

**INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS**

**IRISH GROUP**

**PROCEEDINGS**

**of**

**17th ANNUAL GROUNDWATER SEMINAR**

**on**

**SOIL AND GROUNDWATER  
CONTAMINATION AND REMEDIATION**

**VENUE**

**KILLESHIN HOTEL, PORTLAOISE**

**DATE**

**APRIL 22-23, 1997**

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ISSN 1393-1806

Price £15

Published by: IAH (Irish Group)

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Cover designed by D.M. Ball

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## FORWARD

Groundwater quality in Ireland is generally considered to be satisfactory owing to the abundant rainfall and until relatively recently limited industrial development. That is not to say that there are not problems in certain areas nor that there have not been incidents of contamination.

Over the past five years there have been a number of well publicised incidents of soil and groundwater contamination in industrial areas. Leaks from underground hydrocarbon storage tanks have also caused problems in a number of urban centres.

A limited nationwide sampling for trace organics in Irish groundwaters in 1993 detected elevated concentrations in 50% of the samples analyzed.

It is against this background that the main theme for the 17<sup>th</sup> annual groundwater seminar has been chosen, i.e., Soil and Groundwater Contamination and Remediation.

The programme of lectures to be presented at the seminar will deal with the occurrence and pathways of contamination, the investigation and monitoring of contaminated groundwater and the need for legislation to control soil and groundwater contamination. Examples of contamination and remediation work throughout Ireland and in continental Europe will be provided.

We are continuing with our series of regional lectures. This year the regional lecture deals with groundwater in the South Munster region. Some of the highest yielding wells in the country are located in this region.

On behalf of the IAH Irish Group I welcome you to our seminar and urge your participation in the discussions both formal and informal.

Eugene Daly  
President IAH Irish Group

## THE SOIL SYSTEM VIEWED AS AN ACTIVE ELEMENT IN THE CLEAN-UP AND CONTROL OF CONTAMINATED LAND

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### ABSTRACT

*The soil system is an active element in the behaviour of pollutants in the soils and can be used to enhance the possibilities of clean-up and remediation. The paper describes a methodology that can be used to focus these properties in an effective way.*

### INTRODUCTION

The geological contribution to the solution of contaminated land problems is, slowly, emerging as the dominant one. In particular it is becoming recognised that without detailed understanding of the structure and the properties, often determined by the geological origins, of the subsoils, no progress can be made. However, certain assumptions and models, often derived from the discipline of geohydrology, that have been pressed into service in this field require to be modified or even rejected. In what follows an attempt will be made to provide a framework within which the conventional strength of geology are combined with new elements from chemical engineering to provide a synthesis that is both useful for direct application and potential development.

At this point is worth noting that next to the contaminated land problem as such, which addresses past pollution incidents, there is the field of soil pollution prevention which attempts to avoid future problems. Furthermore there is a relationship to waste disposal, past and present, which should be kept in mind. Most of the technologies and the methodological approach described in this paper apply to all these fields.

The soil contamination problems gives rise to four basic questions :

- \* What contamination is present? - the site investigation problem.
- \* Where are the contaminants going to? - the migration problem.
- \* If the contaminants get there, will there be a problem?  
- the impact problem.
- \* If the impact is significant, what can be done about it?  
- the remediation problem.

The first three problems can be integrated together by the "Source-Path-Target" methodology, a viable subset of risk analysis techniques. The last question is best considered apart.

### RISK BASED EVALUATION OF CONTAMINATED LAND PROBLEMS.

Turning first to the Source Path Target methodology. Risk analysis proper attempts to deal with real rather than perceived risks and this is the focus of the Source-Path-Target methodology. This is the basis of almost all formalised rational approaches to the risk driven assessment methodologies.

The objective of the methodology is to relate events, such as an emission of toxic substances from a contaminated site, to its effect at some sensitive point, or "target" in the environment. This relationship is a chain of sub-events, such as leaching followed by transport by groundwater and subsequent abstraction as drinking water, and is referred to as the "Path" connecting the Source of risk to the Target where its impact will be felt.

**The Source** is characterised by the nature and emission strength of the chemicals in the site.

**The Path** is the chain of pollutant migration events as described above and is a vector. In general there are multiple pathways between source and target and the further removed these two are from each other, and the more members in the chain of events forming the path that have to be considered, the more difficult the analysis.

**The target** is defined by its sensitivity and its position in the environment.

In theory the sensitivity of the target could be defined in toxicological terms given the contaminant and the required dose-effect relationships. However this is not always possible as the data bases are not available and because the pollutants reaching the target often form a cocktail of individual substances whose cumulative impact is only poorly understood. Many countries have approached this problem by setting chemical concentration standards rather than impact values. These are the maximum allowable concentration of MAC based standards of which the former Dutch A, B, C values have received wide application.

However the real problem centres not only around the level of the MAC values themselves, but where in the environment they are to be applied. The conceptual position around the site where the MAC values are applied is called the "target envelope". It turns out in practice that the position of this envelope can have profound influence on the range of remedial countermeasures available and in particular the costs involved.

Systematic and quantitative application of the source-path-target methodology makes it possible to translate the environmental problem at the target to an emission characteristic at the source. In turn this makes it possible to approach the soil remediation problem in terms of manipulating the emission characteristics at the source by geotechnical means. The methodological underpinnings of this will be considered next as the "reactor concept" of the source.

## **THE GEOSPHERE AS AN ACTIVE COMPONENT OF THE CONTAMINATION PROBLEM, THE REACTOR CONCEPT.**

Initially sites were excavated, the contaminated soil either dumped elsewhere or cleaned at great cost. However these measures, apart from being expensive, imperfect and time consuming were also highly disruptive of the use of the site. In recent years the focus has switched to attempting to treat the contaminated soil in place either now or in the future.

These in-situ techniques are of great potential and interest to geologists, geotechnical engineers and can greatly profit from other disciplines that can be called upon.

In order to facilitate this synergy between a wide range of disciplines, a conceptual framework has been sought to focus and hone the contribution of many disciplines in their application to the remediation problem. Such a framework has been found, more or less complete, in the field of chemical engineering. Together with the "Source-Path-Target" methodology it forms a key and effective framework both for present action as well as future development.

Whilst the reactor concept can be used for almost all contaminated land clean-up problems it is especially suited to those problems where the contaminated soil is left in place and treated without the expense and disruption caused by excavation and transport off-site. This restriction, by no means essential, allows concentration on the key issues of the concept and follows the major line of development in the field.

It has been amply demonstrated that excavation followed by replacement with clean soil and treatment of the excavated soils to (assumed) status-quo-anti pristine conditions were ideals seldom to be achieved in real circumstances. Isolation and containment strategies were successfully advanced and many sites have been addressed by these techniques both as holding measures and final solutions. Elementary containment technologies, even when effectively applied, gave rise to serious misgivings however. On the one hand there were risk perception problems that the problem had not really been solved and that leakage was still continuing and on the other hand that the impact of the contaminants on the surroundings had been simply postponed, the so-called "chemical time bomb syndrome".

In an attempt to find a way of combining the advantages of the in-situ techniques with the containment strategies the "soil as a reactor" methodology has been proposed. This views the site as a large in-situ chemical reactor.

Chemical reactors are contained systems holding re-acting chemicals and being subjected to some sort of control to achieve predetermined results. The chemical reactor being considered here is engineered and performs in the ground using geotechnical methods rather than being constructed as part of a chemical facility such as a refinery. None the less the entire conceptual armoury of chemical engineering can be focused on the problem of contaminated sites in this way.

Just as there are only four questions that can be asked of a polluted site, there are only three to be asked of a chemical reactor :-

- \* Does the reactor leak? - **The integrity question.**
- \* What goes on inside? - **The process question.**
- \* How can it be checked and manipulated? - **The control question.**

Each of these questions will be looked at in turn below.

A concept basic to chemical engineering is that of "unit operations" where each manipulative step is considered apart and is often carried out in a different process vessel. Examples are distillation, separation, extraction, reaction, adsorption and so on. Equally the in-situ process can be analysed in different components and it will be possible to assign different parts of the site, or the same part at different times, differing roles in the process. Not all of the process steps need be carried out in-situ. This is the case where, for example, contaminated groundwater is pumped up and treated above ground but on-site before reinfiltration.

The unit operation concept allows the whole site to be seen as a series of related sub-systems. In principle there are several basic relationships between systems :-

- \* A single reactor. This is the simplest system of all.
- \* Multiple reactors arranged in parallel (after each other) or in series (next to each other). This is the next stage of complexity and is commonly found in practice.
- \* Systems of multiple reactors connected together in series and parallel structures forming highly complex systems. These are the most flexible but the most difficult to design and implement.

Further, the reactor types can be classified into :-

- \* Batch reactors which are emptied and recharged at set intervals giving a discontinuous process, for example conventional land farming techniques.
- \* Continuous reactors where the reactants and products are continually added and removed giving a continuous process. An example of this is forced leaching with chemical infiltration.

A single site can be mixed depending upon the phase being considered. For example in the leaching example, this is continuous for the infiltrating chemicals but batch for the contaminated soil itself.

The effectiveness of fixed bed reactors can be measured by many parameters of which the most common are :-

- \* Conversion - how efficient are the processes themselves.
- \* Residence time - how close to the theoretical optimum is the system driven measured by the time it takes for the reacting chemicals to move through the system.
- \* Contact efficiency - are all the soils exposed to the reacting chemicals or solvents to achieve the overall maximum conversion.

These last two are often viewed together as the "residence time distribution", a frequency curve of residence times.

An ideal reactor is one that doesn't leak pollutants on the path to the target, runs under optimal process conditions that yield the desired results and which can be controlled to ensure that changes and disturbances can be adjusted to easily and quickly. It is the function of geotechnical engineers to build these reactors from contaminated sites.

### **CONTAINMENT AND ISOLATION, THE INTEGRITY PROBLEM.**

There are a wide range of containment technologies of which hard isolation, curtain walls and barriers, form one category and geohydrological isolation, manipulation of the groundwater flow regime, constitute the other. Their application can be found in standard geotechnical engineering texts. However some points are worth noting and are dealt with in what follows..

The effectiveness of containment techniques are commonly measured by the release flux of pollutants to the environment. (In fact the flux of water is often specified for cut-off walls!). The overall effectiveness of a containment technique is rarely measured at the target. Typically releases of kilograms per year (for benzene for example) at source are likely to be significant at the target.

Of critical importance in the design is the effective lifetime of the system for it is within this lifetime that the in-situ reactions have to be completed. Data from several in-situ treatment systems suggest that the lifetimes will have to be assured for decades if not centuries in order for these systems to stabilise to fail safe levels.

There is little information on the failure mechanisms of correctly installed systems partly because they have not been systematically monitored. For hard isolation techniques such as cement-bentonite cut-off walls or plastic foils the failure mechanisms are technical in nature and amenable to investigation. However for soft containment strategies such as geohydrological isolation and interception techniques, the continuous maintenance of the system poses the greatest failure threat and this in turn depends on many factors operating in society at large. In particular the maintenance of these systems in periods of loss of institutional control has not been looked into deeply. It is this concern that has lead to design concepts aiming at passive fail-safe behaviour as mentioned above.

In the design of the reactor wall there are basically three strategies :-

- \* Hard isolation techniques such as sheet piles, cement-bentonite cut-off walls and plastic sheeting.
- \* Migration interception techniques such as drainage ditches, vertical drains and sub-surface drains.
- \* Geohydrological techniques involving reversing the local field flow regime from away to towards the site. This is often called "pump & treat" and can be integrated into the in-situ process itself.

These will be quickly considered in turn to identify the areas of concern to the designer.



Cut-off walls forming the boundary of the reactor and of perhaps internal sub-systems are well known. Impermeability is often sought with water releases less than  $300\text{kg/yr/m}^2$  being commonly specified. This is often difficult to achieve as-built and it is even more difficult to assign any excess leakage found in, for example a pumping test, to the wall, the strata underlying the site or the joint between them.

In fact the real design point is the migration flux of hazardous chemicals through the wall and this has lead to the concept of using the chemistry of the wall as a barrier. For example it has been suggested that the cement in the cement-bentonite wall will buffer the pH in the pore liquid in the wall to a high value and thereby causing in-situ precipitation of heavy metals and/or forming a barrier to acids. Similarly the iron oxides resulting from a rusting sheet pile could form effective adsorption sites in the region of the barrier.

These mechanisms are of importance in the discussion of the failure mode of these walls by cracking, erosion or chemical destabilisation. It could be argued that even though the wall has an increased water flux through it at failure, the chemistry can still, for a time, effectively retain the hazardous material in the site.

Next to the well known geotechnical concerns of stability, construction material and technique, it is the integrity of the wall in the hostile environment of the polluted site that is of most concern. This is especially so since the active application of foreign chemicals such as solvents, acids and other aggressive materials introduced to effect the remediation will place an even greater burden on the material design. Many of these chemicals if leaked would form a greater hazard to the environment than the pollutants in the untreated site themselves. This need for adequate long term stability of the wall material has lead to the introduction of laminated and composite plastic/cement constructions.

The problem is compounded by the difficulty of locally monitoring the state of a single cut-off wall and the fact that very small cracks or windows can lead to environmentally significant releases. This can be addressed by installing double walls with a monitoring space between them or by always ensuring a reverse gradient from the surroundings into the site.

The overall reactor integrity is not only dependent on the wall construction but also on the base, often chosen as an (assumed) continuous impermeable strata under the site and on any capping design chosen. In many cases it is a problem for a geologist to assess the chances the base strata is continuous. Usually the only information available is at discrete points of sounding or drilling and the extrapolation of this information to the rest of the site is difficult.

Compared to the other technologies, interception for liquids has received less attention partly because it is only applicable to the saturated zone and to relatively shallow aquifers. On the other hand the technique is extensively used for vapour control both at polluted sites and waste disposal sites proper. The flow of vapours through soils under pressure is not fully understood and in particular local heterogeneities in the soil seem to play a dominant role and this has lead to some sites with poor capture ratios and escaping vapours. This effect coupled with dangers of soil liquefaction on liquid or gas injection has resulted in turn to suction systems being invariably used for air stripping and bioventing applications limiting the driving force to some half atmosphere underpressure. As vapour phase reactions such as forced oxidation or reduction can show promise, this can be an area of fruitful research.

The other major containment technology is that of geohydrological isolation. The basic technique is simple and well understood. In order to prevent loss of chemicals and pollutants from the site, the source is pumped and the hydraulic gradient ensures that all the flow is to the site. This technique is most commonly applied to operating industrial sites, often being described as a pump & treat inventory reduction technology, although the reductions are in fact minimal in terms of impact at target or real inventory reduction.

This apparently simple and geotechnically well understood technique is fraught with, amongst others, geotechnical difficulties. Firstly the net result is an, often large, abstraction of polluted water that has to be treated before discharge. Furthermore this flux of water is through the reactor volume and this may be undesirable given the process conditions required. Secondly the changes in head across the site can cause serious differential settlements leading to environmental and economic consequences far beyond those likely from the original pollution. Thirdly the heterogeneities and general unknown properties of the soils can lead to poor estimates of the influence area of the pumps jointly and individually and this can in turn lead to poor capture efficiencies of the chemicals concerned. Experience has also shown that a large array of small well points can develop severe instabilities or hunting problems as time goes on. A further concern is the need to operate the system over many years and this leads to maintenance problems at the well points and above ground. Last but not least of the disadvantages of this technique is the possibility of pulling pollution from a neighbouring site to the one being cleaned with all the legal and economic consequences that that brings.

Two major geotechnical challenges can be identified with this technology. The first is to maintain capture efficiency at an absolute minimum of overall abstraction volume and in heterogeneous soils. The second is to be able to design self adjusting well point arrays that give stable capture efficiencies under changing conditions.

Lastly mention has to be made of more exotic techniques of creating containment barriers such as utilising fluid density contrasts (fresh water lenses in a salt water aquifer and temperature driven flows), Ostwald effects (electro-osmosis, thermo-osmosis etc.) and biochemical barriers.

Finally before leaving the integrity problem it is worthwhile to mention the difficulty and the need for adequate monitoring techniques for the effectiveness and condition of the containment system both during installation, in operation and in the long term. This is a key area of current research.

## THE PROCESS PROBLEM

Having ensured that the "walls" of the reactor are secure, it is possible, in principle at least, to apply any combination of chemistry and physics to the problem. In fact this is likely to be necessary as most chemicals that are found in society are found in polluted sites in one place or another. Furthermore the chemicals are often present as mixtures in one or several phases. Some pollutants actually form part of the solid granular matrix of the ground, for example ashes and waste metals on tips.

The processes available are physical (dissolution, strip-ping, extraction, evaporation and separation and so on) or chemical, (oxidation-reduction, acid-base, leaching, precipitation and the whole spectrum of organic and biochemical reactions). The chemicals that have polluted the site were originally made using sophisticated and dedicated chemical techniques and there seems to be an unwarranted optimism in the geotechnical community, and especially their clients, that a single simple technique will clean a site up.

The design of the clean-up process is difficult for several reasons :-

- \* The efficiency of the process has to be extremely high. For example phenol tar removal efficiencies in the order of 99.99% minimum have been commonly specified and Cadmium extractions of the same order will be required to meet some existing legal standards.
- \* The range of reaction conditions, temperature and pressure is very restricted compared to those used by the chemical industry.
- \* The cocktail effects mentioned above. For example, acid extraction of heavy metals with cyanides present as copollutants could prove fatal for the operator.

In fact the major successes to date have been on simple sites with single pollutants, often only at a demonstration project level. These design constraints lead to the following process characteristics :-

- \* Multiple sequence techniques either in time or at different parts of the site, stripping followed by biochemical degradation in the bioventing technique, for example.
- \* Multiple passes of the same technique leading to process times of many times the single reactant residence time in the site.

Taken together these generally mean that in-situ clean-up is a time consuming affair and that process presimulation using modelling techniques has become more and more necessary.

There is little contribution that the geotechnology as such can make to the process design, its' real contribution being at the next stage, the implementation and control of the reactions to the conditions arising out of the physics and chemistry.

## THE CONTROL PROBLEM.

Once the reactor has been built and the chemical process decided upon then it has to be applied. This has two aspects :-

- \* Adjusting the conditions in the reactor to achieve the desired reaction strategy.
- \* Monitoring the process and adjusting the conditions were necessary.

The whole theory of process control can be imported into environmental geotechnics at this point.

The objective of the process is to control and influence progression of the clean-up in time and across the site.

The variables generally available for control are :-

- \* Reactant or solvent concentrations at the input to the system. This is an easy variable to control in most situations.
- \* Contact time between the system components, generally controlled by the rate at which the process is driven. This depends on factors such as permeability to the reactants and is often bounded by a too low a maximum.
- \* Limited temperature control and almost no pressure control. These limitations are less severe than might be expected in that small temperature changes can have significant reaction rate effects and pressure has little effect except in vapour phase reactions.

Exotic processes will have exotic control variables and in some processes there may be no effective control mechanism on hand to use.

The second process variable is worth looking at most closely as it can be there that geotechnics can make a major contribution. There are two aspects of the problem. Firstly the actual average time of contact between reactants and polluted soil and secondly the actual time of contact between each element of polluted soil and the reactants. These two can differ widely because of the sharp coupling between the pore sizes and their connectedness on the one hand and the local flow velocity on the other.

As far as the first is concerned, no system or sub-system can be driven much harder than its permeability will allow given a reasonable head to avoid liquefaction and piping, and no faster than the permeability coefficient if the system is unsaturated and gravity drained. Furthermore multiple phases such as oils, gases and biomass can have orders of magnitude effects on these conductivities.

If the properties of the site are unsuitable for achieving the desired contact times they will have to be changed by techniques such as soil conditioning, in-situ granulation, fracturing, jet grouting and so forth. These techniques have been rarely applied to in-situ treatment but should significantly extend the range of sites that can be successfully treated.

The actual distribution of contact times around the system average is a very important variable. It is measured by the so-called residence time distribution at the site. This term usually refers to the

distribution of travel times of water through the site and can be measured using tracer techniques and estimated using modelling techniques. Its extension to reacting and interacting chemicals is always a modelling exercise, physical or mathematical, and usually of the highest order.

There are two factors influencing this distribution. Firstly, there is the overall geometry of the flow situation, differing flow lines giving different travel times. Secondly the distribution reflects the heterogeneity of the system. The chemicals flow around impermeable strata and only diffuse into them slowly. This means that the bulk of the chemical travels more quickly than desired whilst the inaccessible pores are only slowly accessed by the reactants.

Of course the same considerations applied to the initial pollution load in the beginning and they will have penetrated less deeply into, say, clays than sands. However in many cases there has been ample time to diffuse into the impermeable layers and there is but a limited time to send the reactants in to get them out.

In general the sharper the residence time distribution, that is the more uniform the travel times, the more efficient is the reaction process. This can be helped by geotechnical measures directed either at homogenisation of the soil (mixing, micro-fracturing clays etc.) or by arranging the flow processes such that each heterogeneity is treated as an apart system. Again this is usually studied using computer models before field application. The data requirements for effective modelling of heterogeneous systems can be very severe and statistical techniques are often invoked.

In order to control a process it has to be monitored. This is the well documented problem of sampling and/or in-situ measurement. The former has major reproducibility disadvantages and give only snapshot information whilst the latter is in its infancy. Actually the specifications for an in-situ process monitoring probe are less severe than an in-situ absolute determination probe designed to replace sampling and laboratory chemical analysis and more progress has been made in this application.

## CONCLUSIONS

This paper has attempted to introduce a new methodology which used alongside the risk based techniques for remedial assessment and design can lead not only to successful harnessing of the geosphere in its own clean-up but to new avenues of, hopefully, fruitful development,

## THE PROTECTION OF GROUNDWATER QUALITY IN THE UK; PRESENT CONTROLS AND FUTURE ISSUES

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### ABSTRACT

*Groundwater pollution and its prevention are discussed in the context of the currently perceived issues in the UK and Europe and the future challenges, particularly in addressing historical pollution within the existing regulatory framework. Contamination from industrial processes and facilities is considered to be the most serious point source but its significance has not been appreciated because of the preoccupation with landfills. The influences of legislation, education and policy are reviewed and the growing impact of liability issues discussed. Progress in the development and implementation of the Environment Agency's Groundwater Protection Policy is described. Developments in the use of groundwater modelling and risk assessment techniques are considered in the light of the growing need to examine the cost-effectiveness of remedial treatment of historical pollution.*

### INTRODUCTION

Over the past five years groundwater issues have been higher on the UK environmental agenda than at any time previously. However, the awareness of the public in general, and industry in particular, about the importance of groundwater as a water resource and the need for its protection remains at a relatively low level in comparison to other developed countries. The publication and dissemination of a national policy for the protection of groundwater in 1992 has helped to raise the profile (NRA 1992). European initiatives have placed groundwater on the political agenda and, through the production and implementation of Directives, affected particular businesses, most notably those in agriculture, waste disposal and property development. Nevertheless it remains a truism that "out of sight is out of mind" and there is still a need for better education about the potential for many different land users to affect the underlying groundwater environment.

The growing realisation of the extent of groundwater pollution under industrial sites coupled with a better technical understanding of the hydrogeological and biogeochemical processes that govern pollutant transport in underground strata will lead to interesting challenges for regulators and industry alike over the next few years if we are to ensure that our water resources are secure for use by future generations.

### GROUNDWATER QUALITY ISSUES

There is no catalogue or database of groundwater pollution for the UK. The lack of collated data and a national view has handicapped regulators from focusing on the main activities that have caused groundwater pollution. A preoccupation with landfill has also diverted attention and resources away from other important sources of pollution.

One problem has been the poor standard of our groundwater quality monitoring network. For historical reasons this has been based largely on public supply sources and has never been designed according to specifically identified objectives. Thus what data have been collated give either an optimistic impression, based on public supply abstractions which have received protection over the years from potential sources of pollution, or the opposite where it is based on monitoring around pollution sources such as landfills for specific legislative reasons. It is therefore difficult for the Environment Agency, apart from any other interested party, to gain a good understanding of the state of the nation's groundwater. The lack of resources invested in basic groundwater monitoring over the years will need to be redressed, perhaps at the expense of our surface water surveillance network. The National Rivers Authority (NRA) reviewed the situation in its latter years and the Environment Agency will draw up an overall monitoring strategy.

## **DIFFUSE POLLUTION**

The majority of groundwaters that are considered to be contaminated have been affected by diffuse pollutants from agricultural land use practices. Nitrate concentrations in abstracted groundwater for many outcrop areas of our Major Aquifers will exceed the maximum allowable concentration for drinking water supply (50 mg/l as  $\text{NO}_3$ ) early in the 21st century.

### **Nitrate**

Concentrations in pore waters leaving the soil zone from under intensively managed agricultural land can exceed 50 mg/l by several times. It is only the dilution afforded by mixing with low nitrate water from non-agricultural areas in the same catchment and older water at depth which allows the water companies to continue to utilise groundwaters in the traditional way. Even so it is necessary to treat groundwater supplies in some areas in order to maintain blended water in the distribution system below the legal limit. The first full-scale nitrate removal plant became operational in 1990 in the Lichfield area. (Woodward 1994). Others have followed and if the current rise rates are maintained it will become an increasingly common feature in those central and eastern parts of the country where a heavy reliance on groundwater coincides with intensive agriculture and low rainfall.

### **Solvents**

Similarly diffuse pollution in those urban areas which coincide with Major Aquifers has had a significant impact on groundwater. Studies of Birmingham and Coventry in particular have shown the widespread existence of chlorinated solvents in around 80% of sampled boreholes. (Lerner and Tellam 1992). In these areas the ubiquitous use of solvents in the motor and associated industries has resulted in large numbers of discrete sources coalescing to give rise to a diffuse pollution problem. Chlorinated solvents are also a significant source of pollution in rural areas from point sources. At least 14 public supply boreholes need treatment in order to keep supplies to domestic users below the very low legal limits (30  $\mu\text{g/l}$  for trichloroethylene and 10  $\mu\text{g/l}$  for tetrachloroethylene). (Harris 1993).

### **Pesticides**

Similar very low acceptable pollutant levels have made the case against the third category of pollutants, pesticides, difficult to establish. Maximum allowable concentrations for individual pesticides are as low as 0.1  $\mu\text{g/l}$  (ie five orders of magnitude difference from the concentration for nitrate). For many pesticides analytical techniques have not been devised and for many others detection levels and maximum acceptable levels are similar. Sampling protocols have to be exceedingly stringent at such low concentrations and it is doubtful whether much confidence can be placed in positive data unless there is evidence of repeated exceedance and concentrations significantly in excess of the detection limit. However, it is certain that the non-agricultural use of the herbicides atrazine and simazine presents a

very real threat to groundwater. Several borehole supply sources have become significantly contaminated, some severely enough to be taken out of supply or to necessitate treatment. Several examples can be found of the affected source being situated close to a railway line where periodic spraying has taken place onto a largely soil-free surface, sometimes within a cutting and therefore closer to the water table.

There are fewer examples of significant contamination from the purely agricultural use of pesticides. The use of soakaways for the discharge of washings or wastes may lead to an exceedance of the attenuating capacity of the soil or underlying strata and will be a significant threat, particularly on fissured aquifers, but much research remains to be carried out before we can quantify the risks. Concerns have recently been raised about the increasing planting of maize since the early 1990s and the consequent use of atrazine as a pre-emergent weedkiller on a more widespread basis.

## POINT SOURCES

Herbicide spraying on railway track can be considered a linear source of pollution while soakaways are classical point sources. Such discrete sources of pollution can give rise to very significant effects which by their very nature are geographically confined. Because the processes which attenuate pollutants once they enter the ground can be readily overloaded by high concentrations of pollutants, groundwater contamination may spread for some distance as a well-defined plume.

The Department of the Environment carried out a very broad overview of groundwater pollution in England and Wales in 1988 (DoE 1988) but a more comprehensive study was undertaken for the NRA in 1995 (De Hénaut et al 1996). Although the data for the study was derived from limited sources, the results give the best indication of the nature and extent of point sources of groundwater pollution in England and Wales.

Landfill sites are numerically the most significant category of land use identified in the study, since the data collected is biased towards those land use categories which are more highly regulated, but in terms of their actual impact on groundwater they are considered to be somewhat less of a problem than other sources and types of pollutants.

Industrial activities have undoubtedly given rise to the most significant examples in the UK. Incidents are increasingly coming to light as companies carry out evaluations of their property, in connection with land sales, new development or environmental audits, which involve an investigation of groundwater quality. It is now apparent that beneath the majority of industrial premises that handle, manufacture or store organic chemicals in liquid or soluble form, the groundwater will be found to be polluted to some degree. The extent of localised contamination at some locations can be significant with percentage levels of some soluble compounds encountered at some distance below water table.

The main point source groundwater contaminants are organic chemicals. These have many uses such as fuels (hydrocarbons) and degreasants (chlorinated solvents), or in various manufacturing processes (eg cutting oils, a variety of raw chemicals). Other sources relate to the deposition of waste chemicals, for example the products of coal-gas and coke manufacture (creosote and acid tars). Significant cases from controlled landfill are difficult to find, although where the attenuation capacity both within and outside the landfill has been exceeded, substantial groundwater pollution has been recorded. Examples include landfills at Helpston, Cambridgeshire and Pakefield, Suffolk where pesticide disposal has impacted on groundwater resources, with the former affecting a public supply. (Anon 1993a)

Significant pollution from inorganic chemicals (apart from nitrate) is generally much rarer because of the differing scales of concentration considered to be a problem and the specialised conditions in which they will be mobile. For instance heavy metals are rarely a problem in the groundwater environment

since they can readily adsorb onto the rock matrix unless there are particularly acidic conditions, or other conditions that give rise to increased solubility.

Incidents of groundwater pollution from point sources have been difficult to identify since reliance must be placed on contamination reaching a monitoring location, a borehole or spring for example. Because groundwater moves so slowly within aquifers, it can often take many decades for the effects of polluting activities to be detected. By then there is a substantial volume of water, and rock, which is affected and clean-up is very difficult, and expensive. Where incidents are identified which present a long-term threat to public water supplies derived from groundwater, the approach of the Environment Agency is usually to require the occupant to carry out a site investigation and identify the extent of the pollution. Once sufficient data are available a modelling study can be undertaken to determine the likely fate of the pollution plume, the timescales involved and the risks to public supplies or other potential discharge points such as watercourses. A scheme of remediation is then developed and tested against the model. Experience to date shows that larger companies tend to be willing to co-operate in such approaches, although even with these the large costs of a groundwater site investigation and potential clean-up can be difficult to finance, particularly in times of recession. There is more reluctance with smaller companies or landowners who lack the necessary funding and also where the pollution results from a previous use of the site such that the liability is inherited.

However, there are relatively few instances of highly significant impacts on groundwater users. We still await an example on the scale of Love Canal which did so much to raise public awareness in North America and galvanise legislation both in terms of prevention and clean-up. The example that has done most to raise issues of historical liabilities is the legal case between Eastern Counties Leather and Cambridge Water Company that was eventually determined by the House of Lords (Anon 1993b). This involved a claim for compensation in respect of a public supply source that was contaminated, and subsequently had to be abandoned, due to contamination by trichloroethylene which had entered the groundwater as a result of practices at the leather company. The Law Lords determined that, although there was no doubt of the source of pollution, the polluter could not be held responsible for his historical actions when it could not have been foreseen that they would give rise to the problems that occurred. These new concerns over liability for contaminated land and groundwater, fuelled by the debate over new and proposed contaminated land legislation and the Eastern Counties Leather case, have made industry consider groundwater pollution much more seriously than in the past. The insurance profession may therefore impart controls that regulators cannot.

## THE REGULATORY FRAMEWORK

The Environment Agency is the primary agency responsible for regulation of the water environment in England and Wales. In Scotland and Northern Ireland the role is undertaken by the Scottish Environmental Protection Agency (SEPA) and the Department of the Environment respectively. Other bodies have an indirect regulatory role, most notably Local Authorities. Control is exercised through a combination of, legal requirements, statutory and non-statutory codes of practice, published policy and guidance documents, together with general advice and education.

