefore a time series of repeatable data from permanent monitoring wells would greatly assist if a quantitative risk assessment were to be undertaken. SVS allows you to determine the optimal siting of expensive permanent vapour monitoring locations, prior to emplacement.

Methodology

- A Steel Probe is driven into the ground to a predetermined depth (usually between 1 and 3m below ground). The probe is retracted slightly to pull back a short sleeve and expose a short, screened 'window'. It is through this window that the sample is drawn into a sample bag.
- The probe is sealed at ground surface with hydrated bentonite or clay to prevent atmospheric air being drawn into the sample.
- Soil vapour is first purged through an O_2/CO_2 meter to detect the presence of atmospheric short-circuiting.

- After readings have stabilised, and it has been confirmed that atmospheric short-circuiting is not occurring, a lung/vacuum box is attached to the probe. The lung box works by applying a vacuum outside the tedlar bag (sample bag) and in turn drawing a sample from the ground/probe into the tedlar bag. This minimises contact of the soil vapour with the sampling equipment. Sampling equipment is purged three times in such a manner and after each purge the tedlar bag is attached to a PID/FID. Readings from the PID/FID give an indication of the presence and magnitude of hydrocarbon vapours. (The PID is very selective in its response, and reacts strongly to aromatic compounds and alkenes while responding little, if at all, to most alkanes. The PID can give erroneous readings because of its selective response and also due to its sensitivity to moisture. For this reason, the field-measured results are used only as a rough screening tool, as they often give misleading results.) If required, a laboratory sample is taken in a tedlar bag. Field parameters are re-checked for a final time to verify that short-circuiting to atmosphere has not taken place.
- The probe is removed and the probe, particularly the screened 'window' is thoroughly cleaned.

Summary

SVS is a very useful tool for rapidly and inexpensively delineating organic contamination sources in the field. The technique gives a quick indication of the presence of lighter end hydrocarbons, and the magnitude of concentrations present in the areas investigated. The method allows a wide spatial distribution of data points for a reasonable cost in a reasonable time, with minimal intrusiveness. If required, bag samples can also be taken in the field and sent to an analytical laboratory, where speciation can be undertaken to more fully quantify the composition and concentration of the organic vapour.

The method, however, does have limitations:

- SVS is useful under certain conditions only – where there is granular soil or fractured media, where lighter end hydrocarbon is present and where the water table is not too shallow (otherwise water is drawn into the sampling equipment).
- The data are not easily repeatable.
- The data obtained are semi-quantitative.
- The method is susceptible to short-circuiting with atmospheric air.
- The method is susceptible to misleading results due to erroneous PID responses and subsurface permeability variations.

Orla Dwyer, KOMEX Environment and Water Resources

Review
Classic Landforms of the Burren Karst

by David Drew.

Published by the Geographical Association; *ISBN 1-899085-91-2*

As the opening sentence states, "The Burren is the best karstic region in Ireland". However for many years the area has lacked a comprehensive guidebook to this classic landscape, the last being the introductory chapters to Tratman's Caves of N.W. Clare in the 1960's. Since then concepts have developed and much work has been done, notably by Dr. David Drew of Trinity College Dublin. So who better to write "Burren Karst", a new edition to the series of classic landform guides produced by the Geographical Association. The booklet is not intended for cavers but one of the seven sections is devoted to "The caves of the Burren" and another describes the hydrology of the Gort-Kinvara lowlands.

The booklet begins with a brief introductory section defining the area and the geological variations in the limestone sequence. The next section relates the present landforms and hydrology to the underlying geology and structure and shows how glaciation has accentuated some of these underlying trends.

The following sections describe the enclosed depressions and limestone pavements of the area; this reviewer was surprised to read that there are 1500 enclosed depressions in the area, of which 500 are over a square kilometre in size. While most of these are situated in the eastern Burren and away from the shale margin, i.e. consistent with their development in a mature karst environment, there is an interesting cluster on the western side of Knockauns Mountain, perhaps indicating the shale margin here has not moved much. The depressions and valleys of Ailwee Hill have their own subsection, as do the large depressions of Kilcorney and Carron. But apart from the comments that many of the depressions contain glacial deposits and that the water table is now some 240 metres below the mostly phreatic cave fragments in the area, there is sadly no evidence of the date or mode of formation of these features.

Perhaps the most classic landforms in the Burren are the vast expanses of bare limestone pavement. An excellent, but perhaps not a typical example, at Sheshymore gets a detailed description and a superb aerial photograph forms the frontispiece. The peculiar Karren, which are found in the intertidal zone, are described in another section, again with some excellent photographs and diagrams.