## LEGAL CONTROLS

Groundwater protection was not specifically addressed in UK legislation until the Water Resources Act of 1963 and only then for the very narrow activity of discharging effluent direct to groundwater by means of wells, pipelines or boreholes. Although various other activities were brought under control in the Control of Pollution Act 1974, these all related to point sources of potential pollution and it was not



until the Water Act 1989 that legislation designed specifically to control diffuse pollution, from agricultural land use, was introduced.

The single most important influence on groundwater quality legislation and pollution prevention practice has been the European Directive on the Protection of Groundwater from Dangerous Substances implemented in 1981. It also only relates to point sources of pollution but requires the protection of *all* groundwater from specific substances or groups of substances (List I and II compounds) regardless of present or future use and the extent of the aquifer within which it is contained.

The relevant legislation under the jurisdiction of the Environment Agency is mostly contained within the Water Resources Act 1991 and effectively takes forward those provisions within Part II of the Control of Pollution Act 1974 and the Water Act 1989 which relate to the water environment. Further powers are contained in the Environment Act 1995, most notably those relating to the clean-up of contaminated land and the enhanced powers to require remediation of polluted groundwater. It is an offence to pollute controlled waters, including groundwater. Powers have been available to prosecute the owners of sites for allowing or knowingly permitting pollution to take place from their land. (Section 85 of the Water Resources Act 1991). However, it is difficult and expensive to gather sufficient evidence to prosecute a polluter since the drilling of boreholes is both costly and uncertain. This is reflected in the fact that only three prosecutions regarding groundwater pollution events were taken by the NRA in its lifetime. Powers have also been available under Section 161 of the Water Resources Act for the NRA/Environment Agency, to forestall or remedy pollution where necessary by carrying out relevant works itself and reclaiming the costs of so-doing from the site owners. Although S.161 powers have often been invoked in the case of surface water pollution incidents, they have rarely, if ever, been used in promoting the clean-up of historically contaminated groundwaters, or in cases where the groundwater is interacting with surface waters and causing a consequential deterioration in quality. This was primarily because the high expense of undertaking remediation works was not funded within the regulatory authority, particularly when there was in most cases little likelihood of successful cost recovery.

The introduction of Section 57 and Schedule 22 (para 162) of the Environment Act is therefore a welcome legislative addition to the regulator in this field and should provide an impetus to the further improvement of controlled waters. However, few powers are available to the Environment Agency to *prevent* pollution. Most of its powers are retrospective once pollution has occurred. This presents a problem for groundwater since clean-up is a very difficult and long-term process, highly expensive and rarely completely effective.

Section 92 of the Water Resources Act 1991 enables the Secretary of State to make Regulations to control any activity and thereby prevent pollution. The only Regulations introduced so far relate to the storage of farm slurries and agricultural fuel oil. The vast bulk of potentially polluting activities remain uncontrolled for the purposes of avoiding pollution of controlled waters.

Section 93 approaches pollution prevention from a different perspective by allowing for the definition of statutory zones within which various prescribed activities can be prohibited or only permitted under formal consent of the Environment Agency. Statutory zones have been a common feature of European pollution control practice for many decades and there are isolated examples of their past use in local situations in the UK. Although they have a place in surface water pollution control, they are not considered appropriate in the UK today, for general groundwater pollution prevention purposes, because of the inherent uncertainty in zone definition. However, statutory groundwater protection zones have effectively been introduced by the back door in relation both to Nitrate Sensitive Areas (NSAs) and the designation of land as Nitrate Vulnerable Zones (NVZs) set up for the control of diffuse pollution of nitrate from agricultural land use practices.

Processes which are prescribed under the Environmental Protection Act 1990 are controlled by authorisations granted by HMIP. The authorization process considers possible discharges to all media, including groundwater and can be a powerful preventative tool in requiring such measures as bunding around storage tanks, above ground distribution pipework etc. However, there are many processes which are not covered under the Integrated Pollution Control (IPC) procedures and often only specific activities on a large site are controlled by this means.

## **INDIRECT CONTROLS**

Apart from direct legislation, other legal controls and requirements can be highly effective in preventing pollution or minimising its impact. The most important, and often undervalued, of these are the controls within the Town and Country Planning Act 1990 and related legislation. The policies in statutory development plans are particularly important in that they set out the framework for land use change and provide the key reference in determining development applications. Many developments, ranging from large industrial estates to graveyards, which pose direct or indirect threats to groundwater require planning permission. The Environment Agency is a consultee of Local Planning Authorities (LPA) over new development and measures to limit the effect of the particular activity can be requested in any planning permission granted where no other legislation exists to control it.

Another example of an indirect control concerns the requirement for underground petroleum storage tanks to be licensed under the Petroleum (Regulation) Acts 1928 and 1936 by the relevant local authority (fire authorities in Metropolitan areas). Although the Environment Agency plays no formal part in this, its aims and those of the licensing authority are similar; there should be no leakage.

Codes of practice have been developed for many facets of industry and agriculture. These are produced by government departments or industry and are a powerful way of promoting ideals and achieving consistency. Relevant examples are the Code of Good Agricultural Practice for Water, the series of Waste Management Papers, published by MAFF and DoE respectively, and the Institution of Civil Engineers Guide to Contaminated Land: Investigation, Assessment and Remediation. However, unless there is a statutory requirement to follow the guidance it is unlikely to be universally applied. Education and promotion of the guidance has a vital role to play in achieving its aims.

Sometimes it is sufficient to draw the attention of the user or manufacturer of the particular chemical to the problems that result, since they are often unaware of the impact of their actions/product. The use of atrazine by British Rail as a herbicide on the permanent way is a good example. This was taken out of use as a result of informal discussions between the water and railway industries and has since been prohibited for non-agricultural use in general.

## **EDUCATION**

Public understanding of groundwater and the need for its protection is low within the UK. To some extent this reflects our relatively low usage of groundwater for drinking water (around 30-35% of the total) compared to some other developed countries (Denmark 98%, Germany 89%, Netherlands 67%, USA 50%) and there have not been any significant pollution events to catch the public imagination. In Germany and the Netherlands for example it is a common sight to see road signs delineating the boundary of a water protection zone. Besides having the effect of making the area off-limits for the transport of potential contaminants, this is a simple device for increasing public awareness.

Occasionally groundwater issues are used by local objectors in an attempt to help them resist particular developments which they oppose for different reasons more immediate to themselves. Invariably on these occasions a purist viewpoint is taken and strict interpretations of the EC Groundwater Directive are promoted without wishing to understand the complexities of the many factors that the professional

hydrogeologist has to take into account. The concept of risk is particularly poorly understood. The professional is as much to blame for this situation as anyone since there has been little previous attempt to promote understanding beyond a narrow group of specialists.

The United States in particular has a high level of public involvement and consultation in local decision making. Some States have promoted groundwater awareness campaigns within local communities aiming much information at schoolchildren. The annual Childrens' Groundwater Festival sponsored by the Nebraska Groundwater Foundation<sup>1</sup> is a good example. They are attempting to promote better understanding in a popular way including demonstrations, visual aids and even folk songs. "Hey Mister, that's my aquifer" may not get to number one in the charts but it is a novel way of getting a message across to those who may be resistant to other means. Educating children is surely the best way of helping ensure that those in future charge of substances that can cause harm to the groundwater environment will at least be aware of their responsibilities. It is an area that has received limited recognition in the UK and one that the Environment Agency would do well to address in future. The publication and promotion of the Groundwater Protection Policy has started this process in a general way but much remains to be done.

## GROUNDWATER PROTECTION POLICY

Policies to protect groundwater sources are not a new idea. Many examples can be found in the UK water supply industry of protected areas, relating to the perceived source catchment, within which activities were restricted or banned. This was in some ways easier than today because the management of local water supply was often in the hands of the same body that controlled development, the local authority. Sometimes bye-laws were used. In the Margate Act 1902 the water authority was given the power to control drains, closets, cesspools etc. over an area of 1500 yards from any well or adit. Brighton Corporation also obtained similar powers in 1924 over an area with a radius of two miles around individual sources abstracting from the Chalk. (Thresh and Beale 1925). In more recent times the formation of the Regional Water Authorities in 1974 gave an opportunity to develop more widespread policies across water supply boundaries and catchment divides. The first of these was published by Severn-Trent Water Authority in 1976. (Selby and Skinner 1981).

The formation of the NRA provided a further opportunity for national policy development and a document, published in 1992, has been adopted by the Environment Agency.<sup>2</sup> It sets out a framework for groundwater protection decision making, particularly in land use planning. One objective was to make other regulatory bodies aware of the NRA's concerns and approach. It also attempted to raise awareness of groundwater matters and enable a greater internal consistency of approach by the Authority. The national policy is based upon the concept of groundwater vulnerability in order that the greatest protection is given to those groundwater resources most at risk. (NRA 1992)

## VULNERABILITY MAPPING

The Environment Agency has published a series of groundwater vulnerability maps which show in general terms for groundwater pollution where the safest and most risky areas are for the development of potentially polluting activities. The maps take into account the large part that soils can play in attenuating the effects of surface loadings of pollutants and also the generalised geology divided into the

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<sup>1</sup> The Nebraska Groundwater foundation is a non-profit making educational foundation dedicated to educating the public about the conservation and management of groundwater

<sup>2</sup> The Rivers Purification Boards in Scotland produced a draft Scottish policy based on the NRA document and the DoE Northern Ireland are considering something similar.

three broad categories of Major, Minor and Non-Aquifers. These represent the importance of particular rock types for water resources and the intrinsic permeability of the strata. Many other factors also affect groundwater vulnerability in any particular location, such as the depth of unsaturated zone, the presence and nature of overlying Drift deposits and the nature of the contaminants. Since these are so site specific it is important to recognise the maps as planning tools to be used primarily as a filtering mechanism for new development. Site specific studies will always be required when considering detailed proposals. (NRA 1995a)

A total of 53 maps will have been published on a progressive basis by 1998. These are at a scale of 1:100,000, giving complete coverage of England and Wales. The maps have already found acceptance by planning authorities as an aid in the drawing up of structure plans and have also been used by industry in prioritising actions for site investigation and clean-up on sites spread over wide geographical areas. Other uses include the planning of sewage sludge application to agricultural land and in routing new transport infrastructure. They should ultimately gain a permanent place in land use planning.

## GROUNDWATER PROTECTION ZONES

Protection for individual abstractions is aided by the definition of three annular zones around each borehole and spring source which are based on 50-day, 400-day travel times and the whole catchment area, in order of decreasing risk to the abstraction. The zones have been produced by the Environment Agency using proprietary steady-state, two-dimensional model codes (FLOWPATH in most cases) with currently available data. In some cases data availability is limited or the hydrogeological situation too complex for the model to produce zones in which a high degree of confidence can be placed. For these situations zones have had to be produced manually according to defined protocols because of the difficulty of modelling. Examples can be found in karstic aquifers and for spring sources. This is one reason why the Environment Agency has not sought to prescribe the zones in statute since with the provision of additional or better data and subsequent remodelling more accurate shapes may be produced. Borehole pumping rates may also vary and, particularly in heavily exploited aquifers, the resulting changes in catchment shapes can have knock-on effects throughout a series of abstraction sources over a wide area. (NRA 1995b)

The primary use of groundwater protection zones is therefore, like groundwater vulnerability maps, as a screening tool which give broad indications about the potential risks to groundwater. Decision making about specific sites will always require more detailed appraisals of the risks to groundwater which will also take into account the risk limitation which can be introduced by engineering or management techniques. There is also considerable benefit in Water Companies and regulators knowing roughly the area from where abstractions draw their water in order that existing pollution risks can be identified and action taken where appropriate.

The programme of groundwater protection zone definition embarked on in 1992 by the NRA, and due for completion in 1998, is the most ambitious of any European country. Around 2000 individual sources will have had their zones defined and published by then. Manuals will be published describing the methodologies used thus allowing those who wish to refine any zone to do so using a similar approach but with additional data.

A number of zones have been defined specifically for the purpose of delineating areas where controls on agricultural land use will have most benefit for the reduction of nitrate leaching. These have been set up under the Nitrate Sensitive Area (NSA) voluntary schemes and also for the purposes of defining Nitrate Vulnerable Zones (NVZs) under the EC Nitrate Directive. For the most part NVZs are rather smaller areas than the equivalent groundwater protection zones. This is because they have been defined with an inner area of confidence, where they relate to individual groundwater sources, within which there is a

greater certainty that the changes in land use will impact on the abstracted water in the longer term. (Fermor et al, 1996)

## **EC GROUNDWATER ACTION PROGRAMME**

The EC Groundwater Directive has been in force since 1981. It has been recognised that there are many deficiencies in it; not the least that in excluding groundwater resource issues and diffuse pollution it is very narrow in its application. An EC Council Resolution in 1992 followed a Ministerial seminar in the Hague the previous year and has led to the establishment of a Groundwater Action Programme. A Plan was published in July 1996. This has the objective of establishing "a programme of actions to be implemented by the year 2000 at national and Community level, aiming at sustainable management and protection of fresh water resources". It will also provide some key elements for a future framework Directive on water.

Specific objectives are to :-

- i) maintain the quality of polluted groundwater
- ii) prevent further pollution
- iii) restore where appropriate, polluted groundwater

The recognition of the need for an integrated approach such that groundwater and surface water should be managed as a whole paying equal attention to both quality and quantity aspects will improve our legislative base. The final Plan and a revised Directive will be a welcome emphasis of the importance of groundwater and its protection and should help to promote consistency within the European Union.

## **FUTURE ISSUES AND CHALLENGES**

As we learn more about the state of our groundwater resources the biggest challenge will not be so much in protecting it from further deterioration as a result of point source pollution but rather how to address the historical legacy from industry and deal with the diffuse sources from agricultural land use and atmospheric deposition.

## **HISTORICAL LEGACY**

A strategy is required for tackling the legacy of groundwater pollution which emanates from a time when the significance of groundwater pollution was largely unrecognised and the concentrations of pollutants which now give rise to concerns about human health were not able to be detected by analytical techniques. In the USA naivety about the complexity of groundwater flow mechanisms and the efficiency of groundwater clean-up led to widespread remediation targets for drinking water quality which have been difficult if not impossible to achieve, particularly for non-aqueous phase liquids (NAPLs). This philosophy is now being challenged.

Active remediation of groundwater pollution is clearly at a low level in England and Wales (De Hénaut et al 1996). Of the point sources of pollution identified in the NRA study only 44% were having some form of remedial action applied and of these only 25% (11% of the total) seemed to be positive schemes involving techniques other than surface capping or excavation of overlying soils. Pump and treat operations were being carried out in only 8% of the occurrences identified.

Table 1 below is reproduced from a US National Research Council study on groundwater clean-up and illustrates, from an evaluation of some 80 pump and treat operations, the dependence on geological conditions for a range of contaminants. (National Research Council 1994).

Hydrogeology	Contaminant Chemistry					
	Mobile, Dissolved (degrades/ volatilises)	Mobile, Dissolved	Strongly Sorbed, Dissolved (degrades/ volatilises)	Strongly Sorbed, Dissolved	Separate Phase LNAPL	Separate Phase DNAPL
Homogeneous, single layer	1 <sup>a</sup>	1-2	2	2-3	2-3	3
Homogeneous, multiple layers (Triassic sst)	1	1-2	2	2-3	2-3	3
Heterogenous, single layer	2	2	3	3	3	4
Heterogenous, multiple layers	2	2	3	3	3	4
Fractured (Chalk)	3	3	3	3	4	4

<sup>a</sup> Relative ease of clean-up, where 1 is easiest and 4 most difficult

**Table 1**

The Chalk and the Triassic sandstones have been placed into their most likely categories. It is clear that for some aquifers polluted with certain chemical species remediation will be almost impossible and we will have to look to different strategies.

The UK attitude has always been a pragmatic one based on what is practically feasible and economically necessary. This is reinforced by the "suitable for use" approach of government to remediation of contaminated land (and groundwater) which requires that remedial action should take place only where:-

- i) the contamination poses unacceptable risks to health or the environment and;
- ii) there are appropriate *and cost-effective* means available to do so, taking into account the intended or actual use.

This approach cannot be adopted in the prevention of pollution since the current EC Directive requires the protection of *all* groundwaters but where there has been significant historical impact the appropriateness of clean-up or the extent to which it should be employed is a major factor. The Groundwater Protection Policy of the Environment Agency recognises this in respect of urban contamination, such as in Birmingham where the aquifer has effectively been abandoned as a potable water resource. Policy statement D6 states "In areas where historical industrial development is known to have caused widespread groundwater contamination, the NRA will review the merits and feasibility of groundwater clean-up depending upon local circumstances and available funding." Such decisions cannot be taken lightly so there is a need to gather considerable amounts of information in advance. Apart from a relatively few examples the standard of site investigation in the UK is currently poor.

## THE SETTING OF GROUNDWATER CLEAN-UP VALUES

The US experience also cautions us against the use of generic clean-up standards. Drinking water standards are clearly unachievable in many situations and other goals may have to be set depending on circumstance. In almost all situations involving organic compounds there will be a residue left within the pore spaces of the rock, absorbed onto the rock matrix or simply dissolved at low concentrations in the relatively immobile porewater. Natural processes of biodegradation have an important role to play and may, in the right conditions, reduce residual pollutants to background concentrations given enough time. This may be sufficient to prevent any impacts on the biosphere. However, our knowledge of such processes is still extremely limited and it will be difficult for regulators to accept such mechanisms as the reason for inactivity over remediation, without sound research evidence.

There has been considerable work carried out within the DoE R&D programme to consider clean-up values for soils to protect various end users. The former NRA also undertook work to consider appropriate remediation values to protect the water environment and the Environment Agency is currently working on a methodology for setting remediation targets in respect of soils which are continuing to affect controlled waters and also groundwaters which are historically contaminated. There are some difficult legal issues which need to be resolved in respect of the latter.

Developers, site owners and industry are increasingly aware of their liabilities in having given rise to, or owning land relating to, groundwater pollution. Whether clean-up is driven by Section 57 or Section 161 legislation, by redevelopment, or by concerns over civil liabilities, the Agency is being asked for advice about the level of remediation which should take place. This prompted a project which was undertaken by the Water Research Centre on behalf of the NRA.

The Agency is keen not to be over prescriptive regarding the setting of targets and the methodology allows for a site specific approach to be adopted. This involves selecting a target/receptor of concern (borehole abstraction; spring; watercourse) and considering the desired water quality that it is required to be maintained. For example, drinking water standards at a public water supply abstraction, Environmental Quality Standards/Water Quality Objectives for a watercourse. The groundwater quality to be achieved at the place where the groundwater is known to be polluted (ie within the plume of groundwater contamination) can then be back-calculated, given some basic information about the characteristics of the aquifer in that particular location.

Groundwater clean-up is very expensive and will be long-term in its application if highly exacting standards are to be achieved. In the case of smaller firms funding may not be available. The method is intended to make use of the physical effects of dilution and dispersion and the natural biochemical attenuation processes which can occur as groundwater flows through underground strata. It therefore allows for the balancing of costs and benefits and the adoption of a pragmatic approach.

A potential problem arises since the approach is based on the protection of an ultimate receptor which has a known use (borehole for drinking; river for drinking/fishing/recreation etc). In order to gain the maximum benefit from the natural clean-up processes, and balance the costs and benefits, the plume of contamination may be allowed to continue to migrate down the groundwater gradient and pollute, currently unpolluted, groundwater. The situation is dealt with in the methodology by inserting a virtual target/surrogate receptor downgradient. This was done to allow for a degree of attenuation without writing off too large tracts of aquifer.

## NEW DEVELOPMENT AND RISK ASSESSMENT

While the Groundwater Protection Policy provides a framework for decision making over new development it is most effective at the primary planning stage. Once individual proposals are put

forward for detailed consideration site specific issues will always need to be evaluated. Hydrogeologists have usually done this according to their own perceptions and knowledge and often not in entirely consistent ways. Their judgements are not always understood by others and as the groundwater knowledge base is increased amongst the community at large there is a need for standard methodologies that can be applied in a uniform manner. This codification of contaminant hydrogeologists' thinking can be classified under the broad heading of risk assessment. Risk assessment techniques are finding increasing favour in helping the professional in the decision making process and also making the decision more understandable for the lay person. However, tried and tested methodologies have still to be developed for many areas.

One system (LandSim) recently published by the Environment Agency, following work carried out for the DoE and NRA, relates to proposed landfill sites. (Gronow and Harris, 1996). As landfill design has increasingly become more complex, with civil engineering measures reducing leakage rates, the ability of regulators to assess proposals for their acceptability in both short and long term scenarios has decreased. The new methodology will allow regulators and operators alike to test designs against set quality criteria for the target water body/user most at risk. Similar systems will be applicable for assessing the degree to which contaminated land should be cleaned-up to avoid continuing water pollution.

Risk assessment techniques can also be applied to diffuse pollutants. GIS based methodologies are being developed to help assess the risks to catchments, both surface and groundwater, from pesticide usage on farmland and for non-agricultural purposes. Such techniques will be extremely useful in the assessment of the impact of new chemicals on water quality and help in focusing analytical suites on those compounds likely to be present in the receiving water. However it must be recognised that for groundwater matters risk assessment techniques can never be a substitute for decision making. They should always be regarded as purely tools to assist the expert in coming to the best technical decision given the information available.

## GROUNDWATER MODELLING

The role of groundwater models has increased over the years. Formally used mainly in aiding our management of resources as purpose-built, unwieldy one-off projects, models are increasingly finding routine application in groundwater pollution problems as new user-friendly software becomes more widely available. They are particularly helpful in the assessment of risk both for new proposals and where pollution has already occurred. The groundwater protection zoning exercise, which uses proprietary software, has exposed more hydrogeologists to the experience and opportunities afforded by relatively simple modelling. It has also made them aware of the problems of uncertainty and sensitivity inherent in any modelling exercise, which will hopefully encourage a healthy scepticism in the results. Modelling is a highly effective way of encouraging thinking but total reliance on the output is dangerous.

One particular advantage of modelling is that it allows the conceptualisation of ideas in a way that is not possible by other means. This is particularly useful in explaining situations to non-specialists. However, there is still room for improvement in the visualisation of modelled results. Computer graphics techniques have advanced dramatically in recent years and their adoption in the field of groundwater modelling is long overdue. The combination of the two will allow us to literally "see" underground and do much to dispel the "out of sight, out of mind" attitude that has handicapped hydrogeologists in making fellow professionals, industry and the public in general understand the complexities of the problems and the solutions.



## CONCLUSIONS

As we move into the twenty-first century the need to maintain and preserve the quality of our water resources will increase. The challenges for regulatory bodies will be in ensuring that controls are adequate to minimise further deterioration whilst not requiring preventative measures that are uneconomic to put in place.

The extent to which we have already polluted our groundwater will become much clearer over the next few years and decisions will need to be taken over how we deal with historical contamination. The new contaminated land legislative regime will undoubtedly be the regulatory driving force but will require a period for all stakeholders to understand and work with it. Remedial options range between active and passive, with an alternative of letting the abstractor undertake clean-up at the point of use.

To some extent the water industry has accepted the latter of the options above particularly with respect to the problem of nitrate. The water companies are the biggest operators of "pump and treat" in the country. It is accepted that the agricultural industry in general, exhorted by government to increase productivity, has been the critical factor. No individual polluters can be identified and so the burden falls on society, through the water rate. Can the same argument be used with respect to industrial pollution, especially for chlorinated solvents? It is difficult to be clear on the legal situation since much of the British legal system rests on case law. There have been few examples where the legislation has been tested with respect to groundwater. Arguments in the recent *Eastern Counties Leather -v- Cambridge Water Co.* case had to refer to nineteenth century examples for precedent (*Rylands -v- Fletcher*) and very few prosecutions have been taken on groundwater pollution matters. Much of this needs to be clearer. The opportunities afforded by the creation of the Environment Agency and the prominence given to historical pollution in the contaminated land provisions of the legislation which sets up this body should provide the impetus to build a clear strategy.

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## NON-AQUEOUS PHASE LIQUIDS: INVESTIGATION AND REMEDIATION

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### ABSTRACT

*Non aqueous phase liquids (NAPLs) continue to be of concern as groundwater contaminants, partly because many are toxic at very low concentrations and partly because they occur widely in industrialized countries in spills, leaking tanks or from inappropriate waste disposal. Characterization of the behaviour of NAPL migration under contaminated sites depends on many factors including degree of saturation of the subsurface and fluid properties such as density, chemical composition, viscosity and water solubility. NAPL-water flow in the subsurface also depends critically on the geometry of the pore space, whether this is intergranular or a network of fractures. Thus, relative wetting characteristics and relative permeabilities of the phases as well as conventional regional hydraulic gradients will control both natural migration rates as well as recovery rates. Two case studies, in the UK and Canada, illustrate the need to carefully design site investigation and remediation strategies when NAPLs are the target.*

### INTRODUCTION

Until relatively recently, the majority of studies of contaminant transport in hydrogeology have concentrated on the problems of solute and radionuclide transport. In contrast, many of the most frequently encountered groundwater pollution problems in practice involve the behaviour of non-aqueous phase liquids (NAPLs). These contaminant transport problems, by definition, involve more than one liquid phase and in the normal heterogeneity of the subsurface, are much more intractable to both investigation and analysis. NAPL pollution is encountered in Ireland as in other industrialized countries but the hydrogeological regime in Ireland, of shallow water tables, thin glacial soil cover and fractured rock aquifers, poses particular difficulties in the characterization and remediation of NAPL-contaminated land. The following discussion analyzes some of the characteristic behaviour of NAPLs affecting site investigation and remediation. Two case histories are presented by way of illustration.

### PROPERTIES AND BEHAVIOUR OF NAPLs

Non-aqueous phase liquids (NAPLs) are characterised by their hydrophobicity, or water-repellent properties. Although they are essentially immiscible in water, NAPLs may have varying degrees of water solubility. The two most important categories of NAPLs are chlorinated solvents and petroleum hydrocarbons. Solvents are denser than water and are therefore referred to as dense NAPLs, or DNAPLs. Petroleum hydrocarbons, on the other hand, are less dense than water and are known as light NAPLs, or LNAPLs.

Examples of chlorinated solvents that are commonly found as groundwater pollutants include trichloroethene (TCE), tetrachloroethene (also known as perchloroethylene, or PCE) and 1,1,1-trichloroethane (TCA). These compounds are volatile and of low viscosity, as well as having a high specific gravity (Table 1). They are more mobile than water in a porous medium and on entering the subsurface they migrate downwards and through the watertable. Downward movement is halted by

the base of the aquifer (or some other low permeability barrier). Contaminant movement is complicated by the phenomenon known as viscous fingering, down preferential pathways, which can enhance the rate of DNAPL movement and increase the difficulty of locating the spill. Residual amounts of solvent remain behind in the pores through which the solvent has passed: this 'residual saturation' can be as high as 35% in the saturated zone.

Petroleum hydrocarbons behave in a similar way to solvents except that, being less dense than water, they tend to float on a watertable. Their migration is controlled by the watertable gradient rather than by the gradient of an impermeable barrier.

NAPLs are not completely insoluble and the dissolved phase can move in the direction of groundwater flow. Because of their low solubility, and because the accepted water standards are set very low, small quantities of NAPL are capable of contaminating a large area of aquifer over a long period of time.

LNAPLs such as petroleum hydrocarbons can degrade under aerobic conditions. The end products of biodegradation may include simple compounds such as carbon dioxide and water. Chlorinated solvents such as TCE may degrade under anaerobic conditions, albeit very slowly. Some of the degradation products, such as vinyl chloride, may be more toxic, soluble and mobile than the parent compounds.

Table 1 Comparison of NAPL properties with water (after Verschueren, 1983 and Schwille, 1988)

	Specific gravity	Absolute viscosity (cp)	Solubility in water (mg/l)
Water	1	1	-
PCE	1.63	0.9	200
TCE	1.46	0.57	1100
TCA	1.35	0.84	720
Petrol*	0.68	0.55	90-260
DERV*	0.84	3	10-35

\*Approximate or average values

## CHARACTERIZATION AND OCCURRENCE

In summary, contamination of the subsurface by NAPLs has become of increasing concern both because they are of widespread occurrence in industrialized societies and because many of the compounds are recognized as being toxic at very low concentrations. Moreover, many of the subsurface contamination problems occur as a result of near surface waste disposal or from spills and leaks, particularly from underground tanks. Perhaps for this reason, investigation of the migration behaviour of NAPLs has concentrated on their movement within unconsolidated media, rather than within rock aquifers. Thus, understanding and characterization has concentrated on the migration of NAPLs in saturated and unsaturated granular materials such as sands, gravels and tills rather than in networks of fractures. Nevertheless, some basic approaches to site characterization involving NAPLs have evolved and are becoming standard practice. There is significantly less consensus on the corresponding approaches to remediation of NAPLs in the subsurface as techniques continue to be developed and tested.

As with other subsurface processes, NAPL behaviour can be described at a variety of scales. The 'pore' scale is usually the smallest scale at which direct observation may be made. Given the multiphase nature of NAPL migration, the distribution of fluids at this scale is determined by the capillary pressures in the system and the geometry of the interconnected pores (or individual fractures) and pore throats. At the other end of the scale spectrum is the field behaviour, representing an averaging over many pores such that some sort of 'averaged' representative behaviour is achieved. Measurement of local behaviour (eg in the laboratory) does not always translate easily to the field scale. Investigation at the fields scale is essential to effective remediation design.

Identification of the NAPLs involved at a particular contaminated site is a necessary precursor to assessing the potential for their migration. Key properties of identified NAPLs affecting their movement in the subsurface include density, solubility, viscosity, vapour pressure, soil sorption constant ( $K_{oc}$ ) and biodegradation potential. These properties will affect the spatial distribution of a NAPL and its partitioning between the available subsurface phases, that is, between soil, air and water. In turn, the identification of these properties will affect the methods adopted for site investigation and remediation.

Moreover, an important consideration in any site investigation is an evaluation of the volume of NAPL spilled, leaked or otherwise lost. The economics of a chosen remediation method will be affected by this assessment. Appropriate instrumentation and sampling techniques will be required for different types of NAPL. Direct measurement of the thickness of LNAPL (or 'free product') on a water table and attempting to measure the vertical distribution of DNAPL clearly require targeted investigation techniques. Nevertheless, the saturation of an immiscible fluid, defined as the proportion of available pore space which it occupies, ranging from 0 to 1, is an important characterizing parameter for subsurface NAPL contamination. In an LNAPL-water system, each phase competes for the available pore space. There will always be a residual saturation which is the saturation at which a fluid will no longer flow within the medium and can be conceptualized as the proportion of the fluid which would remain in the porous medium under full gravity drainage. This characteristic has clear implications in establishing realistic targets in any remediation strategy.

The migration of competing immiscible fluids, in turn, will depend on the relative wettability of the soil or solid surface of the pores as well as on prevailing pressure gradients. Wettability may be conceptualized as the tendency for one fluid to spread over the solid phase surfaces, coating the grains of a porous medium, while the other fluid occupies the remaining space. In saturated conditions, natural aquifers are strongly water-wet. In such systems, the wetting fluid will coat solid surfaces and occupy the smaller pore spaces and pore throats; the non-wetting fluid, eg hydrocarbon, would tend to occupy the larger pores. However, in the unsaturated zone, most liquids, including water and hydrocarbons, will tend to preferentially wet the solid pore surfaces - the air phase tends to occupy the interior of the pores. This relative wetting behaviour can significantly affect the performance of certain remediation techniques such as air sparging in the vadose zone. Moreover, the presence of an organic fraction in a soil can also affect the wettability of the solid phase, as these materials tend to be NAPL-wet. These considerations significantly affect ultimate NAPL recoverability.

The different wetting characteristics of water and NAPLs mean that the liquid phases may migrate at different rates in the subsurface. Capillary pressure is defined as the difference between the non-wetting fluid pressure and the wetting fluid pressure. Capillary pressure is also a function of the pore size and pore throat size distribution. For an LNAPL-water system, small pore throats are more easily entered by the wetting phase, water. Thus, in the saturated zone, finer grained materials may inhibit the imbibition of NAPL but in the vadose zone, similar granular material may entrap hydrocarbons, making them difficult to recover (Figure 1). These relative capillary pressures for the liquid phases are of critical importance in fractured rocks where the geometry of the fractures will dictate the relative migration of the phases. Moreover, the relative volumes of the liquid phases will

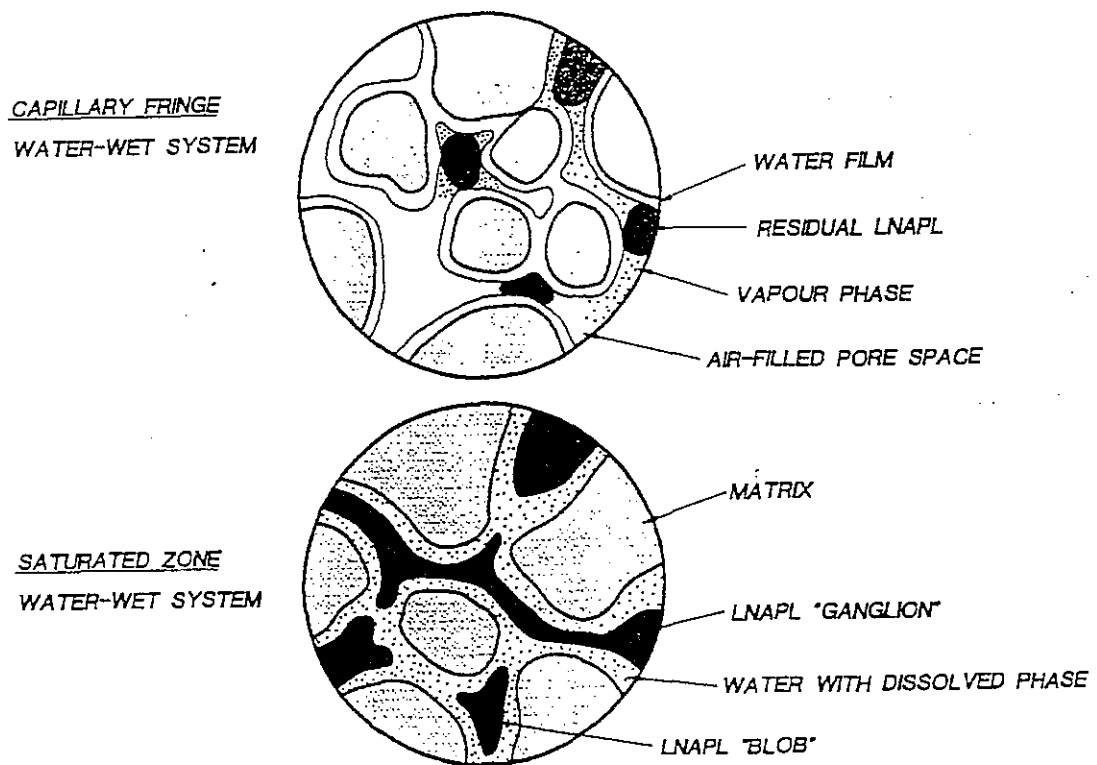


Figure 1 Schematic view of multiphase NAPL system in porous medium (Hardisty, 1995)

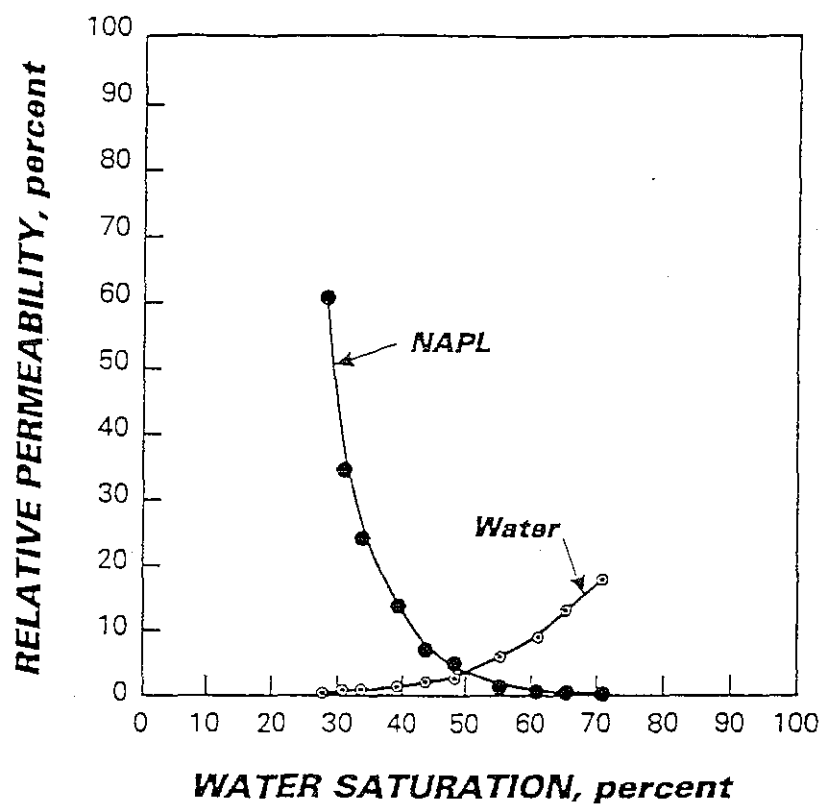


Figure 2 Typical relative permeability curve of LNAPL in porous medium (after Mercer & Cohen, 1990)

also affect migration. Increasing water saturation reduces the available cross-sectional area for NAPL flow, resulting in a lower 'effective permeability' for the NAPL.

In a two-phase LNAPL-water system, there exists an irreducible water saturation. At this point, LNAPL saturation has reached its maximum. As shown in Figure 2, the relative permeability to LNAPL tends to decline rapidly with small increases in water saturation, as small diameter pore throats become filled with water, isolating and snapping off LNAPL blobs. Eventually, wetting phase saturation reaches a point where all pore throats are filled and LNAPL is completely contained as blobs and ganglia within larger pores. In this state LNAPL is unable to flow, trapped within the medium. This behaviour equally applies in networks of fractures of different geometries as in heterogeneous granular media. Under these conditions, remediation techniques may demand changes to the medium (fracturing), to the liquids (eg use of surfactants) or to the pressure regime to mobilize the NAPL. Despite the apparent importance of relative permeability to NAPL flow, and thus, remediation, these type of data are rarely available or measured in environmental investigations. Nevertheless, it is clear that the heterogeneity of natural hydrogeological media in the field can result in apparently anomalous spatial distribution of NAPLs under a relatively uniform regional hydraulic gradient.

## REMEDIATION

Once groundwater becomes contaminated with NAPLs or other chemical compounds there are a number of options for dealing with the problem, including:

- do nothing (also known as passive or natural remediation)
- isolation or containment
- bioremediation
- pump and treat
- soil vapour extraction and air sparging.

The choice of option depends on many factors including the hydrogeology, nature and extent of the contamination, cleanup targets and budget available. The main experience of remediation comes from the USA, and the results are not encouraging: a recent study of the performance of pump and treat systems (the most commonly used remediation technique for NAPLs and other contaminants) found that cleanup goals had not been reached at 69 of the 77 sites investigated (National Research Council, 1994). The main reasons identified for the lack of success were: the physical heterogeneity of the aquifers, the properties of NAPLs (especially the residual saturation problem), migration of contaminants to inaccessible regions (a particular problem with DNAPLs) and sorption of contaminants to subsurface materials. Bioremediation can be a suitable remediation technique for petroleum hydrocarbons but, for the reasons given earlier, is less effective for solvents. In a review study, the National Research Council (USA, 1994) confirmed that the presence of NAPLs in fractured aquifers present the greatest difficulties.

## CASE STUDIES

Case study 1 highlights some of issues involved in investigating DNAPL behaviour in a fractured aquifer, while case study 2 focuses on investigation and remediation of an LNAPL leak into a sandy gravel and underlying fractured sandstone.

## CASE STUDY 1 (DNAPL CONTAMINATION)

A few years ago, an important public water supply (PWS) groundwater source in Eastern England was found to be contaminated by the chlorinated solvents TCE and PCE. The PWS source is located on the outskirts of a city near the confluence of two rivers, with a nearby industrial area upstream (Figure 3). The PWS boreholes abstract from the Chalk aquifer which is several hundred metres thick in this area, although the main water producing zones are located in the upper, more fissured strata. The uppermost bedrock layer is degraded to a low permeability putty-like texture ('putty chalk'). The Chalk is overlain by drift deposits, which typically consist of five to ten metres of sands and gravels and boulder clay.

After discovery of the contamination, the PWS source was taken out of supply and a water treatment system installed. Measures were also initiated to identify the causes of contamination, including a survey of solvent usage which confirmed that TCE and PCE were widely used in the industrial area nearby. Detailed hydrogeological investigations (by Groundwater Development Consultants) were then undertaken in two distinct phases:

- Phase 1 to determine the characteristics and extent of contamination in the Chalk aquifer; and
- Phase 2 to determine the sources of contamination within the drift deposits overlying the Chalk aquifer.

The Phase 1 investigations included the drilling, test pumping and sampling of six exploratory boreholes (Figure 3). The Chalk and drift aquifers were found to be widely contaminated by chlorinated solvents, including TCE, PCE, TCA and carbon tetrachloride (CTC). Maximum concentrations of dissolved TCE in the groundwater of the main Chalk aquifer were generally in the range 10 µg/l to 100 µg/l. However, very high concentrations of TCE were measured in the upper, low permeability putty chalk at one site (borehole 1/6: 19,850 µg/l) and in the permeable drift above this putty chalk at a second site (borehole 1/1: 25,300 µg/l).

Phase 2 commenced with a more detailed survey of past and present solvent usage within the areas of pollution identified during Phase 1. The results of this survey were used to target precise locations for the Phase 2 drilling investigations. Shallow boreholes were drilled at sites of known solvent usage, and significant contamination by chlorinated solvents was found at four of the sites investigated. Profiles of contaminant concentrations with depth at one of these sites are shown in Figure 4. The boreholes were all located within 100 m of the Phase 1 borehole 1/6 which had detected high concentrations of TCE, and to a lesser extent PCE and TCA, in the upper putty chalk. One of the Phase 2 boreholes (borehole 2/3), sited adjacent to a building in which solvents had been used, found very similar maximum concentrations of TCE (18,100 µg/l), PCE (1,720 µg/l) and TCA (1,740 µg/l), at least two metres above the water table.

The investigations led to the development of a conceptual model for the contamination, whereby organic solvents spilled or leaked from the ground surface at a number of sites, migrated rapidly downwards through the permeable drift to accumulate at the top of the low permeability putty chalk in small depressions in its irregular surface. The solvents then seeped slowly through this layer into the fissured chalk below, where flow rates are rapid.

The PWS source, with its water treatment facilities, is still in supply but no attempt has yet been made to clean up the aquifer. In view of the nature of the chemicals involved, their wide occurrence in the subsurface below the industrial area, and the dual porosity characteristics of the Chalk aquifer, remediation would be extremely difficult. Indeed, the author is not aware of any cases in Britain where dense DNAPLs have been successfully removed from deep aquifers.



large aperture fractures, fully intersecting, unit width, continuous LNAPL source

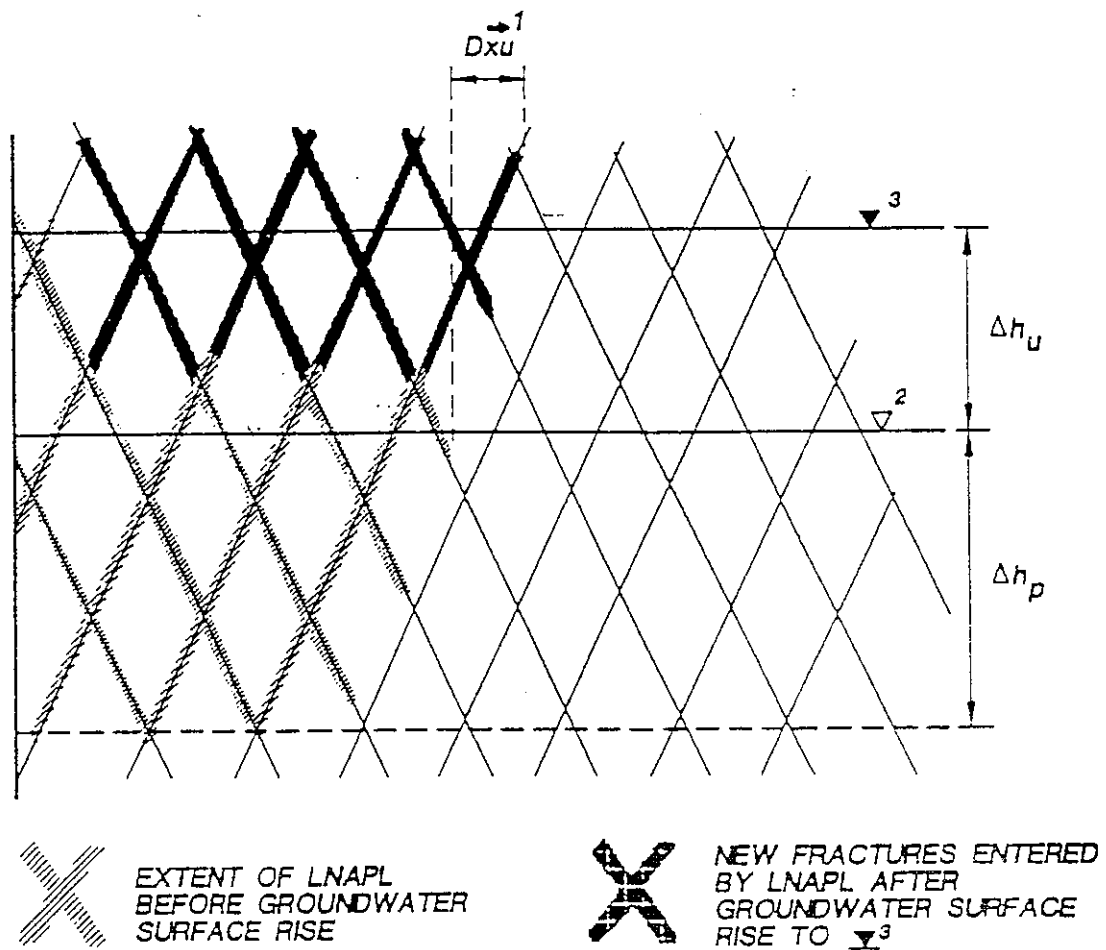


Figure 5 Schematic of LNAPL movement in response to groundwater surface rise in an idealised fracture network (Hardisty, 1995)

## CASE STUDY 2 (LNAPL CONTAMINATION)

Over a period of years, LNAPLs involving a cocktail of hydrocarbons, were leaking from a waste storage lagoon associated with a gas condensate plant in the foothills of the Rocky Mountains in northwestern Canada. Once discovered (the leak was appearing in an adjacent river), the environmental regulatory authorities in Canada required the operating company to investigate the distribution of LNAPLs under the site and institute a scheme for their recovery and remediation. The investigation formed the basis of a detailed field research study into LNAPL migration by Hardisty (1995) which resulted in a better understanding of the behaviour of these fluids in fractured media.

Gas condensate is the waste liquid removed from scrubbing natural gas which was being collected from a group of nearby wells before its onward transmission in transcontinental pipelines. The LNAPLs were readily identified in this case as mainly benzene, toluene, ethylene and xylene (BTEX) compounds. The LNAPLs were normally stored in a lined lagoon before being flared from a safety stack associated with the processing plant. The geology of the site was essentially sandy gravel and till overlying a fractured sandstone bedrock. The groundwater table exists in the bedrock, some 20m bgl, and the hydraulic gradient is low, less than 0.0005, although it increases to around 0.05 near to the adjacent river, some 300m away, into which the groundwater discharges.

Although LNAPLs occurred in the unsaturated sediments above the bedrock, most were found within the fractures in the sandstone. Conventional methods of measuring thickness of LNAPL in granular media are difficult to apply in fractured media. For example, hydrocarbon thickness measured in observation wells screened across several fractures cannot be readily related back to a "true thickness" within the rock, as it commonly does in porous systems. LNAPL migration was clearly governed by fracture network geometry, including orientation and aperture, and particularly by the head of LNAPL driving entry into individual fractures. A wide range of characterization techniques were evaluated at the site including coring techniques, downhole and geophysical methods, fracture mapping, hydraulic and tracer tests. Two new techniques for site investigation in fractured rocks were also developed - sponge coring and in-situ fracture casting. The sponge coring involved surrounding the coring bit and barrel during drilling with an absorbent sponge so as to capture as much hydrocarbon in situ as possible. Results indicated considerably greater volumes of LNAPL in the ground than would have been estimated with conventional methods.

The site investigation resulted in a conceptual model for LNAPL migration in fractured rocks. The model showed that relatively small volumes of LNAPL contained within vertical or sub-vertical fractures can produce significant connected vertical heights (and thus pressure heads) of LNAPL. At the groundwater surface, LNAPL, despite being lighter than water, will penetrate into the saturated zone, depending on the connected vertical height of LNAPL, the density of the liquid and the characteristics of the fracture. In larger aperture sub-vertical and vertical fractures, where the effects of fracture capillarity are reduced, penetration can be several orders of magnitude deeper than predicted by porous medium LNAPL models. As the groundwater surface fluctuates, either due to seasonal changes in recharge or pumping, LNAPL will follow, insofar as the fracture orientation and aperture allow it to do so. Depending on fracture network geometry, lateral LNAPL migration may occur as the immiscible fluid is 'pumped' along by the groundwater surface fluctuations, as shown in Figure 5. The model confirmed that lateral migration distances observed in the field may be considerable, even upgradient. LNAPL was found some 200m upgradient of the leak site in this case. Thus, lateral LNAPL migration was found to be primarily a function of fracture network geometry and groundwater surface fluctuations, rather than regional hydraulic gradients, as is the case in porous media.

LNAPL which migrates into relatively large aperture sub-horizontal fractures, can become trapped as the groundwater surface rises. Within these fracture 'layers', significant LNAPL saturation occurred. LNAPL trapped beneath the prevailing groundwater surface may be mobilized by changes in fluid pressures, either as a result of groundwater surface changes or changes in the connected vertical heights of LNAPL. In turn, this can result in LNAPL flow at considerable depths below the groundwater surface (up to 20m at this site), a phenomenon which is not explained by conventional analysis using equivalent porous media concepts.

Once the distribution of LNAPL was established, mainly in the bedrock under the site, a strategy for remediation and recovery was designed. As the LNAPL occurred in the near-vertical, fractured sandstone bed and was confined laterally by lower permeability shales, recovery involved injecting a grout curtain in the fractured rock. This barrier effectively 'dammed' the LNAPL which could then be scavenged using conventional LNAPL pumping techniques. The depth of the grout curtain, however, was directly controlled by the knowledge of the behaviour of the LNAPL and its depth of penetration in the aquifer. The site investigation took some three years and the recovery is still continuing after three further years.

## DISCUSSION

Ireland is a less industrialised country than either Britain or Canada. Because of this relative lack of industrial development, contaminants such as the chlorinated solvents and petroleum hydrocarbons described in the case studies above, have received much less attention here. However, the recent economic expansion of the country has included the setting up of a large number of computer, pharmaceutical and other high technology industries by foreign and Irish firms. Consequently, trace organic and other industrial contaminants may become more of a groundwater issue in Ireland in the future. A recent survey of trace organic contaminants in Irish groundwaters did detect solvents and petroleum hydrocarbons at several of the sites sampled (K.T.Cullen & Co., 1994). The case studies described indicate significant care is needed in the investigation and remediation of contaminated groundwater associated with contaminated sites in Ireland, given the nature of the likely hydrogeology.

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## PRACTICAL SITE INVESTIGATION OF CONTAMINATED LAND & GROUNDWATER

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### ABSTRACT

*Without site investigation, contaminated ground is a hazard. There are problems with the practice of site investigation and this paper endorses a practical phased approach to the investigation of contaminated land and groundwater that may counterbalance some of the problems. Advantages and disadvantages of conventional techniques of investigation are discussed and some new developments in site investigation are presented. The safety aspects of site investigation of contaminated sites are addressed and the importance of a properly prepared report covering all of the relevant issues is stressed. A good investigation should be focused, realistically budgeted and intuitive.*

### INTRODUCTION

“Without site investigation, ground is a hazard” is the title of a series of four booklets produced by the site investigation steering committee of the Institution of Civil Engineers in the U.K. (Thomas Telford 1993) When the potential hazards that render contaminated land contaminated are added, then the need for site investigation becomes more acute. Dealing with unexpected contamination is generally a bigger problem than having to change foundation type due to variable geological conditions.

The site investigation of contaminated sites could yield a variety of topics for a conference on its own. Individual areas of interest include the need for site investigation, techniques employed, safety in investigation, sampling, and reporting of site investigations. This paper is intended as an overview of some of the above areas and its main use may be in the list of references given.

It is not the purpose of this paper to describe in detail all of the various techniques employed in site investigation of contaminated land sites, but the advantages and disadvantages of the various methods are discussed. Some innovative developments in site investigation are discussed. The paper concentrates on soil and groundwater investigation, but it must be remembered that other mediums may also need to be investigated where contamination is suspected.

An attempt is made to structure the paper as a response to commonly posed questions.

### WHY INVESTIGATE ?

Unless the hazards posed by the natural ground in addition to the hazards added by humans are fully understood then they may jeopardise a project and its environment.

This may sound like a very general statement but various studies have shown that in civil engineering and building projects the largest element of financial and technical risk is linked to the ground. A review of 5000 industrial building projects by the National Economic Development Office (NEDO) in the U.K showed that without exception, on redeveloped sites, unforeseen ground conditions were met during construction. Documented cases of cost overruns on projects, show a high proportion to be caused by having to undertake more elaborate groundworks or foundation design than initially

budgeted, due again to unforeseen ground conditions. Unexpected soil and groundwater contamination form a substantial proportion of these projects.

In Ireland a large proportion of new developments are carried out on re-used land. Virtually all of this land will be contaminated to some degree as a result of past use. Typical problems include buried man made obstructions such as foundations and services, soft spots of made ground, industrial wastes, gas, even unused raw materials and imported fill material.

It is important to establish at this stage that Geotechnical site investigations are similar but have different, requirements, objectives and modes of operation to contaminated land and groundwater investigations.

With geotechnical site investigation one is trying to assess the mechanical behaviour of the ground, while with contaminated land in addition to the above we need to establish soil chemistry interactions and the movement of contaminants.

So called geo-environmental investigations in the U.S have tended to focus more on contaminated groundwater, whereas work in the U.K and possibly Europe has tended to focus more on soil problems. One possible reason for this phenomenon is probably that the U.S has more available development land and the objective of the investigation of contaminated land is to ensure that contamination is not transported offsite by groundwater to an adjacent greenfield site. In the U.K there has been more focus on the remediation of problem sites to a required end use and has therefore tended to look at soil. We probably have a mixture of the two situations in this country, with shortage of land in the Dublin area, but less acute land shortage problems outside of the Dublin area.

### **PROBLEMS ?**

There are a number of commonly quoted problems with site investigation as it practised and these ring true for investigation of contaminated land and groundwater. This is more of a collective criticism than aimed at anyone in particular. Remember site investigation is not just the remit of site investigation companies but includes clients and consultants as well.

### **UNDERFUNDING**

Expenditure on site investigation as a percentage of total project cost is low, and ranges typically from a mere 0.1 to 0.3 % for many projects. In general site investigation is based upon minimum cost and maximum speed. This inevitably increases the risk of poor quality work.

The solution to the problem is not just to throw more money into more site investigation although this is desirable. In many cases, greater benefits for the client can be obtained simply by better planning of the investigation by an experienced person. In the case of contaminated land the person needs to be experienced in the investigation of contaminated sites, or in the case of larger investigations there may be a requirement for a multi disciplinary team approach.

### **POOR SPECIFICATION**

In many cases the person preparing the specification does not have the experience or expertise to prepare an adequate specification. Again this rings true for contaminated investigations.

In the absence of a clearly defined contract specification and without adequate enforcement through supervision, the quality of the investigation will inevitably be variable.

## **POOR PLANNING**

During the planning and design phases of a project, site investigations often suffer from the fast track approach associated with development pressures and construction deadlines. Adequate time should be taken to plan, design and execute the site investigation, and it should be relevant to the design and construction needs of the final project.

## **RELEVANCE**

This symptom results from a combination of poor specification and poor planning, but is a common problem.

Extrapolation of site investigation data from adjacent sites or from locations within the same site may not be relevant to the new location. In addition the proposed end use of the site may not be taken into account in the design of the investigation. In many cases exactly the same investigation may be undertaken whether the proposed end use is a storage yard or a residential property. From a risk assessment view point the person charged with making the risk assessment may need two completely different data sets.

## **POOR FLEXIBILITY**

The one thing that is certain about the ground is its uncertainty. Site and ground investigations should be conducted as operations of discovery. Investigation should proceed in logical stages and planning should be flexible so that the work programme can be varied in the light of fresh information. At each stage it should be possible to assess the degree of uncertainty that remains in relation to vital aspects of the ground.

## **POOR WORKMANSHIP**

A site investigation should be seen as an operation that produces a deliverable product. Short cuts are taken and this often results from poor specification, lack of supervision or poor workmanship on the part of the contractor. In conventional site investigation this can result in poor data. In investigation of contaminated sites, it can result in injury or death. Realisation that appropriately skilled site operatives as well as professionals including chemists, engineers and hydrogeologists are needed for a particular scheme is important.

## **POOR INTERPRETATION AND DISSEMINATION OF RESULTS**

Boreholes or trial pits provide a view only of the ground at the specific locations of the boreholes. Interpretations of the ground conditions between boreholes is a matter of judgement based on hydrogeological and geotechnical knowledge and experience. The results should be interpreted by an experienced person.

## **EXAMPLE**

The following example illustrates how some of these problems arise.

### **The enquiry/Specification:**

Please quote for carrying out a conventional borehole investigation plus testing for contaminants.

### **Questions:**

What is a conventional borehole site investigation?  
What is the purpose of the site investigation?  
What are the likely contaminants?

### **Problems:**

The specification has most likely been written by a consultant or client who wants the job done as cheaply as possible.

It is obvious that little thought has gone into the specification.

The relevance of the site investigation is in doubt without the knowledge of the proposed end use of the site.

The safety of site investigation workers is in doubt without knowledge of the potential hazards.

It is obvious that very little planning will go into this investigation.

This enquiry may well lead to an inadequate site investigation.

The investigation of contaminated land is a complex task requiring input from a number of disciplines, including chemists, engineers, hydrogeologists, biologists and sometimes medical or legal professionals.

## **WHAT IS AN ADEQUATE SITE INVESTIGATION?**

Site investigation aims to determine the nature and behaviour of all aspects of a site. The essence of site investigation is the discovery of facts. The purpose is to ensure that an appropriate information base exists for assessing and managing the risks that may be associated with contaminated land

From The ICE Design and Practice guide for Contaminated land (1994) the following typical objectives for a site investigation are:

- To determine the nature and extent of any contamination of soils and groundwater on the site
- To determine the nature and extent of contamination migrating off-site.
- To determine the nature and engineering implications of other hazards and features on the site
- To identify, characterise and assess potential targets and likely pathways
- To provide sufficient information to identify and evaluate alternative remedial strategies (if required)
- To determine the need for and the scope of both short and long term monitoring and maintenance
- To formulate safe site working practices and ensure effective protection of environment during remediation or development works.



- To identify and plan for immediate human health and environmental protection

## WHAT ARE THE PRINCIPAL ELEMENTS OF A SITE INVESTIGATION ?

A site investigation should proceed in logical stages with planning for flexibility. It should demonstrably contain the following elements.

### 1. DESK and WALKOVER survey

This is an important start to the site investigation and should be considered no matter how small the investigation is.

The first thing to establish is whether the site is likely to be contaminated. A list of sites with a range of activities is attached in table 1.

It is during this stage that a profile for a specific site type can be prepared. A widely used profile is that for a gasworks. Other site profile types can be obtained from various sources or created from experience with similar site types, for instance a profile for a tannery may resemble that for a fellmongery.

The next important step is to identify whether any special safety procedures and precautions may need to be taken during the site investigation. Sheets from Appendix 4 of the guidelines for safe drilling (Thomas Telford 1993) provide a useful checklist for the important criteria.

Before embarking on ground work, much valuable information can be gleaned from existing sources, such as geological and OS maps, aerial photographs and archival material. Reference to vulnerability maps may help to direct the investigation to greater risk areas.

Frequently with derelict land all records of previous use have been lost. Locals or past employees of the factories can provide useful information. Useful information includes the processes used, where raw materials were stored, wastes were deposited, where tanks, pits or tips might have been

A desk study cannot be regarded as complete without a walk-over survey which allows the investigator the opportunity to interpret the findings of the desk study in the context of topography and to develop a preliminary understanding of the ground and groundwater conditions. The walkover is also essential for noting obvious signs of contamination, confirming the site layout and identifying immediate safety hazards

Eventually a time must come when obtaining that last useful piece of information becomes prohibitive in terms of time and expense, so more often than not the investigator has not accumulated all of the facts.

Where a number of sites are being considered for a proposed end use the desk study can be used to rank the sites on hazard potential.

### 2. Ground project interaction

Prior to planning the investigation it is important to consider how and to what extent the proposed project will affect the ground and how the ground will affect the project.

This in some ways is where the proposed end use may have a bearing on the direction or extent of the investigation. Sometimes foresight may be required, when the proposed end use may not in fact be an end use at all, it may be a stop gap or may be a preliminary stage towards a broader based development.

The most practical place to document this phase is in the desk study report and the report should make some mention of the consequences of future changes of use.

### **3. Design of the site investigation**

The objective of a site investigation is to ensure economical design and construction by reducing to an acceptable level the uncertainties and risks that the ground poses to the project. The design is dependent on

**The purpose of the investigation:** This should be clearly understood. Is the objective site clean up or are we looking at preventing offsite migration ?

**What information** does the design engineer require and when is it required ?

The **area and depth** of ground to be investigated. Site investigations have a habit of growing from 100 m<sup>2</sup> to 10 hectares or vice versa when it is necessary to manoeuvre around obstacles. The investigation works may require demolition or site clearance to be undertaken prior to the site works

The **time** required for the investigation

The **budget**, unfortunately tends to be the controlling criterion in a lot of cases, but needs to be considered and controlled and definitely agreed before the work begins.

### **4. Investigation works**

The investigation may include one or a combination of techniques including :

Grab samples, Trial pits, Boreholes, In situ tests, Probing, Geophysics, Sampling and analysis

Other more specialised methods may be required on specific sites.

#### **Grab sampling**

Simply obtaining samples from spoil heaps or directly from the ground. The representative nature of the samples may be doubtful but it can offer a preliminary assessment of the site.

#### **Trial pits**

Trial pits are low cost, allow visual and nasal assessment (in the case of hydrocarbons) to be made and the relationship between the contamination and the ground to be observed. Buried pipes, services or old floors can also be revealed. The disadvantages include the amount of disturbed soil, particularly if contaminated liquid or groundwater occur. Use of plastic sheets to protect clean ground, or in some cases backfill with clean material and offsite disposal may be options. The pits can be retrofitted with standpipes to act as temporary monitoring points or sampling points.

#### **Boreholes**

Boreholes are essential where the depth of contamination exceeds the reach of a digger bucket or where the spoil from a pit may cause problems or where the possibility of pit sides collapsing exists. Samples can be recovered, sometimes undisturbed and standpipes can be retrofitted to the borehole. There are various methods of forming boreholes, ranging from shell and auger to rotary.