The section on the Burren's caves begins by listing 3 factors controlling their development: geology; glaciation and base level changes; and sources of run off.

Four types of cave are listed:

- ♦ Simple stream caves, e.g. Polldubh.
- ♦ Stream caves with high level passages, e.g. Poulnagollum.
- ♦ Polycyclic caves i.e. those whose streams have intersected an older previous passage, e.g. Pollballiny and Faunarooska.
- ♦ Completely abandoned caves, e.g. Glencurran and Vigo caves.

Polldubh and Ailwee caves are then taken as examples of the two ends of this range and described in some detail. Dr. Drew points out that relative ages have not been thoroughly investigated but initial uranium dating results show that the simple stream caves are of Holocene age (less than 10,000 years) while Ailwee cave probably attained its present form 350,000 years ago.

The final section examines the mature lowland karst of the Gort-Kinvara lowlands: a vast area with a maximum altitude of only 30 metres but with a complex hydrology. Comments such as "a major water-filled karst conduit up to 25 m. in diameter" and "mean flow rates of 10,000 litres per second" should be of interest to cave divers who have only started to explore this area.

Overall this booklet provides an excellent concise description of the Burren's landscape both above and below ground and for the first time draws together research from the last thirty years. In each section specified locations including grid references are given where the best examples of features can be seen. The photographs, maps and diagrams throughout are excellent (with the possible exception of the cover photograph that is printed backwards!) Other minor negative comments are the lack of reference to man's influence on the surface features though this may be due to lack of space. I would also consider the price high at £8.95 for a 50-page A5 booklet. Even so it would be a worthy addition to the bookshelf of anyone with more than just a sporting interest in the caves of the Burren.

Acknowledgement: This review was first published in Underground: Issue No. 52, Winter 2001; The Official Newsletter of the Speleological Union of Ireland & The Irish Cave Rescue Organisation.

Colin Bunce, Burren Outdoor Educational Centre

Notice of Upcoming International Conference in Dublin
IWA Conference – Diffuse Pollution and Basin Management - Ireland 2003

Planning for the 7th International Water Association (IWA) specialist conference on diffuse pollution is well in hand. The venue is University College Dublin (UCD), and the conference will run from Sunday 17th to Friday 22nd August 2003.

It is hoped that work currently being commissioned or undertaken to assess various national agricultural support schemes in relation to their environmental impacts can be reported at the Dublin conference. In a European context, the Dublin conference is timely in that 2003 is the start of the next major review of the EU Common Agricultural Policy (CAP). That review cannot be undertaken in isolation from pressures from the World Trade Organisation. In Ireland, Good Farming Practice (GFP) is currently being implemented by the Department of Agriculture, Food and Rural Development and the state agricultural advisory service, Teagasc, is highlighting the financial penalties associated with non-compliance. In addition, catchment initiative projects continue to fuel the debate relating to responsible nutrient and priority substance management by all sectors. While many sectors have already developed 'Codes of Good Practice' such as the agricultural and forestry sectors, such codes and pollution abatement strategies can have no positive impact unless they are properly implemented. Management strategies for diffuse pollution have been developed under seven headings, namely:

- Urban surface water drainage
- Populations on septic tanks
- Management of sludges
- Agriculture sector
- Forestry sector
- Energy sector
- Abstractions

A key focus had been the development of management strategies that will reduce the potential of agricultural activities to pollute surface and ground waters and at the core is the development and implementation of 'Best Farm Management Practices' (BFMP) in which detailed Nutrient Management Planning (NMP) forms a central role. The strategy requires that BFMP be subject to annual certification by an accredited agricultural planner and that implementation be encouraged through an integrated approach involving, as appropriate, the following:

- Encouragement of voluntary uptake
- Encouragement of participation in REPS
- Adoption of cross-compliance
- Enactment of agricultural bye-laws
- Extension of licensing and pollution control legislation

The international character of the IWA diffuse pollution conferences should provide for a very useful forum to present papers from many parts of the world, to compare various existing support schemes, and thereby to derive ideas for better, more sustainable practices. Now is the time to start thinking about papers and involving leading technocrats in our work. The first announcement was launched in April 2002 when details inviting abstracts for submission by December 2002 were circulated.

As with preceding diffuse pollution conferences, there will be a variety of themes, run in parallel, in Dublin. One innovative idea will be to stage a marine / estuarial theme throughout the conference week. There is a sufficient body of research on impacts to warrant such a focus, and it is hoped that marine / estuarial researchers who have not seriously thought about diffuse pollution will focus attention on it now, and participate in August 2003 in Dublin. Example issues are eutrophication associated with agricultural inputs of nitrogen; contamination of shellfish by persistent pollutants and faecal pathogens derived from diffuse sources; hormone disrupting chemicals; bathing water quality in relation to diffuse sources of faecal pathogens; siltation of coastal reefs associated with forestry (logging) and other land use changes; contamination by radiochemicals derived from atmospheric fall out; and bioaccumulation of persistent pollutants (in fish, birds and marine mammals).

Dublin will also feature **Groundwater and Baseflow Protection** as an important conference theme throughout the week during the various session options including platform papers and workshops. The importance of groundwater issues in the context of Integrated Water Resource Management has been clearly signalled by the EU Water Framework Directive and accordingly will be afforded a high priority during the conference.

The Dublin conference promises a festival of exciting insights into contemporary diffuse pollution and basin management issues in an ambiance of Irish hospitality. A conference website has been opened, namely, www.ucd.ie/~dipcon/dipcon.htm. Further information about the conference can be obtained from:

IWA Conference Secretariat
Centre for Water Resources Research
Civil Engineering Department
University College Dublin
Earlsfort Terrace
Dublin

Ray Earle

WORKING GROUP ON KARST

Geological Survey of Ireland | **Geotechnical Society of Ireland**

International Association of Hydrogeologists (IAH) - Irish Group | **Irish Association for Economic Geology (IAEG)**

Preliminary Notice of Seminar
Geotechnical & Hydrogeological Aspects of Karst in Ireland

Venue: Tullamore Court Hotel
Date: 4th October 2002

Draft Programme

Time	*Speaker*	*Topic*
09.00-09.30		**Registration**
09.30-10.00	David Drew, TCD	**The Karst Environment and Karst Hydrogeology : an Overview**
10.00-10.30	Derek Luby and John Kelly, CSA	**Desk Studies for Infrastructural Projects**
10.30-10.50	Matthew Parkes, GSI	**The Irish Geological Heritage Programme Karst Theme, and geological conservation issues in engineering projects in Ireland**
10.40-11.20	Tea/coffee	
11.20-11.40	Donal Daly, GSI	**The Role of Karst in the National Groundwater Protection Scheme**
11.40-12.00	Paul Quigley, IGSL	**Geotechnical ground investigations**
12.00-12.20	David Ball, Consulting Hydrogeologist	**Drilling and construction of wells in karst areas**
12.20-12.45		**Discussion**
12.45-14.00		**lunch**
14.00-14.30	M. Creed, UCC	**Remedial measures applied to the engineering solution of karst problems**
14.30-14.50	Kevin Cullen, White Young Green Ireland Ltd	**Road Construction and the Outflow from a Turlough**
14.50-15.10	E. G. Pettit & Co. speaker	**Case history**
15.10-15.30	Arup Consulting Engineers speaker	**Case history**
15.30-16.00		**Tea/coffee**
16.00-16.20	Conor McCarthy, Jennings O'Donovan	**Flooding problems in the Gort-Ardrahan area of south Galway: engineering options and modelling their impacts on flooding**
16.20-16.40	Paul Johnston, TCD	**Hydrological Modelling in Karst**
16.40-17.00		**Discussion**

For further information contact:

Morgan Burke, Minerex ☎ (01) 2964435
Donal Daly, Geological Survey ☎ (01) 6041490
Derek Luby, CSA ☎ (01) 2964667

A Dispersion Model for Karstic Aquifers

Introduction
Studies of breakthrough curves from tracer tests in karst systems often highlight a strong tailing effect. A modelling approach is outlined below which characterises these tailing effects very well.

As a contaminated fluid flows through a porous medium, it will mix with the non-contaminated water. The result will be a dilution of the contaminant by the process known as dispersion. The following processes are responsible for dispersion at the pore-scale: a) as the fluid moves through the pores it will move faster in the centre than around the edges; b) some fluid will travel in longer pathways than others; c) fluid that travels through larger pores will move faster than fluid that travels in smaller pores. These three effects combine to give mechanical dispersion.