#### **In-situ tests**

Permeability, redox, and resistivity tests are typical tests that may be required on certain sites.

### **Probing**

Probing embraces a number of techniques from hand augers through Boris/dynamic type probing to cone penetration testing (CPT).. The advantages are speed, flexibility and accessibility (upto 20 per day can be achieved). The disadvantages are small diameter, lack of penetration particularly on our boulder clays or where obstructions are met in made ground.

Tools can be deployed through standard CPT equipment including sampling systems with an integrated pneumatic valving system for obtaining discrete water samples from specific depths.

Once the probe hole is completed the hole can be retrofitted with a temporary standpipe and used to accommodate a variety of monitoring devices for instance methane monitors, slimline bailers, soil vapour equipment suitable for the detection of volatile organic compounds.

### **Geophysics**

Geophysics is a useful technique, where the contamination creates a measurable anomaly. For instance increased conductivity caused by a salt plume. Several geophysical techniques are potentially useful in the investigation of contaminated ground. Most of the methods used depend on the principle that the contamination displaces or invades the groundwater and renders the volume of invade soil/groundwater either more conductive or more resistive than the surrounding soil. Ground contaminated by refined hydrocarbons such as fuels, is generally detectable as a resistive zone. Manufacturing by-product spillages may on the other hand appear as conductive zones where there are inorganic ions accompanying the organic contamination. The main advantage is that the techniques are non invasive and do not result in disturbance of the ground. One of the major disadvantages is that interpretation still tends to be subjective. The techniques are more suited to determination of the volume of contaminated ground than the actual nature or intensity of the contamination.

The use of geophysics to identify anomalies that can be further investigated using trial pits or other invasive techniques makes the most effective use of geophysics. A combination of geophysical methods is to be preferred to better define anomalies

Techniques of the future include variants of EM, GPR and spontaneous potential.

### **New and specialist tools**

A number of the new developments seem to have been developed around CPT methods.

The conductivity cone is used to map out chloride plumes, or plumes created by other salts. Chloride is very mobile and the one of the first parameters to signal the advance of a contamination plume.

A temperature cone can be used on landfills to determine the state of degradation of wastes.

The fluorescence cones such as the LIF (Laser induced fluorescence) cone and the ML (Mercury Lamp) are mainly used for the investigation of sites contaminated with hydrocarbons. Determination of the hydrocarbon types is also possible with some cones.

A recently developed system for drilling and sampling contaminated sites is claimed to produce samples both suitable for high quality geotechnical tests and free from cross contamination. It is a cone tipped hollow auger in which the cone is held in place by a pneumatically controlled lock. At the required sampling position the cone tip is released and this then travels inside the hollow auger to the top of the corer and the sample is taken.

Sonic drilling is a new technology developed in the U.S. It is presently under licence to one company only and is therefore quite expensive. The main force behind this technique is a specially designed hydraulically driven vibratory drill head. This drill head or oscillator generates high frequency vibrational forces. When vibrations are adjusted to coincide with the natural resonance of the steel rods the drill string delivers tremendous amounts of energy to the drill head, virtually fluidizing soil particles. In overburden, drilling rates of up to 1m per second can be achieved, whilst collecting relatively undisturbed large diameter core samples.

## SAFETY

The investigation of contaminated land is deemed to be specialist work and must be carried out only by competent contractors using experienced personnel. The best available guidelines for this type of work are "Guidelines for the Safe Investigation and drilling of Landfills and contaminated land" (Thomas Telford 1993).

Another useful guideline is "The protection of workers and the general public during the development of contaminated land" (HMSO, UK. 1991).

In the event of changing legislation, contractors should be aware of current health and safety legislation in Ireland.

On site investigation work may expose personnel to health and safety risks. Hazards may relate to substances present on the site or to its physical condition (unstable ground, voids etc.) Physical injuries including cuts and grazes may increase the risks associated with exposure to hazardous substances.

In general safe working practices in the investigation of contaminated land and landfills need to be promoted. For each project the anticipated hazards should be clearly defined to enable the contractor to select the appropriate equipment, drilling methods, materials for monitoring wells. Contractors should carry the insurance appropriate to the investigation of contaminated land.

All relevant information regarding potential contamination and hazards on a site held by the client or engineer should be provided to the contractor. The type of waste or contaminated ground anticipated should be categorised so that a site can be designated green, yellow or red (Thomas Telford 1993) and appropriate safe working practices employed. A copy of typical designations is attached

A safety plan should be agreed or prepared prior to working

This will include items such as

- controlled entry or permit to work procedures
- Dirty/clean zoning
- Monitoring for toxic gases
- Disposal of spoil
- Safe handling of samples
- Control of nuisance
- Emergency procedures in the event of an accident
- Training or use of personnel to identify hazards
- Protective clothing

## **SAMPLING POINTS, WHERE, HOW MANY AND WHAT IS NEW**

It is clearly not possible to collect an infinite number of samples or to test for unlimited numbers of contaminants.

For some sites it may only be possible to determine the nature and extent of contamination by taking samples over a specific time period. This is where site investigation and monitoring overlap to a certain extent. Examples include measurements of gas movement or leachate migration.

In general the sample containers should be easy to fill, robust and easy to affix labels to.

It is important that the laboratory receiving the samples are happy that the sample containers are suitable. Specially prepared bottles may be required for certain analyses particularly trace organics. It is often advisable to obtain the sample containers from the laboratory doing the analysis.

Samples should be transported and analysed as soon as possible. Transport restrictions may be applied to certain sample types

Scheduling a testing programme is best done with one ear to the analyst and one ear to the client (budget). The investigator needs to be aware of the detection limits for parameters chosen and what the cost of analysis is. When in doubt, seeking advice from the analysts is the preferred way of doing things together with reference to a typical site profile to indicate potential contaminants.

In general it is easier to show that a site is contaminated than to prove that it is uncontaminated. Whatever sampling strategy is adopted therefore, it must be sufficient to demonstrate unequivocally which parts of the site are unaffected (and can safely be excluded from any remedial works) even if this involves extending the sampling and analysis programme beyond that required to simply show the presence of contamination.

The number of sampling points required during a site investigation will depend on the size and topography of the site, the likely distribution of contaminants present and the degree of confidence required. If an adequate amount of points are used then the possibility of finding a localised pocket of contamination during construction is reduced.

Some codes indicate for instance 16 sampling points on 0.5 hectare, with a grid size of 14-18 m. Dependent on budget we may be lucky to have anything from 5-10 typically on any sized site.

The location of sampling points may be based on a regular grid pattern (usually only possible where building have been demolished and open areas are accessible), or a random pattern.

There are simple random patterns such as imaginary "W" or "K" on the site.

Judgmental sampling uses the intuition of the investigator to read the site and locate points on areas where contamination is most likely to occur and is probably a hybrid between random and regular.

### ***New developments***

Home pregnancy testing kit technology is gaining increasing acceptance for rapid on site assessment of contaminants in soil and groundwater. Testing by these immunoassay techniques uses the properties of laboratory developed antibodies which bind to the contaminant of interest in a site sample. A colour development solution is then added, the intensity of the colour being produced being inversely proportional to the concentration of the contaminant in the sample.. The method is sufficiently accurate to detect contaminants even at very low concentrations and tests are less expensive than good

laboratory analysis. There is over 95% certainty that a positive result is correct while false negative results are typically less than 1% and there is minimal cross reactivity. The drawback occurs where unknown contaminants are encountered. The method is useful where some background samples have already been analysed

Dedicated multiparameter probes that can measure temperature, pH, conductivity, ammonia, chloride and D.O in situ are now available.

Early in-situ probes were limited by the inability to decontaminate the probe within the ground once contamination had been discovered

## **FACTUAL/INTERPRETATIVE REPORT**

Sufficient information should be obtained to allow a risk assessment to be made on the following potential target groups:

Short term and long-term health and safety

Attack on construction materials

Constraints of material disposal

Constraints of material containment

The report should be a properly structured and balanced document, presented in an understandable form appropriate to the needs of the user.

Should describe concisely and clearly the site, the works and the results obtained from siteworks and laboratory testing.

The interpretative section should discuss the findings in a way which identifies the lateral and vertical patterns of the contamination. A good balance between numerical and text is important. The concentrations may need to be discussed in the context of published data sources, such as the ICRL, or the Dutch guidelines

## **CONCLUSIONS**

It is certain that without site investigation, contaminated land is a hazard. Adequate site investigation is dependent on proper design, planning and management of site works, adherence to safe working practice and proper dissemination of results and data through reports. The investigation of contaminated land is specialist work, but usually follows a pre-set phased approach. New developments aim to save time on site, increase the amount of work including analyses that can be achieved on site, increase sample integrity and minimise cross contamination.

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**Table 1 Sites likely to contain  
contaminants**

Asbestos works  
Chemical works  
Gas works, coal carbonisation plants and  
ancillary by product works  
Industries making or using wood  
preservatives  
Landfill and other waste disposal sites or  
ground within 250 metres of such sites  
Metal mines, smelters, foundries, steel works  
and metal finishing works  
Oil storage and distribution sites  
Paper and printing works  
Railway land, especially the larger sidings  
and depots  
Scrap yards  
Sewage works, sewage farms and sludge  
disposal sites  
Tanneries



## Appendix III: Site categorisation

Site designation	Broad description
GREEN	<p>Subsoil, topsoil, hardcore, bricks, stone, concrete, clay, excavated road materials, glass, ceramics, abrasives, etc.</p> <p>Wood, paper, cardboard, plastics, metals, wool, cork, ash, clinker, cement, etc.</p> <p>Note: there is a possibility that bonded asbestos could be contained in otherwise inert areas</p>
YELLOW	<p>Waste food, vegetable matter, floor sweepings, household waste, animal carcasses, sludge, trees, bushes, garden waste, leather, etc.</p> <p>Rubber and latex, tyres, epoxy resin, electrical fittings, soaps, cosmetics, non-toxic metal and organic compounds, tar, pitch, bitumen, solidified wastes, fuel ash, silica dust, etc.</p>
RED	<p>All substances that could subject persons and animals to risk of death, injury or impairment of health</p> <p>Wide range of chemicals, toxic metal and organic compounds, etc.; pharmaceutical and veterinary wastes, phenols, medical products, solvents, beryllium, micro-organisms, asbestos, thiocyanates, cyanides, dye stuffs, etc.</p> <p>Hydrocarbons, peroxides, chlorates, flammable and explosive materials; materials that are particularly corrosive or carcinogenic, etc.</p>

### Notes

It should be borne in mind that indiscriminate dumping may have taken place on a particular landfill or contaminated site, and therefore the above categorisation should be treated as a guide only to determining operational procedures.

Landfill sites licensed to accept asbestos waste or other sites where significant deposits of bound or unbound asbestos occur justifiably have a RED designation, warranting the highest level of caution. However, many contaminated sites may have only very small quantities of asbestos, often present as asbestos cement, which (while presenting a hazard) may not in themselves warrant the highest level of protection. In these cases it may be sufficient simply to add mains water to the borehole to prevent asbestos fibres becoming airborne and hence available for inhalation, and to wear disposable 'paper masks suitable for low levels of asbestos.

The presence of radioactive materials on a site has not been included in the above categorisation because these are the subject of the Radioactive Substances Act 1960, The Ionising Radiations Regulations 1985 and the Approved Code of Practice to the Regulations entitled *The Protection of Persons Against Ionising Radiations Arising From any Work Activity*.

The majority of dye stuffs are likely to be in the YELLOW category. However, there is a variety of base materials that have been used for the manufacture of dyes and it is possible that some of these, when in concentrated form, could be sufficiently toxic to require a RED designation. Therefore, unless specific information is available regarding composition, the presence of dye stuffs will justify a RED designation.

In those situations where a desk study has not been carried out, or the desk study has not revealed sufficient information, then the site should be given an automatic RED designation.

## GROUNDWATER MONITORING - FACT OR FICTION

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### ABSTRACT

*Groundwater monitoring is often undertaken to fulfil regulatory requirements. However, the lack of clarity in regulatory briefs and within our environmental legislation often results in the haphazard location of poorly designed wells. The factors required for an effective monitoring system are an understanding of: the local geology and hydrogeology; the facility itself and the surrounding area and; the chemistry of the potential pollutants. Each of these factors are examined in this paper together with a discussion of the validity of analytical results.*

*To ensure confidence in the results of an investigation an effective groundwater monitoring system is required combined with a high degree of quality control and quality assurance during sample collection and analysis. Only then can an accurate risk assessment or remediation plans be undertaken.*

### INTRODUCTION

Groundwater monitoring is a primary facet of investigations of contaminated land, property acquisition/divestiture investigations, most Integrated Pollution Control (IPC) licence applications and environmental management systems. However, in many cases the information being reported is not representative of the real situation. This can often result in unnecessary and costly investigations and remediation work in the future.

To design an effective monitoring system, a number of factors need to be taken into account: the site geology and hydrogeology; the activities at the plant itself and in the surrounding area; the chemistry of the potential pollutants. In addition, it is essential that the samples collected and analysed are representative of the local aquifer(s). Finally, the data needs to be assessed to determine if any deterioration of groundwater has occurred and if it has to assess the associated risks. The importance of each of these factors are discussed below, but firstly, why monitor at all?

### WHY MONITOR?

The reason for monitoring often determines how effective the monitoring system will be. In other words if you do not seek out contamination you are unlikely to find any. A good hydrogeological investigation will seek out pathways of contamination migration and install monitoring wells which will intercept any contaminants. Unfortunately, one downgradient well or three monitoring wells are often installed to fulfil a licence application without considering all the required factors.

There is a need for regulatory authorities to provide more detailed requirements in determining the vulnerability of aquifers underlying potentially polluting activities.

Installation of one downgradient well as outlined in some IPC applications is inadequate. It is unrealistic to expect an industrialist to fully comprehend the difference between a hydrogeological investigation which will fully investigate if an activity has resulted in groundwater contamination and the haphazard installation of poorly designed wells which will fulfil the requirements of the application but bear no resemblance to reality.

The 1990 amendment to the water pollution act defines an aquifer as "any stratum or combination of strata that stores or transmits groundwater". This includes clays and backfill deposits as aquifers. This definition lacks clarity and should be re-addressed. The previous 1977 act gave a clearer definition of an aquifer as "any stratum or combination of strata that stores or transmits sufficient water to serve as a source of water supply". The legislation needs to be resolved to ensure that any vulnerable aquifers underlying potentially polluting activities are monitored.

## **GEOLOGICAL & HYDROGEOLOGICAL CONTROLS**

The occurrence and movement of groundwater together with any contaminants present are controlled by the geological and hydrogeological conditions at a location. Therefore it is necessary to understand these factors before designing a monitoring well or a complete groundwater monitoring system.

### **(a) REGIONAL GEOLOGICAL & HYDROGEOLOGICAL CONDITIONS**

The bedrock geology in Ireland is quite complex with a wide range of rock types which vary rapidly both horizontally and vertically. Regionally, varying geological and hydrogeological conditions determine where water occurs (aquifers) and where it does not (aquitards). For example, granites and shales have little groundwater potential while limestones and sandstones can supply large volumes of groundwater. Irelands aquifers are dominated by fissure flow with little intergranular permeability.

Most of Ireland is covered by a layer of unconsolidated material deposited during the ice age. These deposits include clay with boulders, sands and gravels, clays and silts. The permeability of glacial deposits is determined by the depositional environment at the time. For example, the drumlins of Counties Cavan and Monaghan are typical low permeability till deposits laid down at the base of a glacier whereas melting ice sheets gave rise to the extensive sand and gravel aquifers in the Curragh of Co. Kildare. Varying glacial environments gave rise to rapid lateral and vertical variations of deposits, making the hydrogeology extremely difficult to predict.

The degree of vulnerability to contamination at a location is dependent on the nature and thickness of the overburden, the depth to the water table(s) and the aquifer potential of the bedrock. For example, the karstic nature of the Clare-Galway limestones combined with a thin overburden cover render them highly vulnerable to contamination. In contrast the low permeability nature of the Dublin limestones (Calp) overlain by generally thick low permeability glacial clays result in a low vulnerability to contamination.

The Geological Survey of Ireland (GSI) are currently mapping geological and hydrogeological characteristics to produce regional vulnerability maps. Four groundwater vulnerability categories are used by the GSI - extreme, high, moderate and low. It is expected that these maps will be used in groundwater protection schemes and as a tool in the location of potentially polluting activities (Daly 1995).

## (b) LOCAL HYDROGEOLOGICAL CONDITIONS

While an understanding of regional information is useful, site specific information is required to fully assess pathways for contamination migration and the potential risk of groundwater contamination. For example, based on the aquifer vulnerability map of Ireland, a pharmaceutical plant in the midlands is located above a high yielding limestone aquifer overlain by extensive gravels. However, drilling on site has shown that the plant is underlain by thick low permeability glacial clay, obviously reducing the potential for contamination of the underlying limestone aquifer.

Site specific geological and hydrogeological conditions together with an understanding of the potential contaminants determine the design of a monitoring well and the selection of an appropriate drilling method.

The geology beneath a site can vary laterally over short distances. Any major variations resulting in highly permeable features such as fractures, solution channels and gravel beds will affect the direction of groundwater flow and/or contaminant transport pathways. For example, resistivity studies in one pharmaceutical plant in Co. Cork identified a major fracture zone crossing beneath the site, whereas elsewhere the limestone permeability is low. The monitoring system obviously has to take this fracture into account as it is the main pathway for contaminant migration. Haphazard location of monitoring wells without a clear hydrogeological investigation could easily miss contaminant pathways, thus giving a false picture of groundwater quality.

Investigation of vertical variations in geology is necessary to determine the number of saturated zones beneath a site. The depth of the monitoring well and the location of the screen depends on the depth to the water bearing formation(s) that one requires to monitor. Where more than one saturated zone exists and the requirement is to investigate the lower aquifer, a seal is required to prevent cross contamination from an upper to a lower saturated unit. Some common well designs are described below. (see also Aller, A et al. 1989).

### (i) installation of a typical shallow monitoring well (Figure 1)

Preliminary site investigations or the assessment of geotechnical logs can be used to determine the hydrogeology beneath the site. Logging should also be undertaken during the drilling of the monitoring well to assess the depth to the saturated zone. The depth to the saturated zone and the contaminant type will determine the location of the screening interval.

The borehole is drilled to allow an annulus of greater than two inches around the well material. When the borehole has been advanced to the saturated zone, the well is emplaced. A well plug is fitted to the base of the screen to reduce silting. The annular space between the casing and borehole is filled with the pack material, to a depth of approximately 0.5 metres above the screen. Above this an impermeable seal (bentonite) is installed to prevent the vertical migration of contaminants and ensure the zone of abstraction. The rest of the annulus can then be backfilled with a grout seal. A lithological log and well construction log should be supplied to the client. Wells should be fully developed prior to sampling to ensure the sample collected is representative of the aquifer.

**(ii) Constructing a monitoring well to sample beneath the contaminated aquifer (Figure 2).**

In cases where the upper aquifer is contaminated, care is required in preventing cross contamination during drilling. If possible a investigative boring should be completed to determine the depth to the underlying aquitard. Drilling should be carried out at a wider diameter in the upper aquifer and into the top of the aquitard. The upper aquifer should then be cased off with conductor casing and cemented into place. After approximately 24 hrs, drilling should be continued at a narrower diameter into the second aquifer.

**(iii) Monitoring wells which allow discrete depth sampling (Figure 3)**

There are two ways of monitoring multiple aquifers; a nested completion involving two or more monitoring wells constructed in the same borehole or well clusters consisting of individual wells screened at different depths adjacent to each other. Clusters are the preferred method as they reduce the potential for cross contamination and are more easily constructed. Clustering also allows sampling at discrete depths in an aquifer to determine any contaminant stratification effects for example investigating the vertical extent of contamination at a hydrocarbon spill.

### **SITE USAGE**

The risk of contaminating any underlying aquifer(s) is dependent on the potential polluting ability of the activity together with the vulnerability of the underlying aquifer.

Familiarisation with the facility and its potential contaminants is necessary to design an effective groundwater monitoring network. Investigation of storage areas, transport routes, drainage lines etc. will identify areas of potential contamination. Monitoring wells must be located at strategic points on site to fully identify if groundwater contamination is occurring and if so where it is originating from. The number of sample points will depend on: the area of site and extent of suspected contamination; the number of sampling stages; the degree of confidence required; the cost; future land use; the timescale and the nature and distribution of contaminants

A typical monitoring plan for a large industry is that undertaken at Intel, in Leixlip, Co. Kildare. Groundwater sampling was initially undertaken as part of the environmental impact statement to assess any baseline contamination. Monitoring wells are now located around the perimeter of the site to identify any contamination migrating on to or off the site. Internal wells are located immediately downgradient of solvent and waste storage areas to assess any deterioration in groundwater quality due to leakage from the overground storage tanks or unloading area. Wells were designed to sample the perched water table in the overburden and the limestone aquifer. A groundwater sampling programme is incorporated as part of the company's environmental programme. To assess any variations in groundwater quality, samples are collected for full baseline analysis annually, and quarterly, samples are analysed for a suite of indicator parameters. To date this monitoring programme has been successful in showing that the groundwater migrating beneath the Intel plant is of excellent quality and free of industrial contamination.

Historical and current chemical usage in a plant or surrounding areas will determine the analytical suite chosen. Without this information the analytical results could be confusing and give an unrealistic view of the associated risks.

## CHEMISTRY OF THE POLLUTANTS

Monitoring wells must be designed to take into account the fate and transport of the pollutant in the subsurface i.e. screening depth. The physical and chemical characteristics together with the aquifer geology, and groundwater velocity determine the ability of contaminants to migrate in the soil and groundwater. In general there are three types of contaminants which migrate in an aquifer.

(i) Highly soluble parameters with much the same density as groundwater. For example chloride migrates at a similar rates as the groundwater and therefore are often used as tracers.

(ii) Immiscible compounds-floaters: Low density non-aqueous phase liquids (LNAPLS) such as petrol, float at the top of the water table, usually with some residual contamination in the vadose zone and the capillary zone. The plume will migrate in the direction of groundwater flow with a certain percentage moving into the dissolved phase. Migration and adsorption rates will depend on the chemical involved. The monitoring well should be designed with the screened interval in the upper part of the aquifer i.e. allowing the thickness of product on the water table at all times to be measured.

(iii) Sinkers: These are dense non-aqueous phase liquids (DNAPLs), including those compounds which have a higher density than water, it includes most halogenated hydrocarbons e.g. trichlorethylene(TCE). These compounds move vertically through the aquifer until a low permeability layer is encountered. The speed to which this occurs depends on the density of the chemical and there may also be a concentration gradient through out the aquifer. The plume of contamination does not always follow the groundwater flow direction but may follow the topography of the underlying aquitard. Again some of the contaminant will move into a dissolved phase and move in the direction of groundwater flow. For example TCE may partition into dichlorethylene (DCE) breakdown parameters that migrate at varying velocities. Monitoring well in this case should be designed to allow sampling at discrete depth intervals in the aquifer, however great care should be taken during drilling to prevent cross contamination, as the DNAPLs may migrate vertically through the well annulus (Villaume,1985).

## INTERPRETING THE SAMPLE RESULT

Once the wells are designed correctly, the quality of the sample result depends on the quality of the collection procedure and the laboratory procedure. Sampling errors can be reduced to a minimum by following a standard sampling protocol. When dealing with concentrations in parts per billion there is no space for any sampling error. An example of this is contamination by acetone resulting from a sampler who has recently being smoking and subsequently not wearing gloves during sampling.

The validity of the laboratory results are vital to the success of the investigation. If the methods or analytical results themselves are suspect then it may lead to the whole investigation being discounted. Despite choosing laboratories with high quality assurance and

control procedures, errors do occur. An example of this is the analysis of five samples for Total Petroleum Hydrocarbon (TPH) content as outlined in Table 1.

Five monitoring wells were sampled on three separate dates. In the first instance (July 1997), the samples were analysed for TPH content using FTIR analysis. The results indicated TPH concentrations which exceeded the normal background level but did not exceed the guideline for intervention. TPHs had not previously been detected using FTIR technique and there was no evidence of hydrocarbon contamination at the site. In August 1997 the wells were resampled and analysed by Laboratory 2, which is NAMAS accredited for this analysis. Using FTIR all the samples were found to contain TPH concentrations which exceeded the guideline for intervention. A requested repeat analysis of this well by GC/FID indicated a considerably lower concentration of 1.55ppm (although the sample had been left for a number of days). Duplicate samples were sent to a third laboratory (Laboratory 3) and TPHs were not detected above the laboratory detection limit of 0.04 ppm in Laboratory 3 using GC/FID.

To verify the results, a third round of samples was collected and split in October. To assess any laboratory error, a "blank" (known mineral water) was labelled as MW-5. Concentrations of hydrocarbons which exceeded the MAC were again detected in the results from Laboratory 2 and a concentration of 0.26 ppm was measured for the blank. Nothing was again detected in Laboratory 3. This result would indicate that laboratory 3 which does not have accreditation has the least amount of error and therefore the most realistic result. However, further research indicated that Laboratory 3 uses a clean up method prior to analyses which is meant to remove natural oils but can remove other hydrocarbons. Which is the correct result?

Background levels of contaminants should be determined by taking samples from areas unaffected by contamination under investigation. Quite often when contamination is picked up downgradient of a plant it is assumed to originate at the plant. However, it could potentially originate on an upgradient site or be naturally elevated in the environment. For example recent drilling in Monaghan, indicated concentrations of 3 mg/l of fluoride were detected. Normally fluoride would be detected at concentrations less than 0.5mg/l.

## CONCLUSIONS

Results on their own mean nothing it is their interpretation that allows the associated risks to be assessed. The purpose of an environmental investigation is to determine the vertical and horizontal extent (if any) of contamination in the subsurface. If contamination is present we need to assess the associated risk i.e. rate of migration of the plume, who/what is it impacting and to what consequence etc. It is only possible to determine these risks if the vertical and horizontal extent of the plume of contamination has been accurately determined and there is confidence in the analytical results.

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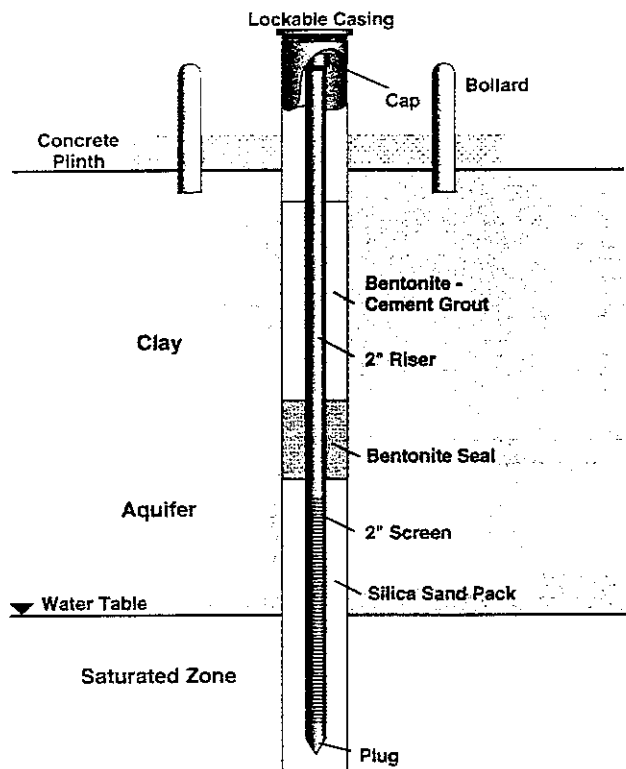


Fig. 1

Typical Shallow Monitoring Well

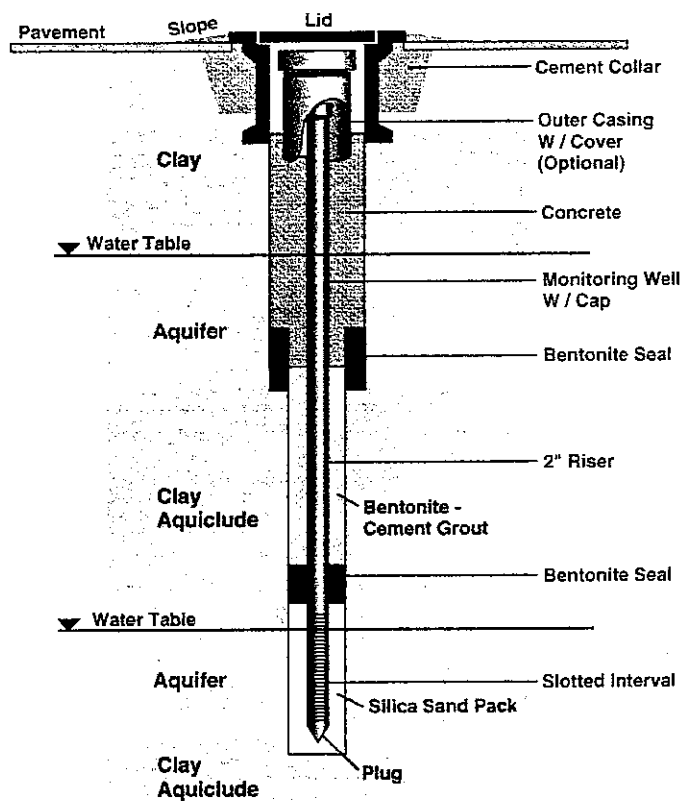


Fig. 2

Sampling Beneath a Contaminated Aquifer

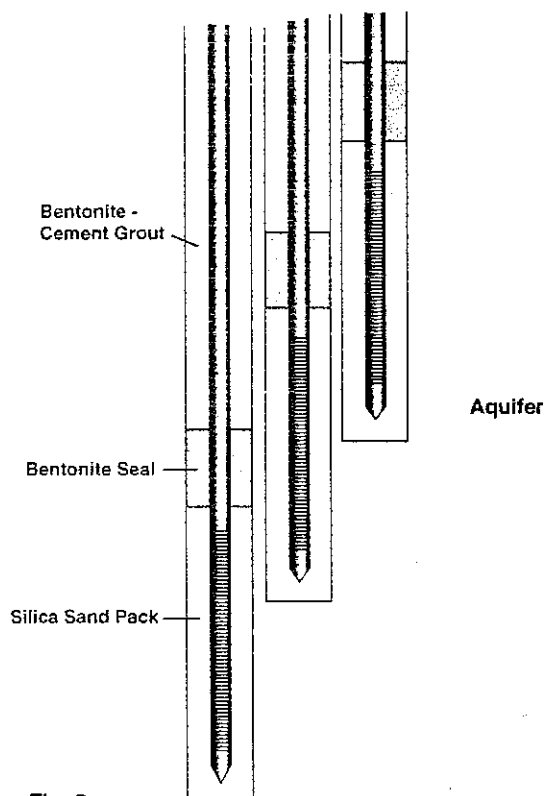


Fig. 3

Well Cluster

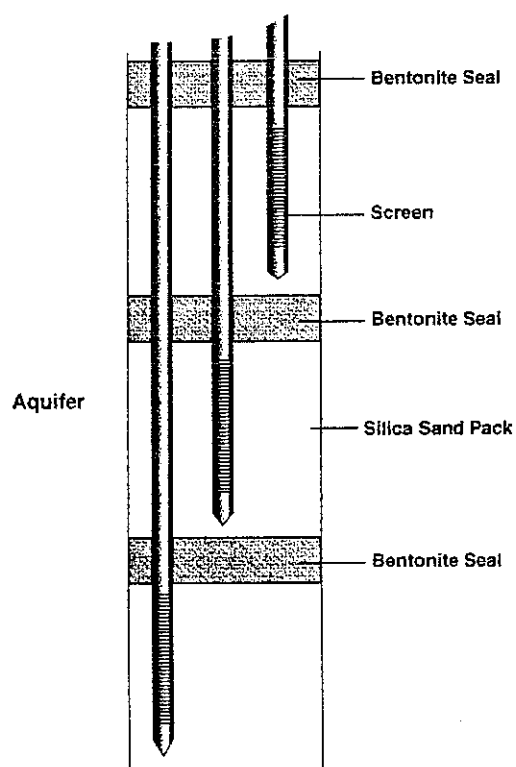


Fig. 4

Well Nest



**Table 1 - Groundwater Analytical Results : Total Petroleum Hydrocarbons (TPHs)**

Laboratory	Analytical Method	MW-1 mg/l	MW-2 mg/l	MW-3 mg/l	MW-4 mg/l	MW-5 mg/l	Dutch MACs	
							S-Value mg/l	I-Value mg/l
3/7/96								
Laboratory 1	FTIR	0.4	0.3	0.2	0.3	0.1	0.05	0.6
22/8/96								
Laboratory 2 (Namas Accredited)	FTIR GC/FID	0.9	3.2	15.1	15.4	21.3 1.55*	0.05	0.6
Laboratory 3	GC/FID	<0.04	<0.04	<0.04	<0.04	<0.04	0.05	0.6
22/10/96								
Laboratory 2 (Namas Accredited)	GC/FID	0.15	0.23**	0.37	0.06	0.26**	0.05	0.6
Laboratory 3	GC/FID	<0.04	<0.04**	<0.04	<0.04	<0.04**	0.05	0.6

**Legend**

MAC - Dutch Maximum Admissible Concentration

S-Value = Target Value

I-Value = Intervention Value

\*Repeat analysis using the GC method on the existing sample

\*\*Samples labelled respectively as MW-2 and MW-5 but consisted of mineral water (Blanks)

## MAKING REMEDIATION WORK - PRACTICAL DESIGN CONSIDERATIONS

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*Good remediation designs need to address a range of factors if they are to be successfully implemented and funded. The standards and techniques used need to satisfy the regulators and meet the legal requirements. Overall the remediation should reduce the risk that the contamination poses to the environment in a cost effective way. Two case studies are presented. The first relates to a local authority lead emergency PCB clean up, which initially appeared to large scale contamination. After thorough investigation the remediation was reduced in scale with consequential cost savings. A series of strategies were considered for the Crown Works and CMI sites with off site disposal of severely contaminated material and encapsulation of the remainder being the preferred solution. The second case study is part of a large scheme to redevelop Cardiff Docks. A waste infilled dockyard had effectively sterilised 20 ha of prime development land and had an adverse impact on a much larger area of new development across much of the bay. Through the use of encapsulation and barrier walling techniques, longterm control mechanisms including real time telemetry monitoring, the site was rendered safe and development of the site and surrounding land was enabled.*

Although it may appear obvious to most people, land remediation is essentially about implementing practical solutions, not something that can be achieved solely on the drawing board. Remediation covers a range of activities but irrespective of the philosophy used there are a number of factors which must be considered when determining the best course of action for site remedial or control works if it is to deliver a practical and successful solution. These factors can be considered under the following headings:

- engineering feasibility
- economics
- health and safety
- environmental impact
- current and future codes of practice
- legislation

Each one has a role to play in ensuring the success of a remediation strategy, although the ranking and importance of each one will vary from site to site.

Engineering feasibility must be considered for any physical solution which is deemed necessary at a contaminated site. This means that the solution must be practical and buildable, and appropriate to the ground conditions. Schemes which require separation of contaminated soil from clean when two are visually indistinguishable must be designed to accommodate the time delays of chemical testing in mind. Cover systems should combine natural and synthetic layer as appropriate and thicknesses of layers must be taken into account both in theoretical performance and the practicalities of laying clay or gravel to a given thickness.

Economics are fundamental to the progression of a scheme, and having established throughout the risk assessment that there is a requirement for clean up, then cost must be controlled to ensure that the

development scheme can generate sufficient funds to cover the additional reclamation costs. This condition applies to both the public and private sector as the case studies that follow show.

When designing the clean up strategy, both health and safety and environmental impact issues must be considered such that when a solution is chosen, it can be demonstrated to have considered all the issues in addition to basic cost. The chosen solution should balance all environmental impacts against cost and final site condition to provide the required reduction in risk, minimisation of environmental impacts and a reasonable cost - thus following the strategy of BATNEEC. In particular, the UK Construction, Design and Management Regulations (1994) require that the hazards to the construction workforce are addressed by the Client, the Designer and the Contractor and this applies especially to contaminated land.

There are a number of codes of practice and policy laid down by government at national and international level. Great skill is required in interpreting these as legal documents and statements of regulators policy. In certain cases there are omissions for certain contaminants and guidance levels, trigger action levels and acceptable environmental quality standards are not readily available. In these cases agreement has to be reached with the regulators about working standards borrowed directly from other countries, eg Dutch guidelines, or created from a combination of other countries standards. Which ever approach is used the environmental engineer is faced with devising schemes which ensure that "significant harm" cannot be caused or pollution of "controlled waters" is prevented.

Recent legislation in the UK, Ireland and NI are establishing "Environmental Protection Act culture" through the formation of new law and independent agencies that have been created to enforce the legislation in a more integrated and holistic way.

The following case two studies cover a range of aspects of remediation projects and illustrate some of the key features of the practicalities of successful remediation schemes.

#### **CASE STUDY 1 CROWN WORKS SITE - WOLVERHAMPTON, ENGLAND**

The investigation of the Crown Works/CMI site in Wolverhampton for polychlorinated biphenyls (PCBs) was undertaken as an emergency response to vandalism of two transformers. Initial quotations from contractors to deal with the PCB spill were up to £0.5 million. Site investigation work revealed lower PCB concentrations than originally anticipated and it was concluded that the original PCB containing transformer fluids had previously been replaced by non PCB containing fluids. As a result it was decided to clean-up the PCBs in conjunction with other contaminants known to be present on the site from historical site uses and previous site investigations. In particular over 150 drums of unidentified substances were present on the site and oil residues and metals could be seen within the ground materials over much of the site.

A site assessment was undertaken to identify sensitive targets around the site and the potential hazards present on the site. A comprehensive contamination investigation was then undertaken in order to design the most cost effective remedial measures to render the site suitable for re-development. Remediation of the site for a heavy industrial end-use considered the isolation, removal or treatment of contaminants to reduce the risks to the potential targets identified in the risk assessment.

A summary of site conditions on which the remediation strategy was based are given below:

- All structures on site are in a dangerous condition
- The site contains a variety of mixed drummed wastes

- Stockpiles of contaminated metal wastes and associated debris cover most open areas
- Damage to transformers has resulted in limited release of PCBs
- CMI site contains fill to depths of 2.5m or more
- Principal contaminants are metals at concentrations grossly in excess of ICRL and Dutch C values
- Crown works site contains fill to depth of 1.5m
- Principal contaminants are metals which, on average, exceed ICRL and Dutch C values
- Deeper made ground (below 1.5m) is saturated at the CMI site
- Shallow groundwater is contaminated
- Boulder clay below made ground is generally uncontaminated
- Deep groundwater is very slightly contaminated

Leaching tests indicate significant availability of metals for transmission to groundwater. Two phases of remediation were established, splitting the site into above ground and below ground conditions.

### Phase I. Above ground clearance

- off-site disposal of degradable materials and asbestos sheeting
- recycling, where appropriate of masonry and concrete from the demolition works to provide backfill/engineering fill
- excavation of PCB contaminated soils in spill areas
- off-site disposal of PCB contaminated water within the culvert together with further testing to monitor the PCB concentrations; further pumping and disposal if necessary

Although extensive sampling of the drummed wastes had been undertaken at the investigation stage, some drums of unreacted nickel catalyst were unearthed which were subject to spontaneous combustion if exposed to the air. These drums were sent for treatment. Great care was taken during demolition to avoid cross-contamination of the site by uncontrolled movement of wastes. The final cost of dealing with the PCB-contaminated soil and water was £30,000 and the total cost of Phase I was £120,000.

### Phase II. Subsurface soils and structures

This phase of the work was completed in 1995 and was selected from four strategy options which created progressively cleaner land with greater flexibility of use, but at an increasing cost. The options, in order of increasing cost are summarised below:

Method	Enduse
a) Capping of contaminated soils and provision of surface drainage	Public open space/limited industrial
b) Capping of site and removal or treatment of moderately contaminated soils	Car parking on CMI site/commercial use of Crown Works site
c) Removal or treatment of heavily contaminated soils from the CMI site and replacement with moderately contaminated soils from the Crown Works site, backfilling with clean fill	Car parking on CMI site, unlimited industrial or commercial use of Crown Works
d) Total removal or treatment of all contaminated soil and water at the sites with clean inert fill	Unlimited commercial or industrial use of both sites

Whilst three options consider the treatment of fill, the diverse and mixed nature of the contamination and parent materials make treatment an expensive solution involving more than one process. After careful consideration of a number of treatment methods including soil washing and vitrification, off

site disposal to landfill was found to be the most cost effective and legal solution. Option b) was finally selected after detailed discussions with the developer. The Environment Agency also required the installation of a vertical barrier around the capped contamination at the CMI site, and this was achieved combining a cement bentonite slurry wall with an engineered natural clay barrier which was toed into the underlying clay. The final cost of phase 2 was £1.2M.

## CASE STUDY 2 PENARTH HAVEN DOCKS, CARDIFF, WALES

Penarth Haven Docks comprise a former dock up to 16m in depth, infilled with predominately domestic refuse from the period 1974-1989. The site was acquired by Cardiff Bay Development Corporation in 1991 and areas around the landfill site were derelict and scheduled for future residential and commercial development by the Corporation. The old docks are surrounded on all land based sides by new development and on the coastal side by a new marina. Extension of the marina had ceased as it could not be brought any closer to the waste filled docks, as had work on the other site boundaries. The problems at the dock had therefore sterilised about 15ha of land based development and a smaller amount of coastal marina development.

Investigations undertaken in 1991 by Aspinwall identified gas and limited leachate contamination occurring from the site. Ammonia transported in leachate from the wastes was adversely impacting on the marina and estuary and gas migration into adjoining land was a major problem. The waste was confined largely to the former dock which still had brick and stonework walls intact and thus the actual position of the waste was clearly defined. Two main strategies for controlling the hazards arising from the 750,000m<sup>3</sup> of refuse were considered:

- removal of all wastes to an off site landfill and backfill with inert materials
- encapsulation of the wastes and installation of gas and leachate control schemes together with long term maintenance systems

Having determined to pursue the on site encapsulation strategy on the grounds of environmental impact, safety and costs a set of design objectives were prepared. These were to:

- exclude landfill gas from all future buildings, services, ducts and enclosed spaces outside the lateral encapsulation
- include sufficient gas control methods to facilitate successful operation throughout the gas producing lifetime of the site for all possible gas emission rates
- use a set of control systems which are the simplest and require the least maintenance to achieve the above objectives

The design includes incorporation of multi-barrier systems and is based on the approach that each barrier is capable of controlling landfill gas in its own right, with each additional barrier providing an extra factor of safety for the whole system. Thus the system includes multiple barriers:

### Lateral containment

- Slurry Wall
- HDPE geomembrane
- 

### Landfill Capping

- Engineered clay cap
- LDPE geomembrane

Gas collection is also designed on a multiple system with horizontal and vertical collection systems, active and passive treatment systems and real time telemetric monitoring of barrier wall integrity. The largest cost component of the remediation was the bentonite slurry/membrane walling. This extends to a length of 1.2km and a depth of 20m. The entire remediation works took almost two

years to complete at a cost of £5 million. The barrier wall not only contained the landfill gas but also formed a major component of the estuary protection scheme and leachate generation control mechanism. Groundwater flowed towards and through the wastes generating leachate as it passed towards the estuary. The installation of the barrier wall diverted groundwater flow around and beneath the wastes through the mudstones and by careful hydraulic control of the levels within the site flow of leachate out of the site was prevented. Initially the reservoir of leachate in the wastes was depleted by pumping and tankering off site and once the barrier walling and capping was in place leachate generation fell dramatically. The residual leachate generated is now pumped to a sewer connection. Land adjoining the site has now been successfully redeveloped for retail development by companies such as Tesco and the marina extended as part of the entire re vitalisation of the Cardiff docklands. The total cost of all the works necessary for the remediation and site infrastructure was £12 million, bringing back 15 ha of adjoining land and 5 ha of land on the actual dock itself.



## THE HYDROGEOLOGY OF THE AVOCA MINES

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### ABSTRACT

*The Avoca Mines are abandoned copper and sulphur mines in Co. Wicklow. They are currently having a severe environmental impact on the Avoca river due to the discharge of acid mine drainage (AMD). This paper discusses the results of an 8 month EU funded study of the hydrogeology of the mines. The mining process has produced a large number of voids and cavities resulting in an increased permeability in these zones. This has created a situation where groundwater inflow into the mines is channelled along the mine workings and discharged to the river at the adits. These discharges averaged 8 to 10 l/s during the period of study (a low rainfall summer period) but have previously been recorded in excess of 65 l/s. For summer conditions the contribution of contaminated groundwater baseflow was estimated as approximately 4.5 l/s. Tentative calculations suggest an average output of AMD contaminated waters from the mines of about 35 l/s. These AMD waters are characterised by a very low pH, high EC and high metal and sulphate levels.*

### INTRODUCTION

In response to the Fifth Environmental Action Programme of the European Union, Wicklow County Council developed an Economic Conversion Strategy for the Avoca/Avonmore catchment. One of the elements of this strategy is the Rehabilitation of Previous Environmental Damage. The abandoned Avoca Mines has resulted in extensive environmental damage within the catchment and the Avoca/Avonmore Catchment Conversion Life Project (93/IRL/A25/IRL/3071) was developed to address this problem. As part of the site characterisation the hydrogeology was studied by the Geological Survey of Ireland during the period of May 1995 to December 1995. Funding for this study came from the EU Life Programme. The scope of work comprised groundwater level monitoring and sampling, surface water sampling, flow gauging, the drilling of six boreholes and permeability testing.

### THE AVOCA MINES AREA

The Avoca Mines are located in the Vale of Avoca, Co. Wicklow. The main topographic feature is the Avoca River valley which divides the mining area into the East and West Avoca Mines (Figure 1).

The bedrock in the area consists predominantly of sediments of the Ordovician Duncannon and Ribband Groups. The Duncannon Group includes the Avoca Volcanic Formation which is divided into three members, and it is at the top of the Kilcashel Member that the mineralization occurs as massive and stringer sulphides (McArdle, 1993).

There are references to mining in the district as far back as the 15th century. Copper mining began around 1720 and both copper and pyrite were mined periodically in the 19th and 20th centuries before the closure of the mines in 1982. The mining activity has resulted in extensive underground workings consisting of a network of levels and shafts that remain largely intact. The later surface mining



methods resulted in three open pits and the waste from the Cronebane Pit resulted in the formation of Mount Platt (Figure 1).

Mining at Avoca has resulted in the removal of material from an anoxic environment to an oxic environment. The material, which generally contains significant amounts of sulphides (predominantly pyrite), has become weathered which, with the introduction of water into the system, results in the generation of acid mine drainage (AMD). This AMD is currently discharging from the old mine adits into the Avoca River, resulting in contamination of the river downstream of the discharge points.

## METEOROLOGY AND HYDROLOGY

The mean annual rainfall at Avoca from 1971 to 1980 was 1171 mm/yr. Raingauges were installed at both East and West Avoca during the study: the monitoring period proved to be very dry with only 217.4 mm of rainfall being recorded over a period from the 31st July to the 19th October, most of which fell in October. The rainfall patterns (from the 1970's monitoring and the present study) were also noted as being very similar to those recorded at the rainfall station at Arklow Water Works. Rainfall at Avoca was 118% of that recorded at Arklow.

Flows in the Avoca River are 'flashy' and responded quickly to rainfall events implying that the bulk of effective rainfall is discharged rapidly as runoff (Flynn, 1994). During the study period flows in the river were very low ( $0.6$  to  $1.0 \text{ m}^3/\text{s}$ ) as a result of the dry summer. The river also appeared to be decreasing in flow (by approximately 23%) between the upper two gauging sections, probably as a result of flow being lost to the underlying alluvium. Below this, the river became a gaining river again.

Discharges from the mines were monitored by v-notch weirs, one at the Deep Adit at East Avoca and two at the Ballymurtagh outfall at West Avoca (Figure 1). Discharges from the adits were very low over the summer averaging 9.8 l/s and 7.6 l/s for the East and West Avoca Mines respectively. However data from previous monitoring by Wicklow County Council show that these values can increase significantly over winter months when rainfall is greater. Discharges as high as 65 l/s have been recorded and mean discharges for a period of January to April 1994 were 38 l/s and 24 l/s for the East and West Avoca Mines respectively. There appears to be a lag of two to three days between recharge into the system and an increase in discharge from the adits.

## HYDROGEOLOGY

Although the volcanic rocks of Ordovician age are classified as regionally important aquifers in Wexford and Waterford, they are only considered minor or locally important in Co. Wicklow. Drilling during the study showed that the bedrock is of variable quality with rock quality designation (RQD) values being poor (<30%) in the upper 20 to 30 m. It is within this upper fractured zone that the majority of groundwater flow is likely to take place. Below this zone the rock becomes fresher and fracturing less frequent and permeabilities are likely to be considerably reduced.

Test pumping of the investigation boreholes confirmed the poor aquifer characteristics, with transmissivity values ranging from 0.04 to  $11.5 \text{ m}^2/\text{d}$ . The wells were pumped at very low rates (4 to  $8 \text{ m}^3/\text{d}$ ) producing drawdowns of 0.5 to 20 m. In some instances there was evidence of dewatering of fractures during the testing. Aquifer storage in the volcanics is also low and hence relatively large fluctuations in water levels may occur as a result of relatively small variations in aquifer recharge and discharge. Hydraulic conductivities of 0.01 to 0.13 m/d for the unmined bedrock and 5 to 35 m/d for

the mined area were inferred from a numerical modelling study of the mines (Lindner 1996). The numerical modelling confirmed that the flow regime is significantly influenced by the mine workings.

Testing of the spoil heaps at Mount Platt also showed very low permeabilities. This is due to the high percentage of fines that comprise the spoil material, with 44 to 51% of the material being finer than 0.063mm. These low permeabilities also may be partly due to compaction effects.

Groundwater levels in the area were generally between 5 and 15 m below ground level during the summer of 1995 and did not fluctuate greatly, except along the steep valley sides where groundwater levels were deeper. Rapid changes in water level also occurred immediately around the mines suggesting steep gradients in these areas. One well on the edge of the Cronebane open pit recorded a drop in water level of 14 m in 25 days. Within the mined area itself the water levels were much lower than those in the surrounding bedrock (Figure 2). Levels in the Vent Shaft and Twin Shafts were 135 and 99 m below ground level respectively. These levels remained constant throughout the dry summer.

### HYDROCHEMISTRY

Previous hydrochemical work in the area by both Flynn (1994) and Gray (1994) concluded that the Avoca mines are active AMD producing sites. Some of the surface water sampling during the course of this study is summarised in Table 1 below. The water in the Avoca River upstream from the mines is relatively uncontaminated, with low EC values and pH values close to neutral. The water discharging from the mine sites is of very poor quality with a low pH, high EC and very high metal and sulphate levels. This has an immediate impact on the Avoca River as, despite the effects of dilution, the pH drops to 5 and metal and sulphate levels increase significantly.

Table 1

Sample Location	EC mS/cm	pH	SO <sub>4</sub> mg/l	Fe mg/l	Zn mg/l	Cd mg/l	Cu mg/l	Al mg/l	AMDI*
Upstream	0.11	6.71	11.9	0.224	0.369	<0.025	<0.01	0.185	94.1
Deep Adit	2.31	3.41	1365	104.4	57.11	0.17	0.645	116.5	24
Ballymurtagh	2.90	3.57	1761	154.1	27.31	0.068	0.989	67.45	26
Downstream	0.17	5.08	40.5	1.896	1.618	<0.025	0.107	1.965	67.2

\*The acid mine drainage index (AMDI) is an objective index for assessing AMD contaminated waters (Gray, 1995). A high AMDI value represents uncontaminated water and a low value indicates AMD contamination.

Water quality in the Avoca River downstream from the adit discharges is poorer than that which would be expected if the only source of AMD contamination was from the adits. This implies that while the adits are the main source of contamination, there is also a contribution of AMD from river baseflow (see below).

The pH of the groundwater in the area outside the influence of the mines is generally low, varying from 5.5 to 6.5. This is a reflection of the nature of the volcanic bedrock which does not contain significant carbonate to buffer the groundwater. Elevated levels of Fe, Zn, Mn, and Cu were also noted in samples taken from local wells throughout the area. Within the mined area itself the groundwater has a high EC, low pH and very high metal and sulphate levels, typical of waters affected by AMD. At West Avoca samples from the shafts were relatively unaffected by AMD. These shafts were sunk outside the ore zone and are located southwest of the open pits and the surface spoil heaps, downgradient from any AMD generated by runoff entering the workings.

Hydrochemical data collected during the study suggest a total AMD contaminated groundwater baseflow of 3 l/s to the Avoca river while increases in river flow, accounting for the adit discharges, suggest baseflow of 6 l/s. These figures, although tentative, are similar and an average contaminated baseflow of 4.5 l/s has been assumed. Assuming an annual mean discharge of 15 l/s from each of the adits, total outputs from the mine can be estimated at 34.5 l/s or  $1.1 \times 10^6 \text{ m}^3/\text{yr}$ .

## CONCLUSIONS

The underground workings of the abandoned Avoca Mines are currently discharging AMD-contaminated water to the Avoca River, causing a severe environmental impact on the river. Monitoring of the river showed very low baseflows during the summer of 1995 reflecting the lack of rainfall in the catchment during the study period. Discharges from the mines were also relatively low during this period but these have been known to increase significantly during the winter months. The volcanic rocks have a secondary permeability and the majority of groundwater movement is likely to take place in the upper 20 to 30 m where the bedrock is most weathered and fractured. Low transmissivity values were derived from test pumping and aquifer storage is likely to be low also. Water levels within the mined area are significantly lower than those in the surrounding rock resulting in a general inflow of groundwater into the mine which is then discharged to the river at the adits. The contribution of AMD-contaminated baseflow to the river during summer conditions was estimated at approximately 4.5 l/s which, although significant, represents only 20% of that from the mine workings. Tentative calculations suggest total outputs from the mines are of the order of 35 l/s as an annual average.

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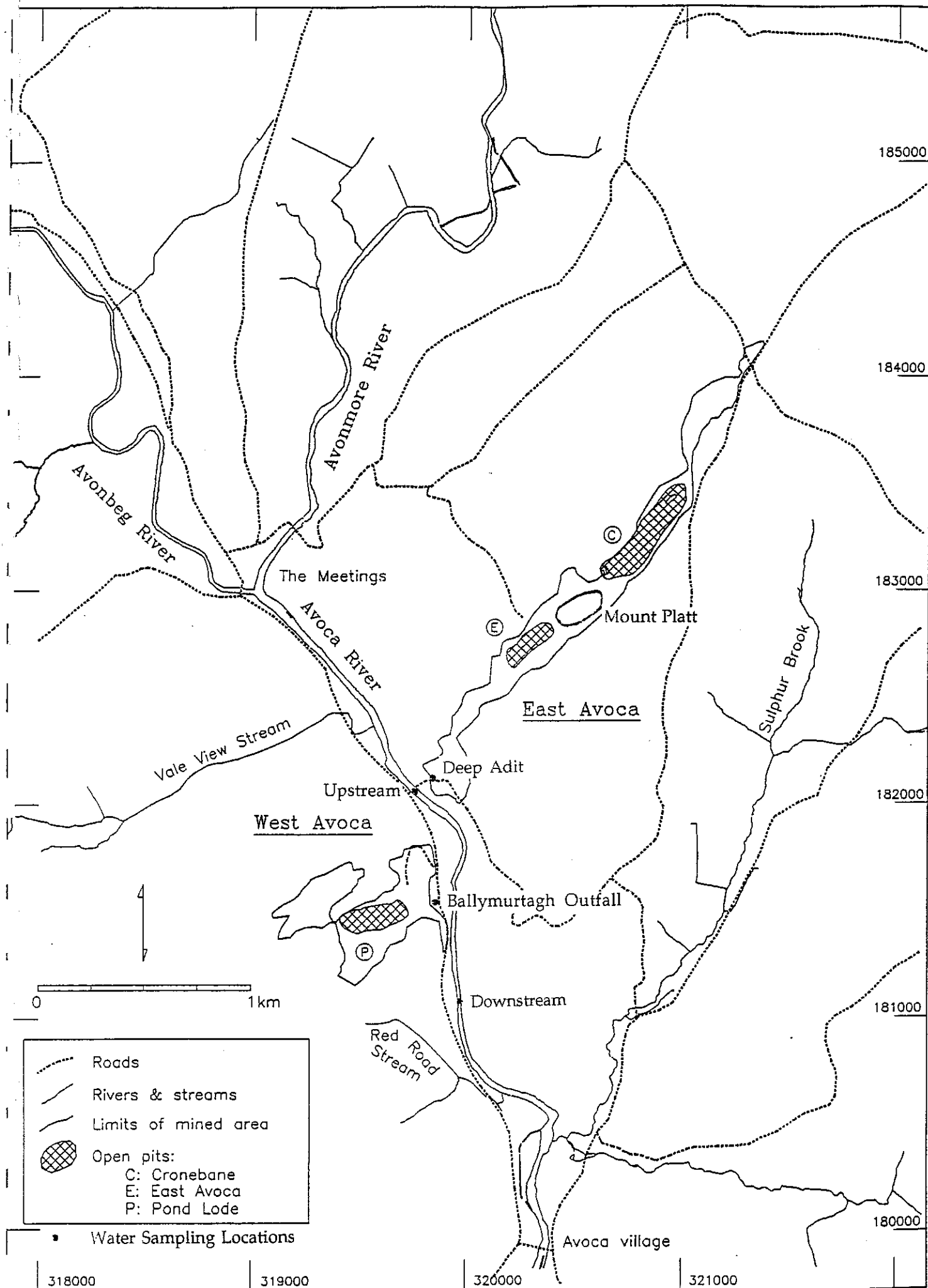


Figure 1 The Avoca area

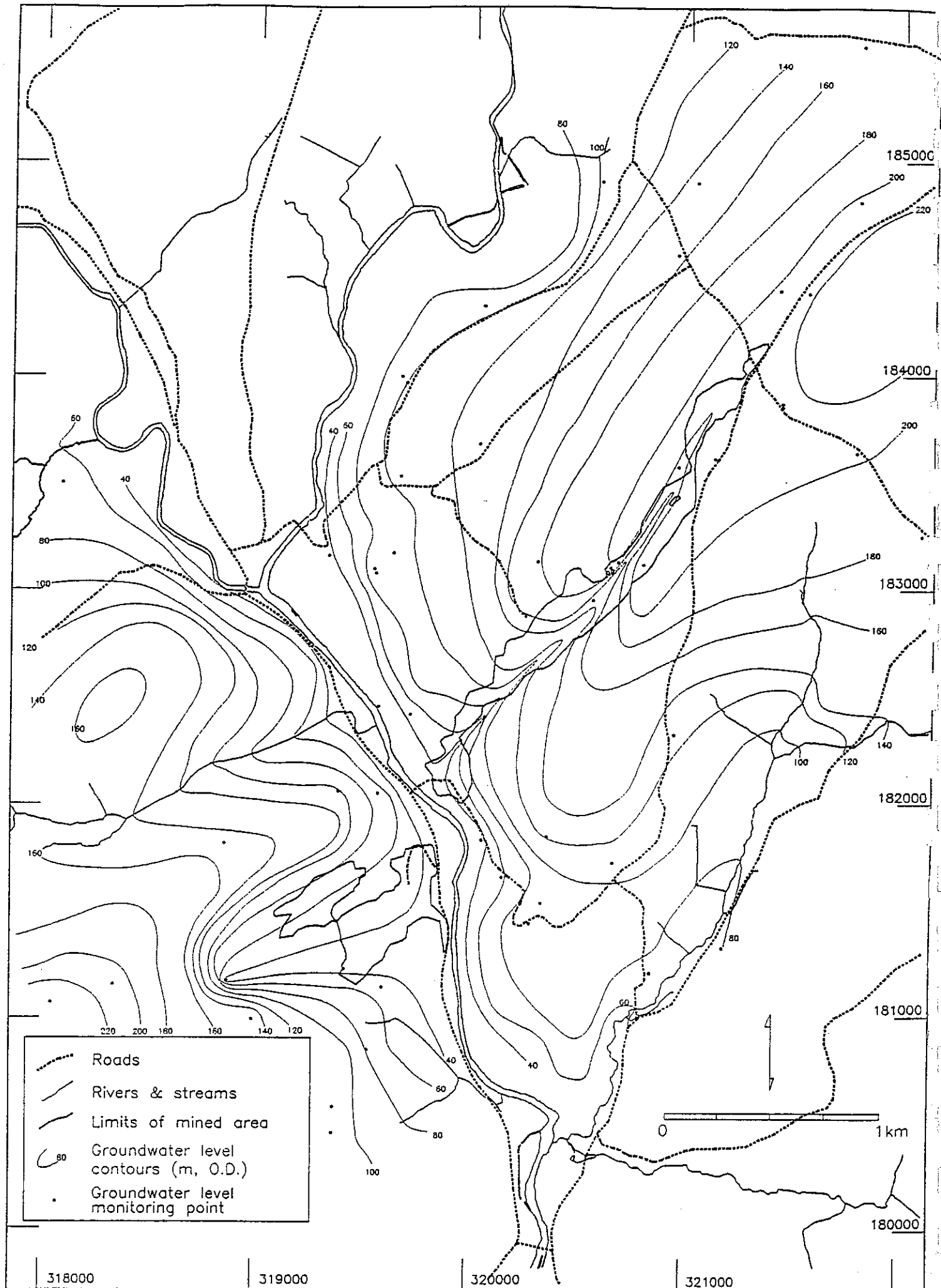


Figure 2 Groundwater level contour map of Avoca area

## PULVERISED FUEL ASH: ITS COMPOSITION AND WEATHERING

SJ Pow  
ESB International

### SUMMARY

Pulverised fuel ash (pfa), furnace bottom ash (fba), and slag are the main waste products produced from peat and coal combustion within utility boilers. Coal pfa predominately consists of spherical aluminosilicate particles, amorphous aluminosilicate glass, mullite, quartz, and anhydrite. Peat pfa consists of calcite, hydrated lime, quartz, brucite, and magnesium carbonate. The majority of the heavy metals within fly ash are concentrated within the fine grained (<2.7mm) fraction.

The leachate generated from coal and peat pfa shows a clear variation with time and between different ash types. The concentration of total dissolved solids (TDS) falls dramatically after one bed volume of interstitial fluid (leachate) has been displaced from the ash. The initial leachate, dominated by admixed and surface adsorbed alkali and alkaline salts, is very slightly acidic due to the dissolution of adsorbed  $\text{SO}_2$  onto the surface adsorbed inorganic salts. However, thereafter, the solution becomes very quickly alkaline due to the hydrolysis of CaO flecks and the dissolution of  $\text{Ca}(\text{OH})_2$ . The next main stage is the release of soluble constituents from the chemical alteration of the glassy matrix with increased weathering. The highest Sr,  $\text{SO}_4$ , pH, Cd, As, and Se levels occur within the ash's initial "lagooned" interstitial water. Cu, Mo, Ba, Ni, and Cr levels are predicted to increase with increased weathering.

### 1. INTRODUCTION

The Electricity Supply Board (ESB) is a vertically integrated, semi-state, electricity company which currently has a monopoly upon the generation and distribution of electricity within Ireland. The ESB group is divided into a number of strategic business units, eg. Power Generation, Distribution, National Grid etc. Power Generation is responsible for the generation of electricity from a broad portfolio of peat, coal, and gas fired power stations. A significant amount of electricity is also generated from the company's hydro power stations.