These processes are regularly used in textbooks to describe flow through a porous aquifer. However, Irish karstic aquifers do not have an intergranular porosity; most significant water movement occurs through conduits. Therefore, the processes described above would not appear to apply to karstic aquifers. However, the implications of scale must be considered. (Indeed this model will not describe the dispersion of a tracer through a large cave over a short distance.) At a broad regional scale, the fissures and conduits in a karstic aquifer may act like the pores of a porous aquifer at the micro scale. The relative importance of each of the individual processes may be different (e.g. the retardation at the pore/conduit wall may not be as important as the pore/conduit size increases) but then these are indiscernible at any scale. Therefore it is suggested that this model should only be used at the catchment scale.

The Multiple Dispersion Model.
This model was developed for predictions of contaminant concentrations at the discharge point of porous aquifers by Zuber (1974) and further developed for karstic systems by Maloszewski et al. (1992). It assumes that the tracer flows from the system entrance (injection site) to the system exit (detection site) in parallel but along different flow paths. Each flow path is characterised by a specific volumetric flow rate, water transit time and dispersivity (dispersion parameter). It assumes that there is no interaction between the flow paths, and the possible diffusion of tracer in the micro-porous matrix and/or temporarily non-active parts of the aquifer are ignored. The concept is outlined in Figure 1.

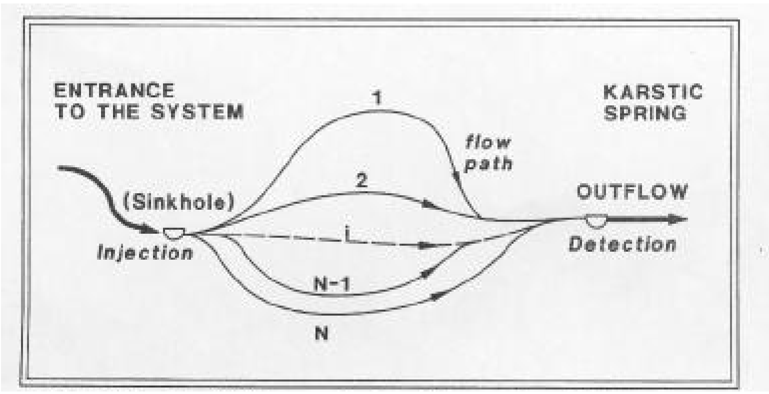

Figure 1 Conceptual Model for flow through a karstic aquifer used in the MDM.

Under these assumptions, the transport of an ideal tracer on the ith flowpath is described by the following one-dimensional dispersion equation:

$$\alpha_i v_i \frac{\partial^2 C_i}{\partial x^2} + v_i \frac{\partial C_i}{\partial x} = \frac{\partial C_i}{\partial t} \qquad (1)$$

where C_i (t) is the concentration of tracer in the outflow, α_i is the longitudinal dispersivity, and v_i is the mean water velocity, for the i^{th} flowpath, respectively.

The solution to equation 1 for an instantaneous injection of tracer has the following form:

$$C_i(t) = \frac{M_i}{Q_i t_{oi} \sqrt{4\pi (D/vx)_i (t/t_{oi})^3}} . \exp\left[-\frac{(1 - t/t_{oi})^2}{4(D/vx)_i (t/t_{oi})} \right] \quad (2)$$

> *where $(D/vx)_i$ is the dispersion parameter on the i^{th} flowpath, which is equal to the dispersivity (α) divided by the distance of travel x, t_{oi} is the mean transit time of water for the i^{th} flow path and Q_i is the volumetric flow rate. The flow rate should be constant according to the assumptions.*

The model assumes that the total mass of tracer injected (M), is divided into N flowpaths. The proportion of the total mass of tracer that enters a certain flow path is directly proportional to the size of the discharge through that flow path.

The tracer concentration C (t) measured in the system outflow (karstic spring) is the weighted mean concentration from all the flow paths:

$$C(t) = \sum_{i=1}^{N} r_i C_i(t) \quad (3)$$

where r_i is the proportion of the total flow in each flowpath; $r_i = Q_i / Q = M_i / M$ (4)

The combination of equation 3 with equation 2 is called the Multiple Dispersion Model. It is used in a curve fitting procedure to determine all the model parameters. The following parameters are altered to fit the modelled breakthrough curve to the measured tracer breakthrough curve: total number of flowpaths; mean transit time; dispersion parameter; and the proportion of water fluxes for each flow path.

Discussion

This model has been used many times by the original author and once by myself. In these studies, the model does indeed simulate tracer breakthrough curves very well. In my own work in Slovenia (Baker *et al*, 2001) use of the model for a tracer experiment showed that the predictions of the model could be almost perfectly fitted to the observed values (see Figure 2).