Coal and peat fired boilers produce solid waste (ie. slag, pulverised fuel ash (pfa) and furnace bottom (fba) ash) from fossil fuel combustion. In a typical year ESB burns around 2.9 million tonnes of milled peat and 2.3 million tonnes of low sulphur coal. Approximately 72,500 tonnes of peat ash and 300,000 tonnes of coal ash are produced annually. The ash left coal/peat has been burned contains low levels of trace elements, a proportion of which are readily soluble. The remainder are only released by weathering and mineralogical changes over an extended period of many years in response to rainwater infiltrating through the ash landfill.

The main objective of this paper is to provide an insight into the composition of pfa and any changes with weathering over time. However it is impossible to understand the nature of any industrial waste without first understanding the process which produces it. Therefore, by way of introduction, the generation and removal of slag, bottom ash, and fly ash from a utility boiler is described below.

### 2. SOLID WASTE FORMATION AND REMOVAL.

Slag and bottom ash accumulate in the bottom of the boiler. The former is a glassy, angular, non-crystalline material formed from melted coal/peat whereas the latter is a solid, coarse grained, granular ash. The lighter, fine grained, pfa accounts for around 80% of the ash produced from peat/coal combustion. Pfa is entrained within the flue gas and subsequently transported out of the boiler for

collection by either mechanical grit arrestors or electrostatic precipitators ("precips"). The former are used at ESB's peat stations whereas the latter are used at Moneypoint PS. Ash hoppers are used to collect pfa from the grit arrestors/"precips".

At Moneypoint the coal pfa is transferred, using air or mechanical conveyors, to silos/bunkers and is supplied dry for ash sales. However a very small proportion is stockpiled prior to use by passing it through a mixer-conveyor plant and conditioning it with 10-20% water.

At a typical peat station, water is used to "slurry" the peat ash out from the hoppers and transport it via short pipelines to a local settling ("ash") lagoon. The ash can be readily handled as a slurry at concentrations of up to 40% by weight but, typically, the average burden is closer to 20%. The "slurry" water is diluted in the lagoon by the flushing water which prevents scale forming from within the pipeline. The ratio of water used to ash discharged is typically 25:1 by weight. The "slurry"/flushing water is normally taken from a nearby river and is used only once before it is returned to the river as lagoon effluent. Designing the lagoon system in cascade, and placing additional settlement lagoons between the main lagoon and the discharge point, ensures that the water returned to the river is of a high quality.

The fba (about 20% of the total ash produced) falls into hoppers at the bottom of the furnace. It is removed by high pressure water jetting along sluiceways to a coarse crusher and, thereafter, transported to either storage pits or lagoons.

### **3. COMPOSITION (PROPERTIES, MINERALOGY, AND CHEMISTRY)**

#### **3.1 Physical/Hydraulic Properties**

Pfa is a well sorted material because the extraction of ash from the flue gas is physically analogous to the natural aeolian separation of particle sizes, eg. dune sands, loess etc. Typically 65 to 90% of fly ash is finer than 0.010mm. Pfa plots on a textural triangle as a silty loam. Its comparatively low particle density (2.11 to 2.44 Mg/m<sup>3</sup>) arises from the high cenosphere (ie. hollow aluminosilicate spheres which contain trapped air) content. Pfa's porosity and hydraulic conductivity are typical of a silt/silty loam. Total porosity ranges from 42% to 51% and effective porosities vary from only 5 to 10%. The saturated hydraulic conductivity varies from  $1 \times 10^{-8}$  m/s to  $1 \times 10^{-6}$  m/s.

#### **3.2 Mineralogy**

##### **3.2.1 Coal Pfa**

Coal pfa consists of alumino-silicate spherical particles, amorphous alumino-silicate glass, quartz, magnetite, hematite, mullite, CaO and anhydrite. Quartz, glass, and mullite forms the principal matrix of fly ash. Hematite and magnetite are the main Fe bearing compounds, anhydrite and lime are the main Ca compounds, and periclase (MgO) is the main Mg compound. Some Fe, Ca, and Mg is also present within the amorphous glassy phase.

The above mineralogy has been formed from the metamorphism of original coal minerals within a coal boiler at temperatures of up to 1600°C. For example the predominance of phyllosilicates (eg. mica, kaolinite, chlorite, and montmorillonite), feldspars, and quartz in coal explains the preponderance of glass, mullite, and quartz within pfa. The Fe-oxide within fly ash is formed from original Fe-sulphide, carbonate,

and sulphate and, similarly, its Ca and Mg oxides are formed from the alkaline earth carbonates within coal.

### 3.2.2 Peat Pfa

Calcite ( $\text{CaCO}_3$ ), hydrated lime ( $\text{Ca(OH)}_2$ ), quartz ( $\text{SiO}_2$ ), brucite ( $\text{Mg(OH)}_2$ ), and magnesium carbonate ( $\text{MgCO}_3$ ) are the main phases present. Peat is combusted at a significantly lower temperature than coal (approximately  $1000^\circ\text{C}$ ) due to its high moisture content (55%) and large quantity of inerts in the combustion chamber which results in low flame temperatures. Consequently pfa contains a significant amount of unburnt carbon (typically 15 to 20%) which produces relatively high losses upon ignition (ie. approximately 20%) when compared to coal pfa.

## 3.3 Chemistry

### 3.3.1 Coal Pfa

Coal pfa is classified according to its parent coal, eg. sub-bituminous and bituminous pfa are derived from bituminous and sub-bituminous coal respectively. There are not only significant chemical differences between the two classes but also within each class (eg. low pH/high pH bituminous ash) due to subtle compositional differences. ESB burns a mix of US and Columbian sub-bituminous coal.

The composition of typical coal pfa has been researched by EPRI (Electric Power Research Institute), and the UK power industry, and is summarised below:-

- i) Silt sized particles ( $<50\mu\text{m}$ ) constitute 80-95% of the fly ash mass and clay size ( $<2\mu\text{m}$ ) particles constitute 14 to 28% of the particle mass.
- ii) Although the  $<2.7\mu\text{m}$  fraction only constitutes 15 to 30% of the fly ash mass, it contains a significant proportion of the trace elements, ie. 50% of the total As, Mo, Pb, and Zn mass and 40% of the total Cr, Cu, Ni, Se, and V mass.
- iii) The above distribution can be explained by the known degree of volatility within source coals, ie. As, Cr, Cu, Mo, Ni, Pb, Se, V and Zn are volatilised to different degrees and subsequently condense onto the surface of fly ash particles as sulphates and/or oxides. These elements are concentrated within the finest sized fractions due to their greater surface area.

### 3.3.2 Peat Pfa

Peat pfa chemistry varies with the type of peat burnt and the nature of the combustion process. The peat type burnt within a power station can show a considerable variation over time depending on the area of the peat bog harvested and the depth of extraction. Unlike coal, peat ash is geologically a very young fuel and is characterised by high volatile content, high oxygen content, low sulphur and ash contents, low melting point, and low bulk density. A significant amount of information is available pertaining to the chemical composition of peat pfa but, as yet, no correlation relating element concentration to grain size. However, as a first approximation, the partition and distribution of elements from peat into peat pfa is assumed to be analogous to coal and coal pfa.



#### 4. WEATHERING

From the above correlation between element distribution and particle size, one would expect the elemental mass within the surface layers to constitute the most mobilisable fraction of peat and coal pfa. The formation of secondary compounds may control the solution composition of the leachates. In contrast, the elemental mass present within the matrix phases (glassy, aluminosilicate, and magnetic spinel) would be the least mobile and dissolution would only occur with intense weathering. EPRI, ESB, and UK power industry data suggests the following:-

i) Weathering has only a relatively minor impact upon pfa mineralogy. For example the smooth spherical aluminosilicate particles of fresh pfa are not etched during the weathering process and, indeed, a porous, flake-like, weathering product on the surface is the only evidence for it.

ii) Ash leachate composition varies with time. The initial leachate from fly ash contains a number of admixed and surface adsorbed inorganic salts. The initial leachate is very slightly acidic due to the dissolution of adsorbed  $\text{SO}_2$  onto the surface of the fly ash. However, thereafter, high concentrations of Ca, Na, and K are released into solution whose alkalinity is related to the hydrolysis of CaO flecks and dissolution of  $\text{Ca}(\text{OH})_2$ .

iii) UK power industry research suggests that TDS falls dramatically after approximately 1 bed volume (ie. the amount of water required to completely fill the voids of an ash bed) of interstitial fluid has been displaced.

iv) As these salts are solubilised and removed from ash, concentrations of soluble constituents are released from the chemical alteration of the glassy matrix with increased weathering. The leachate after moderate weathering contains appreciable Si and Al which has been leached from the surface glass. The highest Sr,  $\text{SO}_4$ , pH, Cd, As, and Se levels occur within the ash's initial "lagooned" interstitial water. Cu, Mo, Ba, Ni, and Cr levels are predicted to increase with increased weathering.

v) Preliminary UK power industry research suggested that, for a given ash, the initial percolate quality was virtually independent of bed depth, ie. the element activity relationships are similar regardless of location depth. This has been rationalised by postulating that leachate composition is controlled by key solubility-controlling solids and that equilibrium is approached, at least by some elements, on a time scale of days. The comparison of the measured activities with those calculated from equilibrium reactions involving corresponding solid phases suggests that the concentration of Al, Ba, Ca, Cr, Cu, Fe, S, and Sr in solution are controlled by solubility phenomenon. The solubility-controlling solid phases of are assumed to be  $\text{Al}(\text{OH})_3(\text{am})/\text{Al}(\text{OH})_3$ ,  $(\text{Ba},\text{Sr})\text{SO}_4$ ,  $\text{CaSO}_4/\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ,  $\text{Ba}(\text{S},\text{Cr})\text{O}_4$ ,  $\text{CuO}$ , and  $\text{Fe}(\text{OH})_3$ . Solid solutions appear to play an important role in controlling the concentrations of Ba, Cr, and Sr.

#### 5. IMPLICATIONS

ESB's power stations are required under the 1992 EPA Act to have an IPC licence. The impact of lagooned and stockpiled pfa upon local surface and groundwater will need to be addressed within the IPC licence application. Based on our knowledge of pfa, ESB have established a model procedure which should ensure that all relevant factors are taken into account for assessing the impact of ash disposal in groundwater catchment areas.

# **GEOPHYSICS OR DRILLING - WHICH SHOULD COME FIRST IN A CONTAMINATED LAND INVESTIGATION**

Richard Church

Minerex Environmental Ltd.

## **Abstract**

*The use of geophysics can assist in the planning of a drilling programme for a contaminated land investigation. Several questions need to be considered when planning the geophysical investigation and these are outlined. Two case studies are presented to show that, with due consideration, a geophysical survey can assist to plan drilling locations for subsequent hydrochemical and geotechnical sampling and the installation of groundwater monitoring piezometers. A magnetometer system is used to locate buried metal within an industrial landfill site and the VLF Resistivity system is used to determine preferential pathways for contaminant transport within overburden deposits.*

## **INTRODUCTION**

Contaminated land investigations require a desk-study within the risk assesment framework at the initial stage to give a considered, pragmatic and efficient approach to any subsequent fieldwork. This paper presents two case studies in which the use of geophysical techniques can assist in the planning of the subsequent drilling and sampling programme. Geophysics is often disregarded at an early stage in favour of drilling work, but this is sometimes not cost-effective for the client and can lead to drilling and sampling which is not representative of the aquifer, groundwater or contamination present.

## **TECHNIQUES**

Geophysical surveys for the investigation of overburden deposits have often had a mixed reception from industry and consultants. All too often expensive and unsuitable techniques are being applied for clients. Recently, geophysical surveys have benefited from a better understanding of the technique and its application; more reliable and advanced electronic instrumentation and the development of field loggers and personal computer software to enable efficient and rapid acquisition and interpretation. Additionally, the ability of an initial on-site interpretation with many systems allows a more efficient survey to be carried out.

This paper concentrates on techniques for assessing contamination potential and deposit type within the soils and overburden only. Different geophysical techniques may be considered when assessing groundwater contamination in bedrock aquifers.

The desk study and, possibly, a site walkover would determine the likely overburden type and approximate thickness. A survey is planned where there is evidence to suggest that the target material has a sufficient physical property contrast with the surrounding material (host media). To select the geophysical technique to be used several questions need to be considered:

<b>1. Target</b>	What are we looking for, what are it's electrical, magnetic or seismic velocity properties ?
<b>2. Host Media</b>	What is the electrical, magnetic or seismic velocity property ?
<b>3. Contrasting Geophysical Property</b>	Is there a significant contrast between the host and the target in any of the geophysical properties?
<b>4. Depth to Target</b>	At what approximate depth is the target ?
<b>5. Cultural Interference</b>	Are there any cultural features to be considered in the survey: - hard core, overhead power lines, electrical fences?

The physical properties of overburden units are variable depending on their origin, subsequent history, degree of mixing of units (Is it a clayey gravel or a gravelly clay?), presence and electrical conductivity of groundwater or contamination. The techniques used for environmental geophysics include:

1. Resistivity (e.g. Vertical Electrical Sounding, Resistivity Imaging, Constant Separation Traversing)
2. Electromagnetic (e.g. EM16 - VLF, EM31, EM34)
3. Magnetic (e.g. GSM-19 Magnetometer-Gradiometer system)
4. Ground Penetrating Radar (e.g. pulseEKKO radar system)
5. Seismic (e.g. Bison Seismograph system)

Resistivity and Magnetic techniques are used in the two case studies presented below.

### **CASE STUDY 1: LOCATION OF BURIED METAL IN LANDFILLING**

The location for this survey was a disused site of industrial landfilling from a power station and other heavy industry. Some tipping records were kept but these were later found to be inaccurate and much fly tipping had occurred over the site. A development of sewage works was planned for the site which would require pile driving and foundation construction onto bedrock.

The landfill waste principally consisted of pulverised fuel ash (PFA) and building rubble with some heavy oil, plastic and caustic waste also present. The building waste contained steel reinforcing rods and other sheet metal waste.

A full hydrochemical and geotechnical sampling programme was planned for the site to include trial pitting and shell and auger drilling. The groundwater quality for potential foundation corrosion was a principal concern. Prior to the heavy site investigation it was decided to undertake a geophysical survey to locate metal waste which was a concern for the drilling and trial pitting. The survey aimed to reduce the potential for the need to abandon boreholes and the hazard of striking metal waste during drilling and trial pitting.

On the basis of the questions above the following were determined:

<b>1. Target</b>	Buried metal.
<b>2. Host</b>	Landfill material
<b>3. Contrasting geophysical property</b>	Magnetic
<b>4. Target depth</b>	< 15m.
<b>5. Cultural Interference</b>	No cultural interference in area

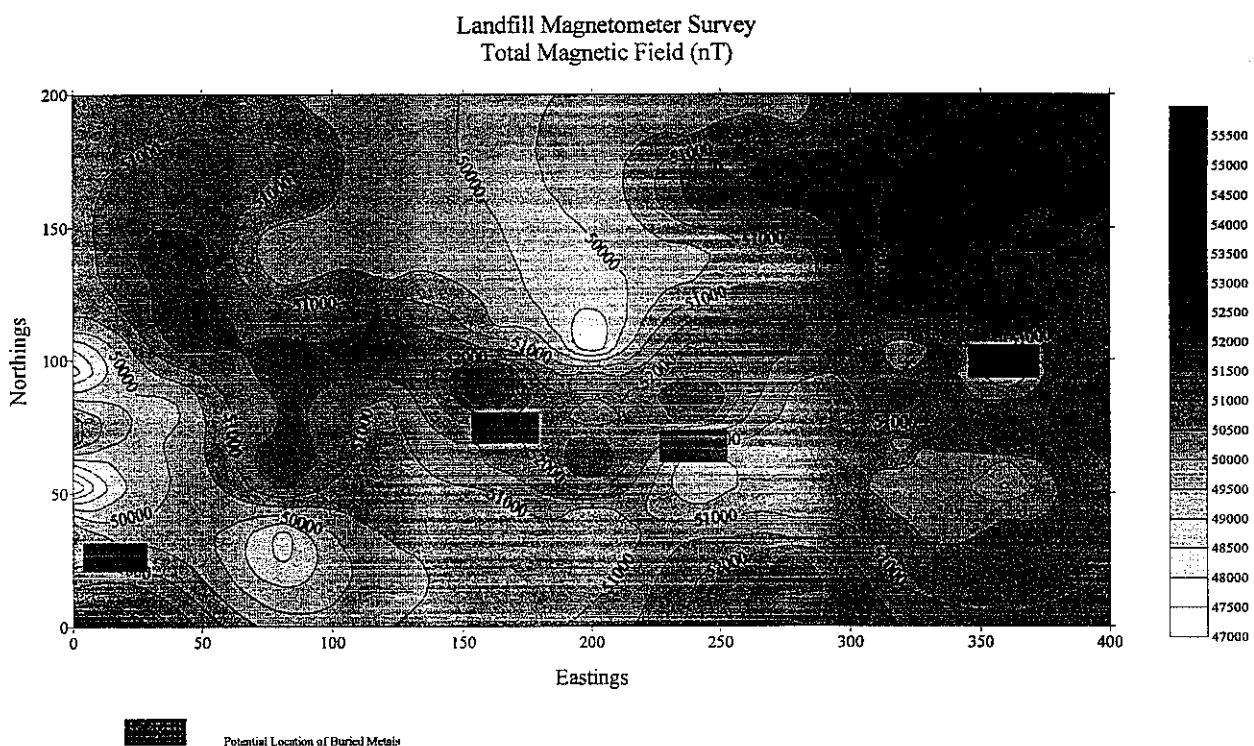
The magnetic technique was chosen over an electromagnetic technique because for a one-man system it offered a greater depth of investigation than the EM31 and was not reliant on distant transmitters which can be unreliable and limit survey orientation (EM16-VLF). The magnetic technique locates ferrous bodies in the subsurface by exploiting the natural magnetic properties of the body.

The equipment used for the survey was a GSM-19 Magnetometer System which uses an overhauser proton precession magnetometer with omni-directional sensors connected to a datalogger unit. The datalogger was set up to record the grid station value and reading as a continuous profile along the line. The data was then downloaded as an ASCII file and plotted through Surfer for Windows. The area surveyed was 400m by 200m in size and lines were undertaken in a north-south direction across the site with a 10m spacing. The station intervals along the line had a 10m spacing. The survey took half a day to set up the grid and two days for one person to complete.

A base station off the site was used to monitor diurnal variations and these were removed from the data before plotting. A plot of the total magnetic field is shown in Figure 1 below. A bipolar anomaly is produced by the metallic waste and the waste location is centred on the crossover of the anomaly.

Subsequent to the survey the locations of borehole and trial pit locations were readjusted based on the results. However, to test the technique one trial pit was dug on an anomaly and this encountered steel reinforcing rods at 4m below the surface.

Figure 1. Contour Plot of Residual Magnetic Anomaly



## CASE STUDY 2: POTENTIAL LEAKAGE OF CONTAMINANTS FROM A MINE TAILINGS WASTE

A survey was required to determine the pathways for potential contaminant plume migration from mine tailings waste. Recharge and mine water passing through the tailings waste leaches dissolved inorganics and relatively immobile metals which forms a groundwater contaminant. It was considered for the survey that the contrast in electrical conductivity between a plume of contaminant and the native groundwater was insufficient for a geophysical technique to delineate.

The overburden deposits were known to consist of a sequence of sands and gravels with lenses of low permeability clays within a silty till. Geophysics was therefore used to determine the preferential pathways for contaminant migration. The following were therefore determined:

<b>1. Target</b>	Gravel Zones
<b>2. Host</b>	Overburden deposits
<b>3. Contrasting geophysical property</b>	Electrical Resistivity
<b>4. Target depth</b>	< 12m.
<b>5. Cultural Interference</b>	Overhead power lines, electrical fences

Resistivity profiling using a VLF-R technique which was fast and cost effective identified more gravel-rich zones within the till/overburden. This allowed the drilling to target these areas with the confidence of sampling the most vulnerable zones for groundwater contamination.

The VLF-R technique utilises very low frequency military radio transmitters which transmit at frequencies within the 14kHz to 25 kHz band. These act as a fixed source of electromagnetic waves which move through the earth and are detected by a receiver which is mobile over the defined survey area. The primary field from the transmitters induce secondary fields in conductive bodies which distort the total field which is measured. The electrical component of the total field is measured by placing two electrodes in the ground 10m apart aligned in the direction of the transmitter. The horizontal electrical and magnetic components of the field can be converted into the apparent resistivity for the ground.

The survey technique gains over the more widely used constant separation traversing techniques in that it is a one man operation however, depth of penetration is limited by the conductivity of the overburden to approximately 10-20m in a clean gravel and 5-10m in a clay. The tool is a good, fast and cheap reconnaissance tool for overburden deposits. The technique is prone to cultural noise (e.g. overhead power lines and electrical fences ) and therefore erroneous data must be extracted before plotting.

The survey was conducted with a 25m x 50m grid spacing and data contoured using Surfer for Windows before being overlain on a basemap of the area. The results and interpretation are presented in Figures 2 and 3 below.

Data from historical site investigation work was used to assist in the correlation of apparent resistivity values to overburden stratigraphy. The overburden piezometers were then located within the gravel zones which formed the preferential pathways for potential contaminant migration. The survey reduced the number of monitoring points required allowing them to be sited in locations to monitor the worst possible contamination.

## CONCLUSIONS

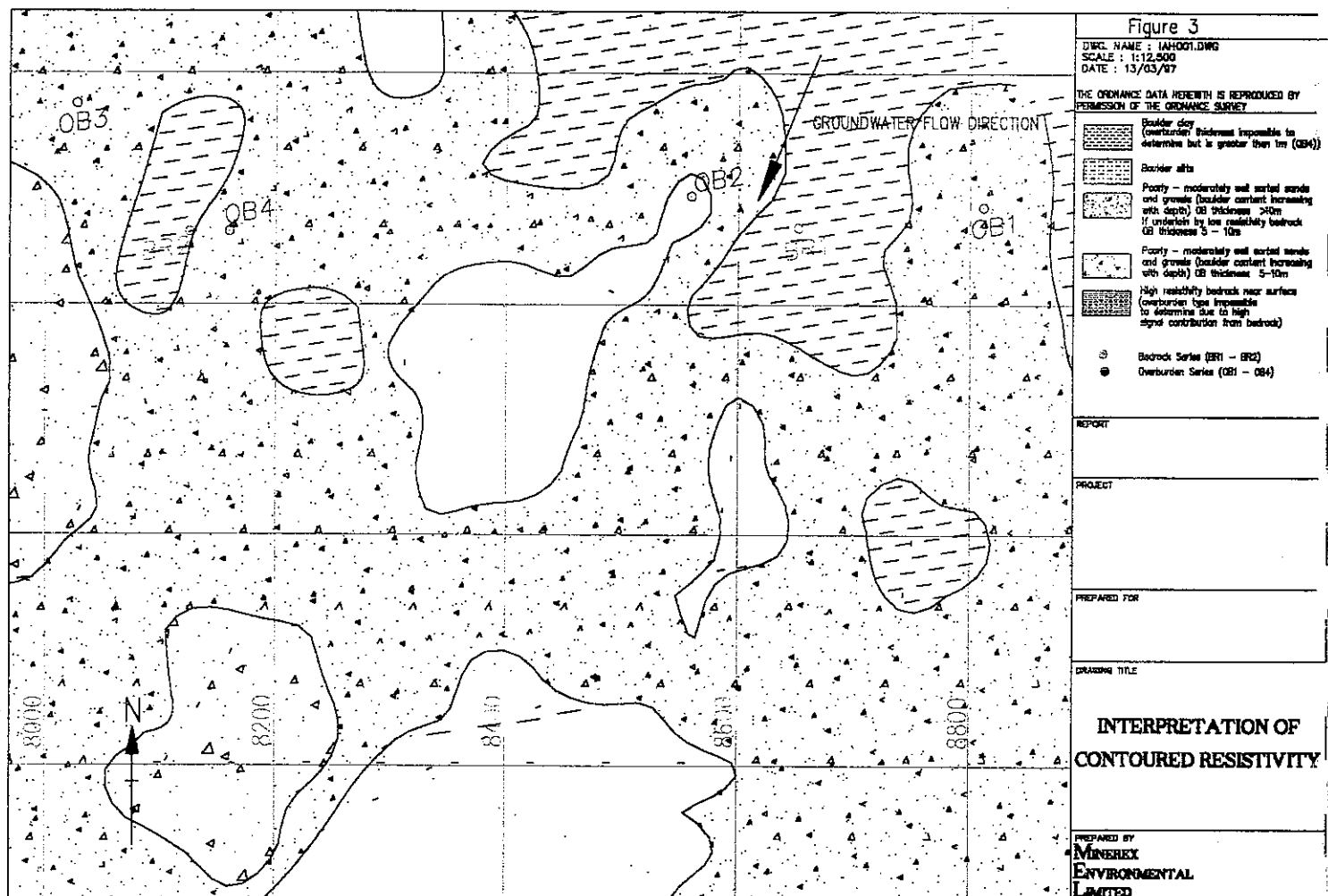
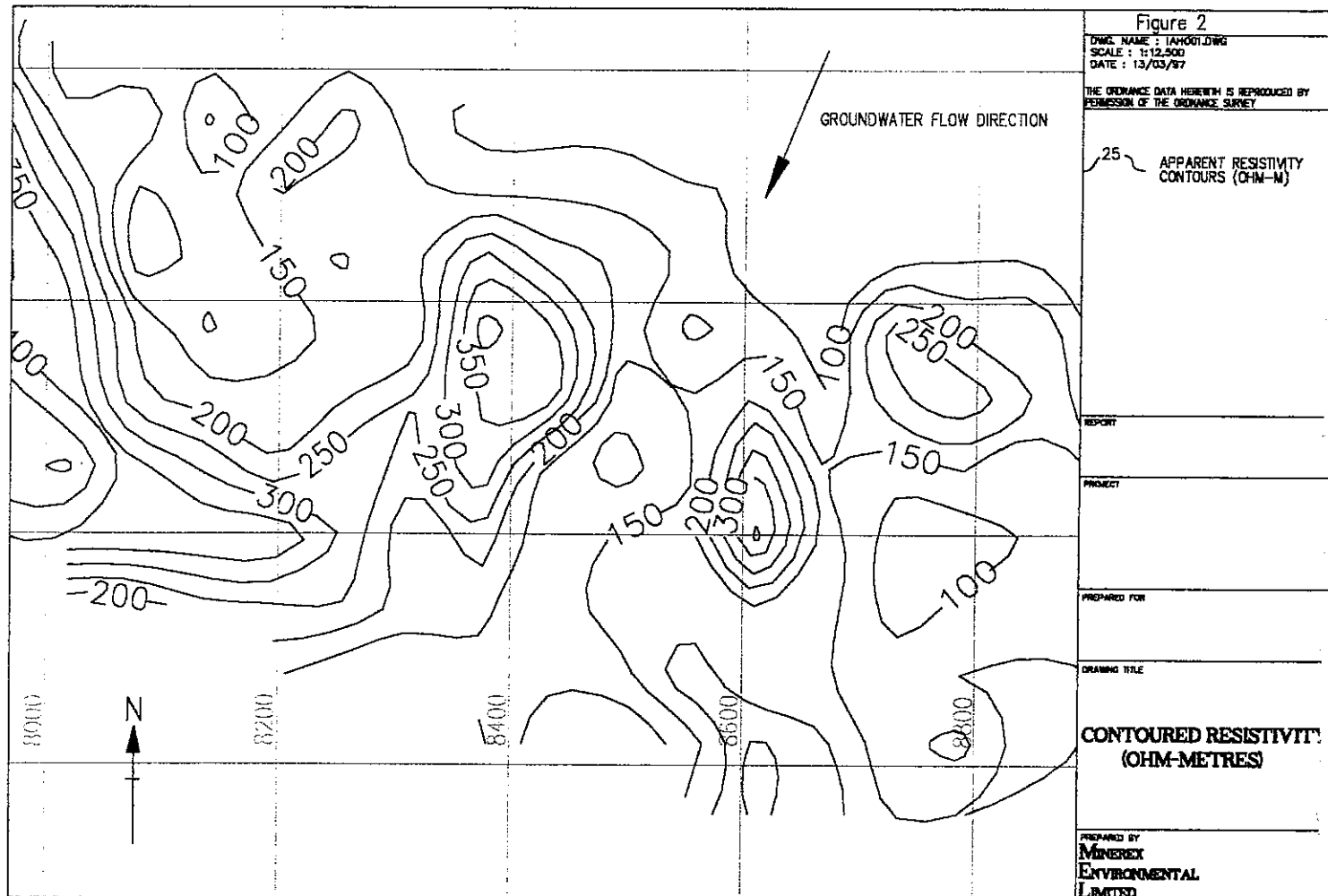
The two case studies aim to show that geophysics can assist at the early stages in the planning of a drilling program. Correlation with the drilling will improve the geophysical interpretation to give areal knowledge of overburden and contamination distribution.

The techniques shown utilise one-person and provide fast coverage making them cost effective tools for a pre-drilling geophysical programme. The choice of the most suitable technique requires due consideration and is dependant on:

<b>1. Target</b>
<b>2. Host Media</b>
<b>3. Contrasting Geophysical Property</b>
<b>4. Depth to Target</b>
<b>5. Cultural Interference</b>

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## EUROPEAN UNION INITIATIVES FOR ASSESSMENT AND ACTION ON CONTAMINATED LAND

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### INTRODUCTION

In its first State of the Environment Report for Europe, *The Dobris Assessment*, (Stanners and Bourdeau, 1995), the European Environment Agency published summary information on contaminated land in Europe. Table 1 presents an estimate of the type and magnitude of contaminated land in Europe. In total, it is estimated that between 47,400 and 95,100 km<sup>2</sup> is potentially contaminated. To put this into context, the Republic of Ireland occupies an area of about 70,000 km<sup>2</sup>.

**Table 1: Estimated Area of Contaminated Land in Europe (source: Stanners and Bourdeau, 1995)**

Source	Landuse (km <sup>2</sup> )	Potentially Contaminated Area (km <sup>2</sup> )
Built-up area (including housing, industry, traffic area)	100,000 - 200,000 <sup>1</sup>	24,000 - 48,000 <sup>2</sup>
Mining area (including mining industries and spoil dumps)	50,000 - 100,000 <sup>3</sup>	15,000 - 30,000 <sup>4</sup>
Military sites	12,000 - 24,000 <sup>5</sup>	7,200 - 14,400 <sup>6</sup>
Landfills	2,000 - 4,500 <sup>7</sup>	1,200 - 2,700 <sup>8</sup>
<b>Total</b>		<b>47,400 - 95,100</b>

The area of potentially contaminated sites has been estimated assuming the following:

1. One per cent of the European territory (which is 10.2 million km<sup>2</sup>) is urban. The total built-up area (including industry, roads, airports etc.) is taken to be twice that.
2. Twenty per cent of the built-up area is industrial and 20 per cent of this is seriously polluted. Further dispersion of contaminants increased this area by a factor of six.
3. Estimated from extrapolation of a few national landuse statistics available (including metal, salt and coal mines and mining waste disposal sites).
4. Five per cent of the mining area has polluted groundwater and dispersion increases this area by a factor of six.
5. Extrapolation from the national statistics of The Netherlands and Switzerland.
6. The groundwater is polluted below 10 per cent of the military sites. Dispersion assumption as above.
7. Dutch figures indicate that there are 100 km<sup>2</sup> of landfills in The Netherlands (population 15 million). For the European population of 680 million this equals 4,500 km<sup>2</sup>. This estimate is taken as the maximum due to the generation of less municipal waste in Eastern European countries as compared to Western countries.
8. The groundwater is polluted below 10 per cent of landfills. Dispersion assumption as above.

Table 2 presents a summary of the estimated numbers of contaminated sites in the European Union together with an estimate of the costs of remediation over the next 15 years. In total, it is estimated that in excess of 22,000 sites throughout European Union Member States are in 'critical' condition, and that the projected cost of remediation is in the region of 27 billion ECU.

While the data on both numbers of sites and clean-up costs is admittedly sketchy, these figures provide a general indication of the magnitude of the problem facing the European Union and its Member States. Subsequently, the contaminated land issue is receiving increasing attention both at EU level and within individual Member States.



**Table 2: Summary of Estimated Costs of Contaminated Land Remediation in the EU (Source: Stanners & Bourdeau, 1995)**

Country	Number of Registered Contaminated Sites	Number of Contaminated Sites in Critical Condition	Remediation Expenses Already Spent (ECU)	Estimated Remediation Costs in million ECU for Crucial Sites (15 year programme)
Belgium	8,300	2,000	incomplete information	1,000
Denmark	3,600	3,600	incomplete information	200
France	incomplete data	incomplete data	incomplete information	4,000
Germany	32,500	10,000	228 million	7,000
Greece	incomplete data	incomplete data	incomplete information	200
Ireland	incomplete data	incomplete data	incomplete information	180
Italy	5,600	2,600	89 million	3,000
Luxembourg	incomplete data	incomplete data	incomplete information	50
The Netherlands	5,000	4,000	1,300 million	1,000
Portugal	incomplete data	incomplete data	incomplete information	no information
Spain	4,300			1,000
United Kingdom	incomplete data	incomplete data	267 million/year	9,000
<b>Total EU (estimation)</b>	<b>&gt; 55,000</b>	<b>&gt; 22,000</b>		<b>26,630</b>

Although our relatively late arrival into the industrial age means that contaminated land problems in Ireland are significantly smaller in scale than those of our European neighbours, we have no reason to be complacent. Examples of most of the common types of land contamination being dealt with throughout Europe are to be found in Ireland including old gasworks sites, old waste disposal sites, old mining sites and associated tailings ponds and leaking underground storage tanks. Ireland lacks specific legislation for dealing with contaminated land. However, existing legislation, in particular the Local Government (Water Pollution) Act 1977-90, the Air Pollution Act 1987, the Environmental Protection Agency Act 1992 and the Waste Management Act 1996 provide a considerable range of powers for dealing with contaminated land.

This paper will present an overview of the principal approaches being taken by some of our European neighbours to deal with contaminated land and a summary of EU initiatives in the area, particularly those dealing with risk assessment.

## **APPROACHES ADOPTED IN OTHER COUNTRIES**

Various approaches have been adopted by other countries for dealing with the problem of contaminated land. Some countries such as Denmark and Austria have legislation dealing specifically with contaminated land. The Netherlands has soil protection legislation which encompasses land contamination. Other countries such as the United Kingdom, Germany and France are dealing with the problem in the absence of specific contaminated land legislation. Whether or not countries have introduced specific contaminated land legislation, there are a number of common elements to the approaches taken. They are:

- All countries have both the polluter pays principle and the precautionary principle at the heart of their policies and legislation. In practice, these core environmental protection principles apply mainly to recent and contemporary contamination where responsibility is clearly definable. Establishing liability for sites with historical contamination can be very difficult and so-called 'orphan' sites therefore tend to become the responsibility of public authorities and/or, in the case of land development, the developer.
- Many countries have attempted to quantify the scale of the contaminated land problem through various survey mechanisms. In most cases, this has resulted in the establishment of contaminated land lists or 'registers'. For instance, in Finland it is estimated that there are over 10,000 contaminated sites. France estimates something in the region of 250,000 to 300,000 potentially contaminated sites while in Switzerland the total is estimated to be about 50,000 sites (CARACAS, 1997).

- The sheer number of sites identified as being contaminated means that each country has had to develop ways of identifying those sites that require priority action. This applies particularly to orphan sites or other sites where the owner, for whatever reason, is not in a position to finance the cost of site clean-up. Without exception, risk assessment approaches have been adopted for this purpose.
- The application of risk assessment to the problem of land contamination is resulting in a convergence of approaches used by different countries because the principles underscoring risk assessment are universal.

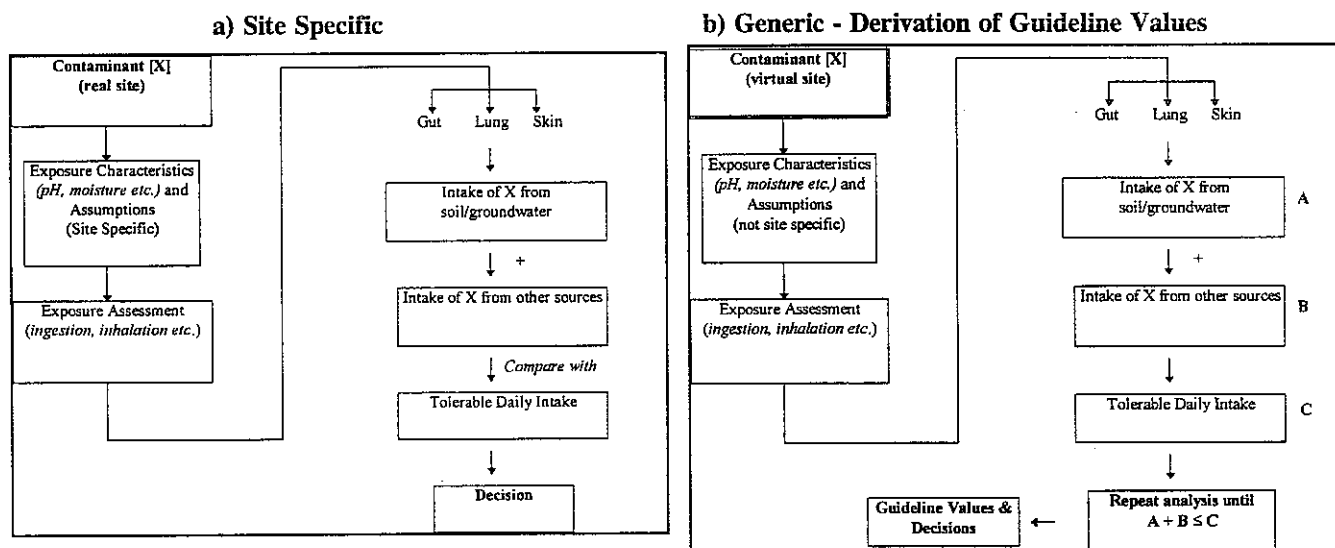
## **RISK ASSESSMENT AS A DECISION MAKING TOOL**

Risk Assessment is being used increasingly as a tool for deciding what to do with a contaminated site. In essence, contaminated site risk assessment, as practised throughout the world, is based on the source-pathway-receptor concept. That is, the objective of the assessment is to establish the risk of damage to a receptor from a contamination source. To do this, one must have knowledge of the pathway from the source to the receptor. The source, generally, is the contaminated site or a point within the site at which the contamination is located. The receptor could be a child or any person that might be exposed to contaminants originating on the site. The receptor might also be the groundwater underlying the site, surface waters adjacent to the site, plants growing within the site, wildlife living within or passing through the site, micro-organisms within the soil or, indeed, buildings, that is, any compartment of the environment or material object that might be at risk from the contaminants contained in or migrating from, the contaminated site.

Risk assessment practitioners have developed numerous methodologies for assessing the risk to various receptors. These include, for instance, the CSOIL model used in the Netherlands and the CLEA (Contaminated Land Exposure Assessment) model used in the United Kingdom. For obvious reasons, most attention has been paid to developing methods for assessing risks to humans and, by and large, guideline values developed in different countries are based on knowledge or estimates of the toxicity to humans of specific contaminants.

When it comes to decision making, there are two basic approaches to establishing action levels for a particular site; site specific risk assessment or the use of generic assessment values/screening values. In certain instances, the combined use of generic/screening values and site specific investigation and modelling will be appropriate. Figure 1 summarises the two approaches, with humans as the receptor. The same conceptual source-pathway-receptor approach applies to any receptor be it groundwater, surface water, plants etc.

**Figure 1: Comparison of Site Specific and Generic Approaches to Decision Making in Risk Assessment**

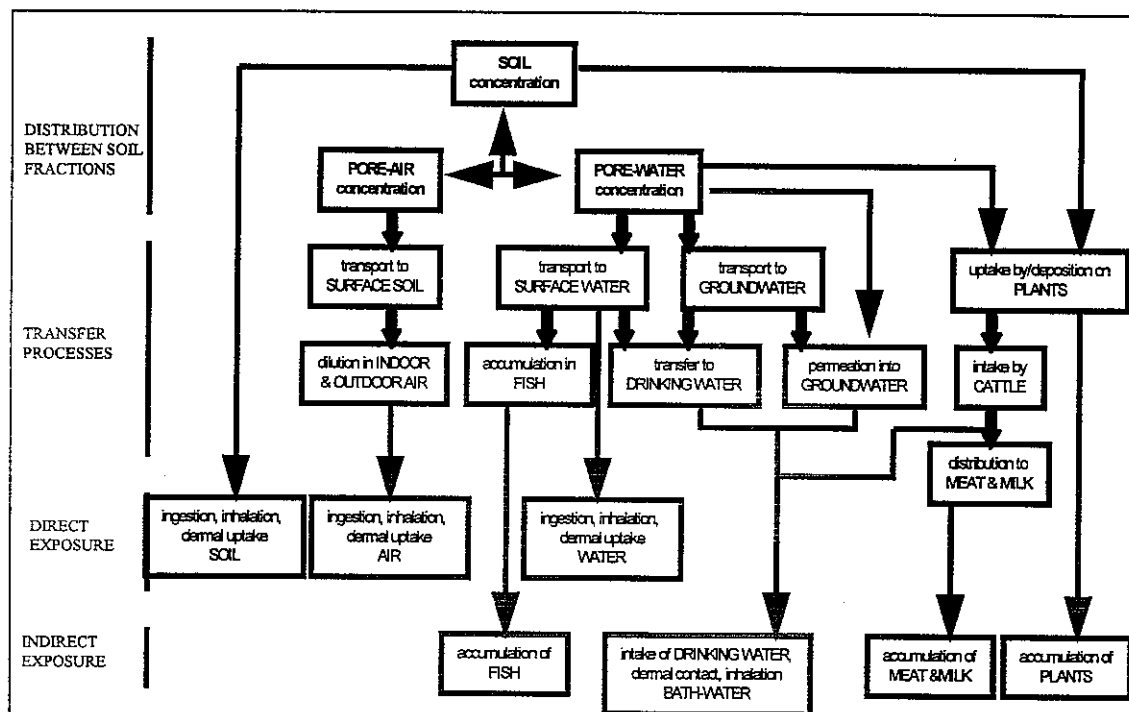


The major difference between the two approaches is that the exposure characteristics such as soil type, pH, temperature and moisture content, which influence the pathway to the receptor, and therefore effect the risk to the receptor, can be established for a particular site when a site-specific assessment is conducted. Where generic values are derived, assumptions have to be made about these characteristics and also about the site itself. It is therefore important, when using generic values, to be aware of the assumptions underlying their derivation. Clearly, there is an advantage to integrating both approaches provided that the limitations attendant to generic values are appreciated. In practice, the distinction between the two approaches is somewhat blurred and it is quite common for screening values to be used when conducting the preliminary assessment of a site to get a handle on the relative seriousness of contamination, followed by a site-specific assessment to determine the actual risks posed by the contamination.

Lists of generic values or screening values have been developed by several countries including the Netherlands, the United Kingdom and Germany. The Dutch list, for instance, consists of target values and intervention values for the following groups of substances: metals, inorganic compounds, aromatic compounds, polycyclic aromatic hydrocarbons, chlorinated hydrocarbons, pesticides, and other compounds. Target values are levels for listed substances where risks to human beings, plants, animals and ecosystems are negligible. By and large, these are 'background' levels. Intervention values are levels for listed substances above which action is required.

Various models have been developed to assess the actual risk of contamination at a site. Examples, as stated above, are the C-SOIL model used in the Netherlands and the CLEA Model used in the United Kingdom. A schematic representation of the CSOIL model is provided in Figure 2 as an example.

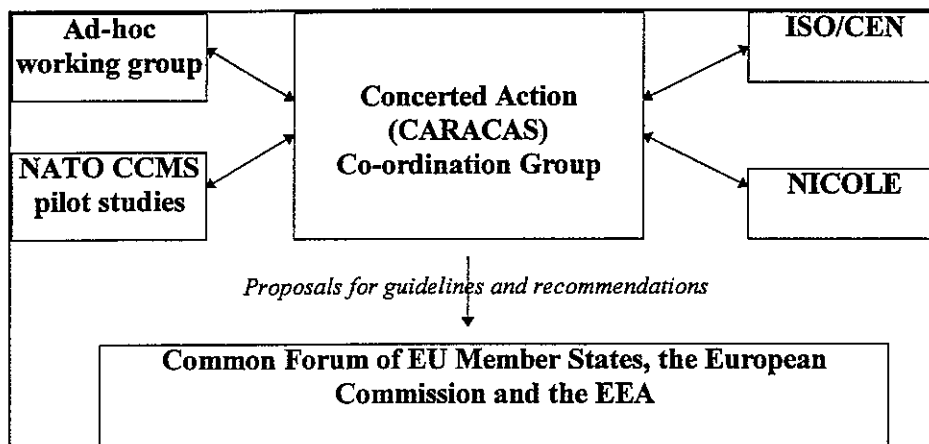
**Figure 2: Schematic Diagram of CSOIL Model (Source: Ulrici, 1995)**



## **EU INITIATIVES FOR ASSESSMENT AND ACTION**

There are a number of initiatives at EU level addressing contaminated land issues. These include the Common Forum on Contaminated Land, the Concerted Action on Risk Assessment of Contaminated Land (CARACAS), the ad-hoc working group on contaminated land, the concerted action Network of Industrially Contaminated Land in Europe (NICOLE) and relevant NATO CCMS pilot studies on the treatment and remediation of contaminated land and groundwater. Figure 3 illustrates the interconnections between these various initiatives, the European Commission and the European Environment Agency. A brief overview of each initiative is provided below followed by a more detailed discussion of CARACAS.

**Figure 3: Interaction Between Various EU Initiatives on Contaminated Land and Risk Assessment**



### **Common Forum on Contaminated Land**

The Common Forum on Contaminated Land was established by Member States in 1994. It intends to serve as a platform to:

- indicate areas in which international activities would be useful,
- link these activities,
- enhance a dialogue between the different international activities,
- collect and discuss the results of the activities and transmit them to the Commission and the EEA,
- formulate a common view on the work that is expected from the EU and its institutions,
- make recommendations to the EEA and the Commission on the technical issues and practical aspects.

It is, essentially, a forum at which Member States can discuss and exchange information about national approaches to dealing with contaminated land issues. The Forum considers that harmonisation of national policy, goals and standards for soil remediation would not necessarily be useful. Harmonisation in the field of methodologies for analysis, risk assessment, derivation of guidance and collection of toxicological data is considered potentially useful by the Forum.

### **Concerted Action on Risk Assessment of Contaminated Land (CARACAS)**

CARACAS stands for Concerted Action on Risk Assessment for Contaminated Land. CARACAS is sponsored by DGXII. The first meeting was held in March 1996 and the project will run for 30 months. Initially each Member State was requested to make a commitment to be represented by the national Environment Ministry and by one or two scientific institutions as the availability of funding was partially dependent on participation of all Member States. DGXII is particularly interested in ensuring that any recommendations made by CARACAS be agreed by all Member States. Ireland is represented by a national delegate from the Department of the Environment with the EPA providing scientific advisors.

Risk Assessment is now accepted as the most appropriate method for assessing the pollution potential and health and safety implications of contaminated land. However, methodologies for Risk Assessment are still in the developmental stage. CARACAS has three main objectives;

- to identify, compile, assess and review all relevant Research and Technology Development projects and scientific approaches to risk assessment in the participating countries,
- to propose scientific priorities for future Research and Technology Development (RTD) programmes,
- to elaborate guidelines and recommendations for assessing risks from contaminated sites.

CARACAS has brought together administrators, scientists and engineers working in the field of contaminated land and risk assessment from all the EU Member States along with Norway and Switzerland. As stated earlier, the main objective of CARACAS is to elaborate guidelines and recommendations for assessing risks from contaminated land. This is being achieved by compiling information on relevant RTD projects and approaches to risk assessment employed by participating countries.

- Collection and assessment of information has been organised into six Topic Groups, each of which is dealing with a specific aspect of contaminated site risk assessment.

The Topic Groups are:

- Human Toxicology
- Ecological Risk Assessment
- Fate and Transport of Contaminants
- Site Investigation and Analysis
- Models
- Screening/Guideline Values

The scope of work for each Topic Group is summarised in Table 3.

**Table 3: Scope of Work of CARACAS Topic Groups**

TOPIC GROUP	SCOPE OF WORK
HUMAN TOXICOLOGY	Review the key issues in using toxicity data for assessing risks to human health, and identify key principles
ECOLOGICAL RISK ASSESSMENT	Recommend ecotoxicological evaluation systems for characterisation of ecological risk
FATE AND TRANSPORT OF CONTAMINANTS	Select processes affecting fate and transport of contaminants and evaluate their role in risk assessment
SITE INVESTIGATION AND ANALYSIS	Recommend site investigation strategies to obtain the quality of data necessary to estimate risks with confidence, taking into account data variability and cost-effectiveness
MODELS	Explore and advise on the central issues relating to the use of models for risk assessment
SCREENING/GUIDELINE VALUES	Evaluate scientific basis of screening/guideline values and their role in decision making

The Human Toxicology Group is focusing on issues such as appropriateness of primary data (exposure conditions, mode of delivery, chemical form); extrapolation from high to low doses and from animals to man; mechanisms of toxicity; exposure to mixtures and bioavailability of contaminants in a soil matrix.

The work of the Ecological Risk Assessment group involves characterising exposure and effects in various organisms and biological systems, including issues of bioconcentration, bioaccumulation and biomagnification.

The group looking into Fate and Transport of Contaminants is concerned with many issues relevant to removal, attenuation, phase transfer and bioavailability of contaminants, especially in complex mixtures. Processes include speciation, bio- and photo-degradation, plant uptake, sorption/desorption, dissolution, diffusion and volatilisation.

The Site Investigation/Analysis Group is reviewing national approaches to sampling and analysis and seeking to identify the most crucial parameters for risk assessment. It will also seek to make recommendations on data quality needs and good scientific practice so that statistically valid and cost-effective data can be provided.

The many models available in the Contaminated Land and Risk Assessment community, including priority setting models and exposure/risk assessment models are being reviewed by the Models Group. The group is looking into the validation and applicability of different models.

Group 6 is reviewing the role of Screening/Guideline Values in risk assessment and the scientific and policy basis for them. The Group is comparing and contrasting different soil policy approaches and the role of guideline values in soil management frameworks. Various protocols for deriving these values are being examined including the basic assumptions and methodologies underpinning them.

Finally, a seventh Topic Group has been set up to evaluate Methods for Risk Assessment. This Group is charged with reviewing and making recommendations on methods to integrate the basic elements of risk assessment such as soil, sediment and groundwater sampling, exposure modelling and measurement, effects assessment and risk evaluation. There are overlaps between the Topic Group briefs and many CARACAS participants are members of more than one Group.

### **NATO/CCMS Pilot Study**

The Committee on Challenges of Modern Society (CCMS) was set up by NATO in 1969. There have been three pilot studies on contaminated land funded by the CCMS; 1980-1984, 1986-1991 and 1992-1997. The first study culminated in a report which provided a state of the art review of measures then available for dealing with contaminated sites. The second study involved the demonstration of remedial action technologies for contaminated land and groundwater. The current study is a continuation of the second but includes technologies at an early stage of development along with those ready for full-scale demonstration. In total, the current study consisted of fifty five active projects covering a wide range of technologies including biological (bio-venting, in-situ bio-treatment, bio-piles, slurry reactors, white rot fungi) physico-chemical (soil vapour extraction, soil washing, solvent extraction, *uv* treatment), chemical treatment (ozone oxidation), thermal treatment and stabilisation/solidification. Many of the projects involved more than one technology, for example, soil vapour extraction with in-situ biotreatment or soil washing followed by biotreatment or thermal treatment. The majority of the projects are concerned with the treatment of organic contaminants including PAHs, PCBs and BTEX compounds.

### **Network of Industrially Contaminated Land in Europe (NICOLE)**

NICOLE is a concerted action of the Environment and Climate RTD Programme of the European Commission. It began in February 1996. It is industry-led and aims to provide a forum for the dissemination and exchange of scientific and technical knowledge and ideas relating to all aspects of industrially contaminated land. It is planning two scientific conferences where the progress of EU-funded projects relating to contaminated land will be reported. It also has four working groups which will establish workshops on particular aspects of contaminated land. These are: site assessment and characterisation; contaminant behaviour and risk assessment; control methods (remediation and containment); and measurement and monitoring.

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## **RISK BASED DECISION MAKING AT CHEMICAL RELEASE SITES: SOIL AND GROUNDWATER PATHWAY**

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### **ABSTRACT**

*The use of risk assessment, in both a qualitative and quantitative sense is outlined and discussed. Risk Assessment is a powerful tool and should play a role in the planning and implementation of corrective action programs at chemical release sites where contaminant migration and/or potential exposure exists. It allows movement away from the use of prescriptive, generic criteria, which are easy to use (hence their attraction) but usually misrepresent the actual site specific condition. There are of course limitations with risk assessment, as there are with any approach, and the quality and comprehensiveness of the data used as well as the heterogeneity of the site environment need to be considered before advancing all the way down the quantified risk assessment route.*

### **INTRODUCTION**

A 1990 survey yielded about ten distinct formal risk definitions (Vlek, 1990). For our purposes risk equals the product of the consequence of an event happening and the probability of that particular event occurring. The purpose of a risk assessment is to carry out an evaluation of the possibility that toxic effects will occur, by quantitatively predicting exposure levels and then combining them with toxicity information.

Wherever chemicals are stored, handled or used in quantity it must be expected that some releases to the environment will have occurred as a result, whether that be to air, surface water, soil or groundwater. Larger industries are regulated to control and minimise such emissions. Releases to air or surface water are often the most readily detected, because they are either visual, olfactory or result in obvious impact on a wider environment (e.g., fish kills or obvious sheen on surface water). It is often, however, possible to implement corrective action immediately by isolating or mitigating the source of release which often results in immediate improvement.

In contrast, soil and groundwater contamination often goes unnoticed until an on-site or "distant" receptor is affected or a change of land use takes place (e.g., highlighted during divestment driven investigations or site redevelopment). By the time realisation takes place, the extent of contamination may be large and require a considerable degree of assessment prior to implementation of an appropriate corrective action solution. Interim corrective action may be needed to address immediate concerns (risks).

Risk assessment represents a powerful tool that can be used to identify, on a site-specific basis, the contaminants of concern, their potential migration pathways and routes of exposure, and the extent of any risk to human health or the environment. The risk assessment is, however, only as good as the data set it represents and generally the more assumptions inherent within the process the less useful is the "answer". Tiering of the risk assessment process represents a mechanism by which the



scale of the risk assessment and degree of quantitation used to guide a corrective action program is commensurate with the urgency and magnitude of the threat posed by the contamination in question.

Risk assessment should not be seen as a "black box" allowing the "polluter" and their consultants to manipulate data to get the right answers, as some sceptics argue. It should be an open, objective, scientific effort incorporating a systematic approach whereby health and ecological risks can be assessed and where appropriate quantified. Risk management follows with the assessment of liability and formulation of procedures for the control and management of these risks based on deriving risk based clean-up goals.

### WHY USE RISK ASSESSMENTS

The aim of quantitative risk assessment is to ensure human health and environmental protection on a site specific basis, removing the burden of having to rely upon conservative, generic remediation standards. The approach is designed to address the problem of misallocation of resources at sites which pose no threat to human health or the environment. Society has spent enormous amounts of money to remove or destroy contamination at sites where actual risks have been either exaggerated or mis-represented. Actual risk is often low or virtually zero, because no one is actually exposed to contaminants from the site.

### THE ALTERNATIVES

It is not uncommon for site data on soil and/or groundwater contaminant concentrations to be compared to generic criteria and in the past remedial decision making has been based upon them. The best example of such criteria are the Dutch standards, although other such lists have appeared or are appearing. The Dutch Intervention and Target values can be over-prescriptive, due to their inherent generic nature, by not considering site conditions associated with current and potential future land use. The Intervention value is the same whether you are considering a chemical plant or a children's playground. It is my understanding that even the Dutch, who have been at the forefront of European thinking on soil and groundwater protection, have realised that multifunctionality (the protection of land to ensure suitability for all land uses) is idealistic and not economically viable. Land quality which is fit for purpose is much more appropriate and is the philosophy which underpins new approaches (in the United Kingdom for example).

The UK contaminated land policy spells out a commitment to the suitable for use (fit for purpose) approach to the control and treatment of existing contamination. This supports sustainable development both by reducing the damage from past activities and by permitting contaminated land to be kept in, or returned to, beneficial use wherever practicable (sustainable Development UK DoE 1994). The approach requires corrective action only where :-

- contamination poses unacceptable actual or potential risks to health or the environment; and
- there are appropriate and cost effective means available to do so, taking into account the actual or intended uses of the site.

### QUALITATIVE RISK ASSESSMENT

Risk based decision making should form a fundamental part of contaminated site assessments. It can be used to plan site investigations and on an ongoing basis during their implementation. During

the early stages of assessment, when the database is relatively restricted, qualitative rather than quantitative risk assessment is used. During initial site assessment important areas to better understand include :

- current and proposed future land use
- potential contaminant sources
- potential exposure pathways
- obvious environmental impacts
- location of potential receptors

One debate that is often necessary is whether groundwater represents a receptor in itself or merely a potential migration pathway. This will depend upon its resource status or potential, both locally and regionally.

The above information is used to establish what can be termed a conceptual site model (CSM) which presents the site in the context of its underlying subsoil and bedrock geology and its environmental surrounds. It is a qualitative evaluation of potential sources, exposure pathways and receptors identified during the desk study and site reconnaissance visit. The CSM is essentially a description of how potential chemical sources could migrate and lead to exposure and increased levels of risk in potentially exposure receptor populations (which could be human, animal or "environmental").

The CSM is used to plan site intrusive investigations, following which it is refined to reflect the new data as analysis proceeds in an iterative, phased way. Soil and groundwater chemical data can be compared to generic criteria at this stage for the purpose of simple screening. If site soil and groundwater chemical concentrations are below the standards then no further action should be required, provided the sampling program has taken full account of the CSM and the important potential contaminant migration pathway receptor scenarios.

The EPA have defined risk assessment as the product of exposure probability and consequence (Derham 1996). In many cases, they believe, relatively simple evaluation of exposure probability can be made using professional judgement and experience, based on knowledge of the site in question. This concurs with the CSM qualitative approach as outlined above. The outcome of this simple risk assessment process is a score matrix from which it is possible to obtain a risk rating.

A good example of such a matrix has been developed has been developed by the Geological Survey of Ireland with regard to Aquifer Protection (Daly, 1995).

Each matrix is specific to a particular activity (reflecting pollutant loading). Risk is assessed on the basis of the likelihood of contamination (groundwater vulnerability to pollution), and the consequence of a pollution event (groundwater resource potential). Put simply, the lower the groundwater vulnerability, and the more limited the groundwater resource potential, the lower the risk, as outlined below:

## GROUNDWATER PROTECTION MATRIX

(adapted from Daly, 1995)

Vulnerability Rating	Source Protection			Resource Protection		
	Site	Inner	Outer	Regionally Important	Locally Important	Poor Aquifers
Extreme (E)						
High (H)						
Moderate (M)						
Low (L)						

Arrow reflects direction of decreasing risk.

## QUANTITATIVE RISK ASSESSMENT

Quantitative risk assessment (QRA) may need to be used for sites having relatively complex contamination issues, where a qualitative study yields questions not answers. At sites where there is a perceived risk to either onsite or off-site receptors there is likely to be a need to quantify the risk and possible derive remedial targets ("clean up criteria"). As outlined previously this must be a systematic and rigorous assessment to provide a technically sound and justifiable result. The result may be positive or negative in the sense that risks appear acceptable or not, and whichever is the case a risk management/communication exercise is likely to be required.

The basic steps of quantified risk assessment (QRA) are as indicated on Attachment 1.

## IDENTIFICATION OF CONTAMINANTS OF POTENTIAL CONCERN

Firstly if a QRA is to proceed successfully it is essential to ensure that all chemical parameters which may be relevant at a particular site have been analysed. All data must then be collated and critically reviewed to determine the range of contaminants present and their lateral/vertical extent. If there are Qa/Qc issues with some of the data then it may only be appropriate for use in qualitative assessment.

The need to define a shortlist of contaminants of potential concern relates to the fact that it is both impractical and unnecessary to assess the risk posed by all chemicals. These are risk drivers. Contaminants of potential concern must be chosen carefully, with not only high concentration or widespread distribution influencing the selection procedure. Contaminant toxicity, mobility, persistence and even treatability need to be considered.

## POTENTIAL EXPOSURE PATHWAY - RECEPTOR SCENARIO IDENTIFICATION

This essentially represents modification (update) of the Conceptual Site Model (CSM) to reflect ones exact understanding of the site environmental setting and the proximity and activities of local potential receptor populations (to include predicted future land use scenarios). The potential fate and transport of site contaminants is merged with the site setting information to come up with plausible (potential) contaminant migration pathway to receptor scenarios. The exercise is designed essentially to streamline the subsequent exposure assessment. An example chemical specific output from this exercise is given as Figure 1.

<b>SITE CONTAMINANT :</b> Methylene Chloride <b>MAIN SOURCE OF LOSS :</b> Underground Drainage <b>LAND USE :</b> Onsite (Industrial) Offsite (Farmland/Residential)		
POTENTIAL PATHWAYS	POTENTIAL RECEPTORS	
	Initial	Additional
Direct Contact	Onsite worker	N/A
Volatilis Egress	Offsite Resident (nuisance)	N/A
Groundwater <sup>*1</sup>	Nearby River	Local Community (Potable Supply)
Air Dispersion	N/A	N/A
Surface Runoff	Nearby Stream	Stream Ecosystem

**Figure 1: Idealised Plausible Pathway - Potential Receptor Scenario Matrix. For a single contaminant of potential concern.**

#### EXPOSURE ASSESSMENT (HUMAN HEALTH)

Designed to quantify the magnitude, frequency and duration of exposure for the migration pathway and potential receptor populations selected for quantitative evaluation. It is essentially a two step process :

- **Step 1:** Exposure concentrations are predicted (e.g. mg/l in water, mg/m<sup>3</sup> in air)
- **Step 2 :** Chemical & pathway specific intakes are quantified for individual receptor groups ( mg/kg/day)

It may be possible to measure exposure point concentrations (e.g. water, well or tap water concentrations). If not numerical modelling will be required to predict the fate and transport of contaminants as they migrate from the site to the receptor, to provide the predicted exposure point concentration. Such models usually use conservative assumptions,(for example by ignoring certain contamination attenuation mechanisms) and therefore usually err on the side of health/environmental protection. All assumptions used need to be clearly stated so that any reviewer can judge the representatives of the result. It may be too conservative or be perceived as not conservative enough. In either case further model refinement and/or offsite monitoring may be required.

Chemical intakes, are represented by a series of intake equations which combine a number of separate input parameters. An example of a simple intake equation would be that associated with drinking water ingestion is as follows :

$$\text{Intake (I)} \quad = \frac{C(\text{mg/l}) \cdot IR(\text{l/d}) \cdot EF(\text{d/yr}) \cdot ED(\text{yr})}{\text{(mg/kg/day)} \quad \quad \quad BW(\text{kg}) \cdot AT(\text{d})}$$

<sup>\*1</sup> Not considered to have local resource potential

Where C is the site specific measured or modelled groundwater chemical concentration, IR is the ingestion rate, EF the exposure frequency, ED the exposure duration, BW average body weighted and AT averaging time.

There may be any number of intake equations relating to exposure via oral (ingestion), inhalation and dermal contact routes. During the exposure assessment all applicable pathways for each receptor population are grouped, however it is commonly left until the risk characterisation stage for intakes to be summed across pathways.