Two flow paths appear to be sufficient to describe the tracer breakthrough curve examined. This could be considered a reflection of two flow systems in the karstic aquifer, through a small number of conduits and a set of fissures. The initial peak represents flow in the conduits and the second peak, which is lower, represents flow in the fissures, where the advective flow of tracer is slower and there is more dispersion.

Where a certain karst system has already been modelled using the above methodology, a possible application of the model may be in environmental protection and risk assessment. In the case of a point source pollution incident, if it were possible to estimate the mass of pollutant that entered the system and the discharge at the outflow, then the peak pollutant contamination could be estimated from the model. The dispersivity of the karst system will determine whether there is a flashy peak or a more subdued low-tailing peak. If the peak concentration can be determined at the outflow, an assessment of the impact on aquatic flora and fauna at the discharge location, and on drinking water quality, can be made.

Conclusion

The Multiple Dispersion Model (MDM) described above is potentially a useful analysis tool in predicting the severity of pollution incidents in karstic environments at a regional scale.

References

BAKER, G., PETRIC, M., PARKIN, G. & KOGOVSEK, J. (2001) *Surface and Groundwater interaction of the Bela stream and Vipava springs in South-western Slovenia*. Acta Carsologica **30**/2, 217-238, Lubljana.

MALOSZEWSKI, P. (1994) *Mathematical modelling of tracer experiments in fissured aquifers*. Freiburger Schriften zur Hydrologie 2: 1 – 107.
ZUBER, A. (1974). *Theoretical possibilities of the two–well pulse method*. In: Isotope Techniques in Groundwater Hydrology: 277-294. IAEA, Vienna.

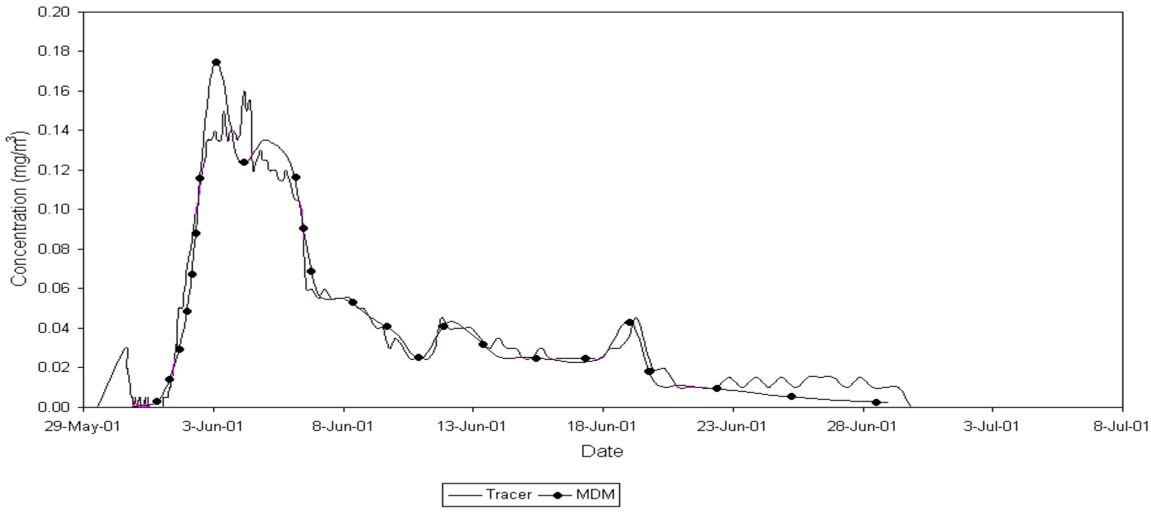

Figure 2. Multiple Dispersion Model results from Slovenia

Gerry Baker, Geological Survey of Ireland

National and Cultural Landscapes : The Geological Foundation

Dublin Castle, 9-11 September, 2002

This conference is designed to stimulate discussion on the future of our landscape and its geological foundation. Early registration closes on 7th June, 2002. Registration forms available at:
www.ria.ie/committees/geog_conf.htm

CONTRIBUTIONS FOR THE NEXT ISSUE OF THE NEWSLETTER

Contributions for the next issue should arrive before 1st October 2002 to:

The Editor, GSI Groundwater Newsletter,
Geological Survey of Ireland,
Beggars Bush, Haddington Road, Dublin 4.
Email: donaldaly@gsi.ie

*****

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.