## **TOXICITY ASSESSMENT (HUMAN HEALTH)**

Toxicology is the study of the adverse effects of chemicals on living organisms. A toxicity assessment within the QRA process is commonly carried out in parallel with the exposure assessment. It collates and assesses relevant toxicity data for the chemicals of potential concern to come up with chemical specific reference criteria. An essential part of this task would be the retrieval and evaluation of toxicity data for each selected chemical. This can be achieved by interrogating databases and information provided by leading centres of expertise including WHO, the Dutch RIVM, various governmental DoE and DoH bodies and US EPA sources.

This task is not as straightforward as it may initially seem. This is because chemical specific dose-response estimates provided by the different sources can vary, sometimes widely (even when their interpretation is based on the same originating study). There are various carcinogenic and non carcinogenic effects, which are treated separately. This may result in a number of reference values being brought forward for the same chemical.

One other complicating factor which is worthwhile introducing here, because of its widespread use by industry and society, is how to assess mixed chemicals such as hydrocarbons. Until quite recently total petroleum hydrocarbons (TPH) has often been ignored in QRAs, the focus being on individual components of petroleum products such as BTEX hydrocarbons and polycyclic aromatic hydrocarbons (PAH's), which are thought of as the key risk drivers. However, as an example, weathered gasoline contains little BTEX and benzo (a) pyrene (a particularly toxic PAH) yet may include a large proportion of branched alkanes and other hydrocarbons. These are by no means non-toxic and not considering them may lead to an underestimate of potential or actual risk. By sub-dividing the petroleum product into fractions for which there are specific toxicity criteria (Reference doses) a more scientific (although arguably still relatively crude) assessment can be made.

## **RISK CHARACTERISATION (HUMAN HEALTH)**

In this step the exposure and toxicity assessments are integrated into, where possible, quantitative expressions of risk. These are done for carcinogenic and non carcinogenic effects separately. Risks characterisation proceeds along a set pathway, as follows :

- quantification of risk from individual contaminants
- quantification of risks from multiple chemicals
- combining risks across exposure pathways.

Risk characterisation serves as the link between risk assessment and risk management and is therefore a key step in the ultimate site decision making process.

## ECOLOGICAL RISK ASSESSMENT

The preparation of an environmental risk assessment (ERA) is usually concerned with the issue of potential environmental impact of off-site migration of contaminants from a site to the surrounding environment. The ERA is less rigorously structured than the corresponding human health risk assessment, but none the less follows a similar format. Key objectives of an ERA include the following :

- describe the distribution of species within the potentially affected area;
- compare the distribution of contaminants with the distribution of species;
- select key species and endpoints to assess ecological effects;
- estimate exposures by, and characterise risks to, ecological receptors.

The ERA technical approach may need to include laboratory media toxicity tests, bio-monitoring and bio-assays, comparison of contaminant levels in key species taken from the site to the same species taken from a reference site, and comparison of contaminant levels in species to levels known to cause toxic effects in the same or similar species. Key species (receptors) can include those that are vital to the structure and function of the food web, those that exhibit a market toxicological sensitivity to the contaminants, species for which toxicological data are readily available in the scientific literature, and those that are ubiquitous across habitats.

## TIERED APPROACH TO RISK ASSESSMENT

The US standard ASTM ES-38 "Guide for Risk-Based Corrective Action (RBCA) at Petroleum Release Sites" and the soon-to-be published CONCAWE report WQ-STF27 "European Oil Industry Guideline for a Uniform Risk-Based approach to Corrective Action Decisions" which was undertaken by Dames & Moore on behalf of the European Oil Industry represent tiered approaches to site and risk assessment. These are three tiered systems with equal protection of human health and the environment at all tiers. Tier 1 is relatively simple and generic whereas if assessment progresses to Tier 2 and Tier 3 it becomes more sophisticated and site specific.

Although at this time this tiered approach has been developed specifically for the petroleum sector the philosophy and principles which underpin it are applicable to all types of site. The petroleum industry has been able to develop an approach first partly because they are dealing with a relatively restricted suite of chemicals that can be characterised relatively easily.

## POINTS OF NOTE AND IRELAND SPECIFIC CONSIDERATIONS

The risk assessment process although recognised as a powerful analysis tool can cause the risk to be overstated (perhaps by many orders of magnitude) if used without a good site specific knowledge, and particularly if

- unwarranted assumption are used instead of relevant site specific data
- use of theoretical "worst-case" or upper bound values in each of these assumptions
- single values instead of a group or range of values for each variable as the exposure equations are used.

Therefore it is critical that all assumptions, professional judgements, and alternative choices should be clearly identified and their impact characterised in each risk assessment. The focus should be on

getting site specific information where possible or practical, to replace assumptions. This includes, for example subsoil or bedrock parameters as well as chemical data. Where variable in the exposure equation should be assigned a group of values with the applications of probabilistic rather than deterministic models.

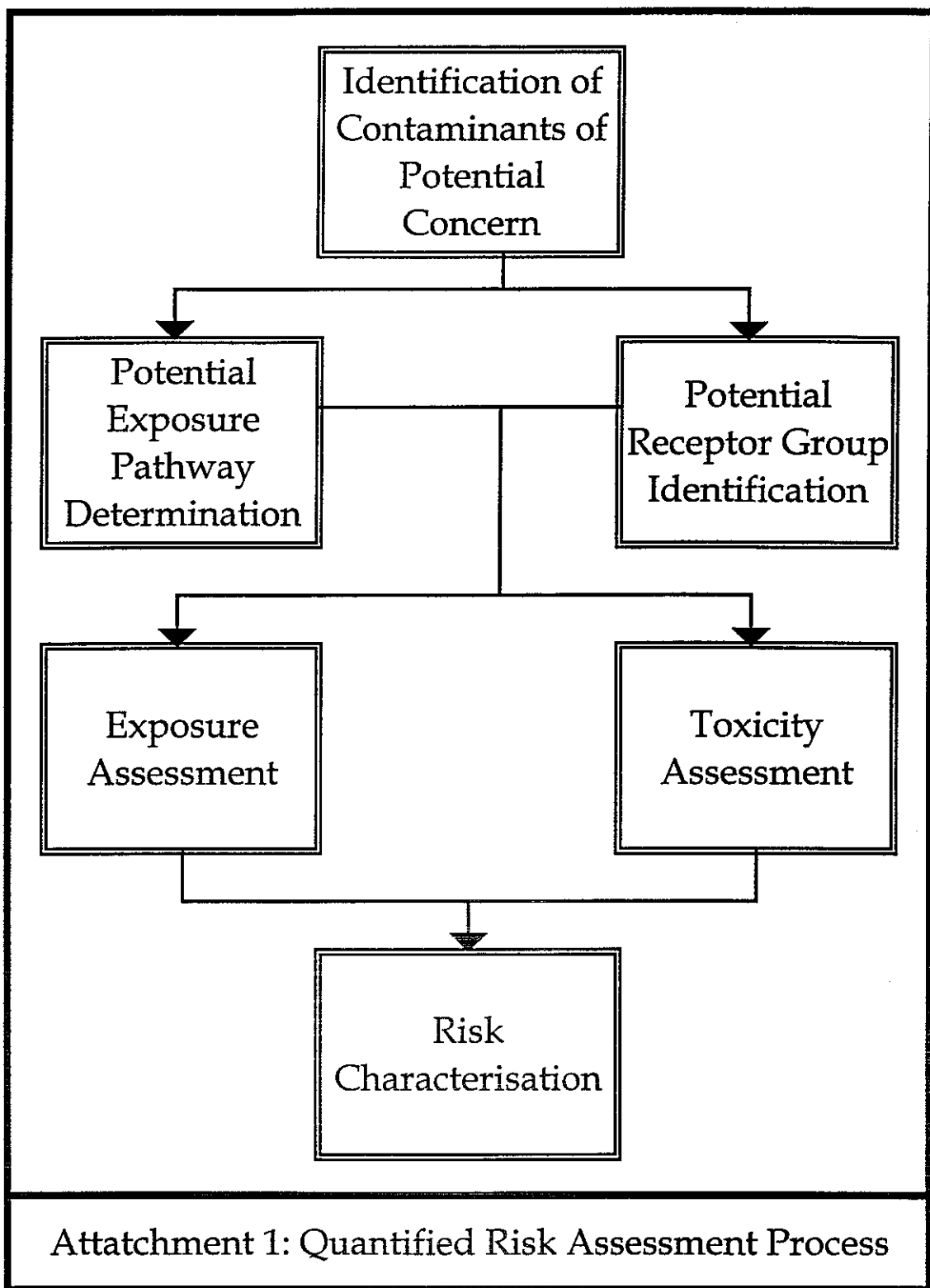
It should always be remembered that QRA is only as effective and useful as the quality of the data utilised. Limited databases may only be suitable for qualitative study or if you are happy to except conservative estimates of risk. If conservative estimates of risk (when extreme) are used to plan corrective action programs then unnecessary clean-up may well be implemented with no real benefit to the environment or society. This should be deemed a misallocation of limited resources which would more wisely spent elsewhere (e.g., on new equipment to abate an air emission from the same site)

Numerical groundwater modelling can often form the basis for exposure assessment during QRA at sites where the groundwater pathway is important. This is all very well in relatively homogeneous aquifer systems. Unfortunately these are not commonplace in Ireland, with the preponderance of Karst limestone. There is perhaps little point in setting up a numerical model to predict contaminant fate and transport in a Karst or fractured aquifer system. The uncertainties are too great. Similarly monitoring in such aquifers is also problematic unless detailed tracer studies are undertaken which serve to prove groundwater pathways.

The best risk based approach at complex sites may involve control or removal of a critical migration pathway (e.g., groundwater pathway to a river or supply well) rather than more active remediation. Such a containment approach is often the most cost effective solution which allows a facility to then address the sources of chemical release in a controlled and programmed way. Once the latter has been achieved and therefore the mass of contamination in the system is finite then a more active corrective action program can be implemented to address residual contamination. Site specific, risk based remedial goals would then be derived and agreed with the regulator (for soil and/or groundwater) and a corrective action programme leading through to cessation of the remedial activity implemented.

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## SOLUTIONS TO LEAKING HOME HEATING OIL SYSTEMS

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### ABSTRACT

*The storage of home heating oil on private residential property is widespread and common in Ireland but in recent years there has been a noticeable increase in the number of tank and line leaks and as a result significant volumes of oil are often released to the subsurface. These releases can have a detrimental effect on both the local environment and property values whilst also disrupting everyday life in the home. The "solution" in the past has been to treat the symptoms and to ignore the problem. However this reactive approach is no longer acceptable to our increasingly litigious and environmentally-conscious society. To better serve the home owner's interests a more comprehensive procedure is needed whereby a set of proven and site-specific remedial actions are prescribed in the event of a heating oil leak. Both the building industry and home owners need to be informed as to the seriousness of the current situation and the relatively simple preventative measures which can be taken to avoid its continued occurrence. Prevention is seen as the only secure policy for the future.*

### 1. THE BACKGROUND

Whether they realise it or not, home owners with oil storage tanks have put themselves in the unenviable position of storing several hundred gallons of a highly inflammable and toxic chemical on their property. If this chemical escapes to the ground it can migrate both laterally and vertically to cause a host of detrimental effects both on the home owner's property and that of his neighbours. The unsuspecting home owner does not have to apply for a licence to take on this onerous liability; neither is there any equipment certification process or manufacturer's maintenance schedule to meet. Every home owner with an oil-fired system is expected to become an expert in oil storage from day one without the benefit of any form of training.

Although available since the 1950's, oil-fired domestic heating and cooking systems have proliferated in recent years. The basic system being installed today comprises a burner coupled by a narrow diameter pipeline to an above-ground oil storage tank. Today the grade of oil on the market is limited to kerosene or diesel although in former years medium grade and even heavy fuel oils were generally available.

The oil-fired systems are relatively economical to operate, require little maintenance, and are flexible enough to meet most household needs. Installation of the system requires little or no expertise and is often undertaken by the local plumber or handyman.

The logical location for the oil tank is to the rear of the house, out of sight and close to the burner itself. Heating oil is readily available from local merchants throughout the country and can be delivered rapidly. All delivery tankers now have a reasonable length of flexible dispensing hose which can reach even the most inaccessible domestic tanks.

### 2. THE PROBLEM

The problem begins when a significant quantity of oil is released in an uncontrolled fashion. This usually happens when a leak develops in either the tank or the connecting pipeline. However uncontrolled releases have also been known to occur during refuelling for a variety of reasons, most of them avoidable. Slow leaks are especially difficult to detect and it can take some time before a symptom manifests itself which is recognisable by the home owner.

Corrosion is the most obvious reason behind a leak developing in a tank or pipeline but there are a host of others as will be discussed later in this section. In the case of mild steel tanks the corrosion is rarely perceptible from external appearances and is generally more developed on the interior surface of the tank due to the constant condensation and evaporation of water vapour above the surface of the oil as a result of diurnal temperature changes. These susceptible interior surfaces are virtually inaccessible and no amount of external tank maintenance such as repainting will postpone their eventual failure. Typical failures can occur after about thirty years but are dependent on variables such as the gauge of steel used and the exposure of the tank to frequent temperature changes.

Underground tanks are less susceptible to such temperature changes but even these generally have a maximum life expectancy of less than forty years and some have been known to corrode in less than twenty five years. Soil acidity and the action of static electricity are recognised as having a major role to play in the corrosion of underground mild steel tanks.

The plastic tanks that are now on the market are also vulnerable to failure. At least one manufacturer in Ireland has produced tanks which are especially prone to leakage. A recent court case laid the blame at the door of the mould manufacturers but this is scant comfort for the home owner especially when he has been given the reassurance that all tanks are certified as having been pressure-tested prior to delivery. The lifetime of plastic tanks is not yet known but on some of the early tanks the surfaces which are constantly exposed to sunlight (ultraviolet) begin to turn opaque after a few years and subsequently desiccate and become brittle. A realistic lifetime of these plastic tanks is therefore anticipated to be of much the same magnitude as the mild steel tanks. Two other phenomena to which the plastic tanks offer even less protection than the mild steel variety are fire and vandalism. For these reasons mild steel tanks continue to be the preferred choice for industrial applications.

The pipelines linking the oil storage tanks to the burner units have proven to be even more susceptible to leakage than the tanks themselves. Until relatively recently half-inch mild steel pipe has been the preferred choice although in some cases even lighter copper pipe has been employed. These pipes nearly always act as the electrical earth for the mild steel tanks and are thus continuously exposed to a mild form of electrolysis which can accelerate corrosion. However where lines have been lagged with a chemically-resistant coating such as bitumen or Teflon<sup>TM</sup> they are generally adequately protected. Unprotected pipes which are laid in acid soils or concrete have been shown to be especially susceptible to corrosion and in some cases no trace of the original oil pipe remains by the time the leak is investigated.

A relatively recent development has been the introduction of Teflon<sup>TM</sup>-coated copper piping which is expected to be at least as resistant to corrosion as the bitumen-lagged mild steel piping. Unfortunately the Teflon<sup>TM</sup>-coated piping can be severed by a simple garden spade and is thus extremely vulnerable. Furthermore the Teflon<sup>TM</sup> coating is easily scored by careless installation so as to expose the metal and small animals appear to consider Teflon<sup>TM</sup> a particular delicacy!

More recently there have been several cases where pipe joints or unions have been identified as the source of leaks. This particular phenomenon is manifesting itself mainly on new housing estates and can usually be ascribed to under-tightening or cross-threading of the pipe fittings.

### 3. THE IMPACT

Heating oil leaks are generally only reported when their impact is sufficiently detrimental so as to require some form of remedial or containment action. Home heating oil tanks rarely exceed 1,350 litres (300 gallons) but, if the oil were to be uniformly distributed in the subsurface, the total loss of a single tank could theoretically contaminate 270,000 kilograms of soil or 227 million litres of water to a concentration in excess of the Dutch intervention values .

When oil escapes it moves under the effect of gravity and percolates vertically where the ground surface is permeable. It will preferentially follow the line of least resistance such as that created by foundations, wall footings, or recently-dug ground. The oil will continue to attempt to percolate under the influence of gravity until the effect of surface tension created in the soil column is such that it balances the weight of the oil acting on it. The surface tension effect is inversely proportional to

the size of the permeable soil matrix which basically translates into rapid vertical movement in a coarse-grained matrix such as gravel and less penetration at a slower rate in a fine-grained sand or silt.

For obvious reasons sudden heating oil losses are usually noticed by the home owner fairly quickly. However the slight increase in oil consumption caused by a slow leak is virtually imperceptible and the gradual movement of the oil through the subsurface may delay the observation of any symptoms for some time. Some of the symptoms which have been reported in connection with heating oil losses are as follows:

- scorched grass and/or dying vegetation;
- complaints from the neighbours;
- dead earthworms, amphibians, and birds;
- strange odours (both indoors and outdoors);
- funny taste in the water or food (sometimes oil droplets);
- dry scaly skin (like excema);
- headaches and/or stomach sickness;
- oil burner keeps cutting out due to air-locking;
- unusual oil usage.

All these symptoms can translate into a sterile (dead) garden, a house with errant oily odours, a polluted well and water system, and a lawsuit from the neighbours who may have suffered the same consequences. Aside from the cost of the lost oil, the cleanup, and the tank/pipeline replacement, one must consider the gross inconvenience suffered by the home owner, his family and other affected parties. If a cleanup is necessary additional disruptions will occur when the contractors begin remediation and in certain cases the entire ground floor of the house has had to be excavated effectively rendering the house uninhabitable for the duration of the cleanup.

Even these costs and inconveniences pale into insignificance when the potential loss of market value for affected properties is taken into consideration.

#### 4. REMEDIAL ACTIONS

Each heating oil loss has its own particular set of circumstances and requirements and in no way does this paper purport to act as a cleanup manual although some of the following information contained herein may prove useful in understanding the situation.

Immediately a heating oil loss is suspected by the home owner the insurers should be notified. In the event that further advice is needed, either the Environmental Officer in the local authority or the environmental information service ENFO can provide a list of specialists in this field.

It is essential before deciding on a course of remedial action to establish the maximum potential volume of heating oil lost and the period of time over which the loss occurred. Upon being notified of the loss a person with experience of heating oil cleanup should undertake a site visit and an interview of the affected parties as soon as possible. The urgent need for an assessment of the situation is often overlooked and the incident is treated in much the same way as a claim for a burglary or car accident. However, whereas the event of a burglary or car accident occurs at a specific time, in the case of a heating oil loss the damage continues to accumulate after the loss as the oil migrates through the subsurface and for this reason quick action is especially important for the purposes of damage limitation. The following is a list of some of the remedial actions which are commonly needed during cleanup:

- contaminated soil excavation, removal, and replacement;
- plume containment using pump and treat techniques;
- well abandonment and replacement (siting and construction are especially important);
- detergent wash and rinse of household water system following draining (including water appliances);

- excavation of an interceptor trench across the path of oil migration;
- chemical and bacteriological treatment of the subsurface;
- application of an indoor positive pressure system to eliminate vapours;
- groundwater sampling and analysis;
- tank and pipeline replacement including double-containment.

The most effective action which can be taken is containment. If any of the oil-saturated soil is easily accessible it should be excavated and placed in an area which is both covered and contained. Too often however the oil has seeped to below accessible depths and may lie adjacent to structural foundations. Strictly speaking advice from a structural expert should be sought before any deep excavation is undertaken within 5 metres of building foundations.

In rural areas the house is often supplied by its own well. If there is any chance that the well has been compromised the water must not be used for drinking or cooking purposes. If there is no oily odour from the water when it is boiled, it can be safely assumed that the oil content is sufficiently low (<1 ppm) so as to allow the water to be used for all other household purposes including bathing. The oil may appear intermittently however and it is essential to test both the water directly from the well and that supplied via the attic tank. Infants and small children are especially sensitive to water quality and, if there is any doubt, it is preferable to err on the side of extreme caution. Also remember that nearby wells may be affected and that those property owners have a right to know if their well may be affected.

## 5. THE COST

Cleanup costs for most serious home heating oil leaks or spills are likely to exceed a figure of £1,000 under most circumstances. Where extensive damage has occurred, which affects for example a row of terraced houses, cleanup costs have regularly been known to exceed £100,000.

In most reported cases the home owner is not personally liable for the cleanup costs. If the property is insured, coverage may be provided for under a sudden and accidental environmental damage clause. If the fault is one of poor installation, the company which installed the tank should have their own coverage. If the tank or line has been recently installed and has failed, then the tank suppliers may be liable. If the leak occurred on an adjoining property then the respective insurance companies should be in a position to agree liability.

Even if the worst scenario is realised and the home owner must pay for the assessment and cleanup out of his own pocket, it is still strongly recommended that proper specialist expertise be sought. A few minutes telephone advice and, if possible a site inspection, could avoid unnecessary expense and possible later repercussions.

## 6. PREVENTION

Many attempts to reduce the vulnerability of home heating oil storage tanks and lines to leakage have been practised in the past. Plastic tanks are only the latest attempt at improving home heating oil storage systems whilst keeping costs down. Cathodic protection using an electric field to counter corrosion was seen as the answer in the 1960s but fell prey to maintenance problems in the long term. The Teflon<sup>TM</sup> coated copper pipe was also a step in the right direction but, as pointed out earlier, still has its disadvantages.

Double-containment has universally been accepted as an effective solution to the problem of leaking oil tanks at industry level and is now an accepted world wide standard. Double-containment of above-ground oil tanks is also a prerequisite under the IPC licensing system and could easily be adapted to suit home heating oil storage systems. The tank, whatever its construction, is placed within a purposely-constructed bunded area. The entire length of Teflon<sup>TM</sup>-coated pipeline is sleeved with a protective plastic outer cover and preferably routed over ground. Although unavoidable accidental heating oil releases will undoubtedly continue to occur, if these simple construction techniques are adopted, it can be expected that the number of home heating oil losses will be greatly reduced.

## GROUNDWATER IN THE SOUTH MUNSTER REGION

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### *Abstract*

*The South Munster region forms a distinctive hydrogeological province which includes some of the most productive aquifers in Ireland, in the limestones of the synclinal valleys and in the Kiltorcan Sandstones which flank their anticlinal ridges. It also contains some productive, though small, gravel aquifers, and a variety of locally important aquifers. The region has a number of very large natural springs which have been used as water sources for many years, and in this century these have been augmented by many high-yielding boreholes, including Ireland's highest-yielding wellfield in Dungarvan. The region is also notable for a number of slightly warm springs, including the famous spa well at Mallow.*

The South Munster Region includes some of Ireland's most productive aquifers. In 1979 I gave a lecture to the IAH Irish Group's first major conference in Trinity in which I remarked that "it will be many years before their hydrogeology is properly understood". The process of understanding is still nowhere near complete, but while today's talk will repeat much of what I said in 1979, I can present some new information, which may serve to indicate how far we have come in 18 years.

A glance at a geological map of Ireland reveals that the South Munster region is characterised by a distinctive geological orientation, i.e. folding along E-W or ENE-WSW axes. This was caused by the Variscan Orogeny (mountain-building episode) which took place about 300 million years ago. The result is what we see today - a series of anticlinal sandstone ridges and synclinal limestone valleys in the north and east of the region, and in the southwest the succession of anticlinal mountains and synclinal sea inlets which attract so many tourists each year.

Further north, the effects of the Variscan folding reduce in intensity, while to the east the dominant structural trend is Caledonian, along north-northeast/south-southwest lines. So the region is defined by the direction and intensity of the structural trends. This region thus includes the whole of County Cork, most of County Kerry, the southern parts of County Limerick and South Tipperary, and the eastern part of County Waterford. Altogether, the area is about 14,000 square kilometres (of which Cork makes up about half), about 20% of the area of the Republic. Hydrologically, the region includes four main rivers: the lower Suir, the Munster Blackwater, the Lee, and the Bandon, plus a several medium-sized rivers including the Maine, and many small rivers draining to the much-indented coastline. It corresponds roughly to the "Southern Water Resource Region" as defined by An Foras Forbatha in the 1970s and used in the GSI's contribution to the European Community's Groundwater Resources Report published in 1982. The population is probably over 600,000.

Although the limestone valleys occupy a rather small percentage of the area, they are extremely important because they are very productive in agricultural terms, they are densely populated (Cork city, Mallow, Midleton, Fermoy, Dungarvan, Tralee, Killarney, etc.) and they are underlain by extremely productive aquifers. Many of Ireland's largest springs issue from these limestones and have been important water sources throughout Ireland's history, and in modern times these have been supplemented by many high-yielding boreholes. The limestones are often highly karstified and include some of Ireland's best-known caves.

Besides the karst limestones, the region also includes important groundwater resources, though we have much to learn about these other aquifers, which include Quaternary gravels, Devonian sandstones and Carboniferous mudstones. About a quarter of the well records in the Geological Survey's data banks come from this region. The region also forms a low-grade geothermal province, and slightly warm springs are known in counties Cork, Kerry, Limerick and Tipperary.

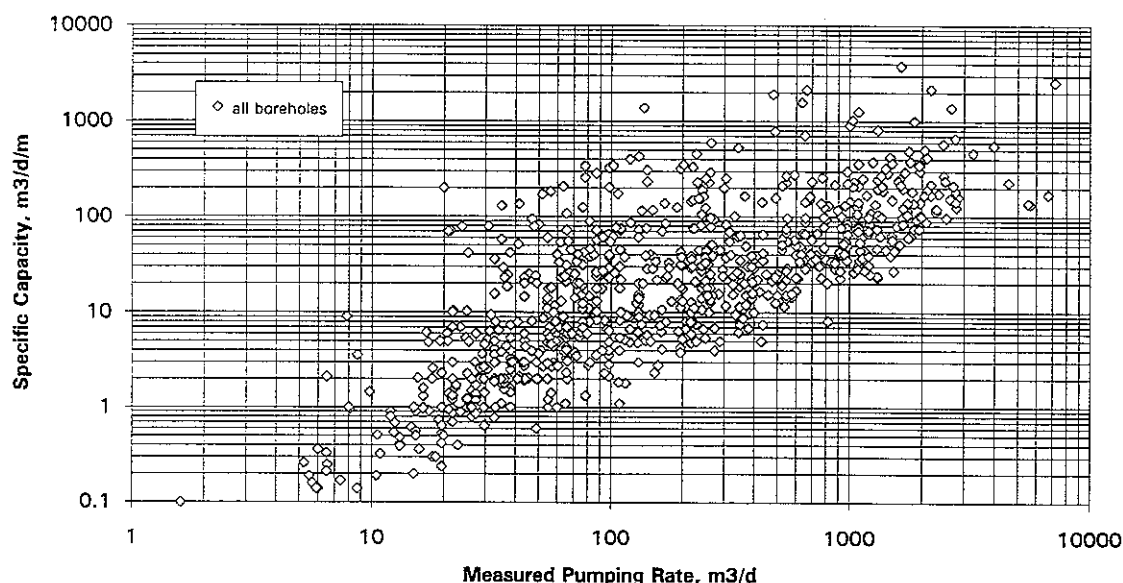
The aquifers of the region can be summarised as follows:

- Lower Paleozoic (slaty) rocks: generally poor aquifers
- The Namurian rocks of east Kerry/west Limerick/northwest Cork: generally poor aquifers
- "Lower Limestone Shale" and Ballysteen Limestone (north and east of the region): poor aquifers
- The "Cork Group" of west and south Cork: poor to locally important aquifers
- The "Old Red Sandstone" (throughout the region): poor to locally important aquifers
- Quaternary sands & gravels (widespread): locally important aquifers
- The Kiltorcan Sandstone (northern part of the region): regionally important aquifers
- The Waulsortian Limestone and other clean limestones (north and east of the region, also in Kerry): regionally important (karstic) aquifers

Since 1979, the GSI has compiled new geological maps of large parts of the region; so far, sheets 18, 20, 22 and 25 are published, sheet 21 is on the way, and sheets 17 and 24 will not be far behind. We also now have much more water well data. Recently I have been compiling the available data from pumping tests in Ireland, and summarising them on graphs, mainly as a way of substantiating our aquifer classifications. At present I have specific capacity data for over 800 boreholes across the country, and some 200-odd data points over the whole of South Munster as I have defined it.

The graphs show specific capacity plotted against pumping rate. Figure 1 shows the total national dataset (800+ points) for comparison. The fairly sharp lower boundary (bottom right-hand of the graph) can be ascribed to two factors: the natural tendency of fissures in an aquifer to get tighter with depth, and the artificial limit to available drawdown imposed by the well depth. Data points towards the upper left of the graph represent wells which have not been pumped sufficiently to stress them, hence the 'yield' is less than the ultimate yield and the indicated specific capacity is artificially high.

**Figure 1: Yields and specific capacities of about 800 boreholes in Ireland**



## Lower Paleozoic (Silurian) rocks

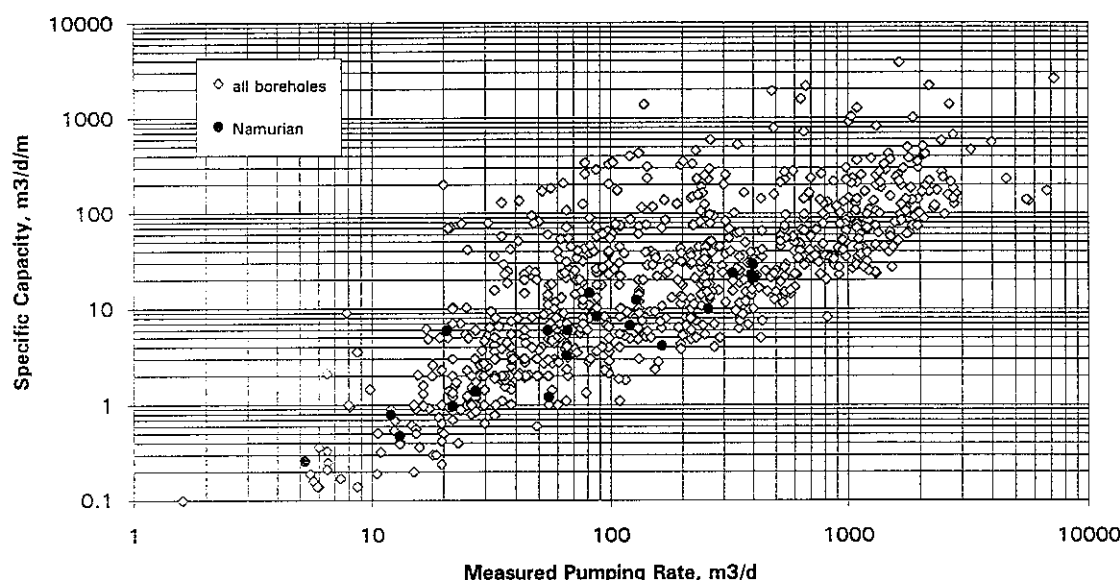
The Silurian rocks are the oldest in the region and occur only in the north and east, where they form the inner core of several mountain ranges, including the Comeraghs and the Knockmealdowns. They consist of very hard slates and greywackes, and are, in general, the poorest bedrock aquifers in the region.

## Namurian

We know little more today about the Namurian succession as an aquifer than we did twenty years ago. This is partly because of its location: the population density and the consequent water demand are low, so most boreholes drilled in it have been for small supplies. Even so, drillers seem to have found it difficult sometimes even to meet these small requirements, and attempts to obtain larger supplies for public sources or industrial supplies have often met with failure. This is understandable enough in the Namurian shales, but even the sandstone-dominated parts of the succession have generally proved disappointing. However, sometimes the sandstones have been more productive, and we may yet learn how to find the more productive parts of the succession.

The graph in Figure 2 summarises our available data on the productivity of boreholes in the Namurian. For the moment, the Namurian must remain classified as, at best, "PI" on the GSI classification.

**Figure 2: Yields and specific capacities of boreholes in the Namurian formations**



## "Lower Limestone Shale" and Ballysteen Limestone

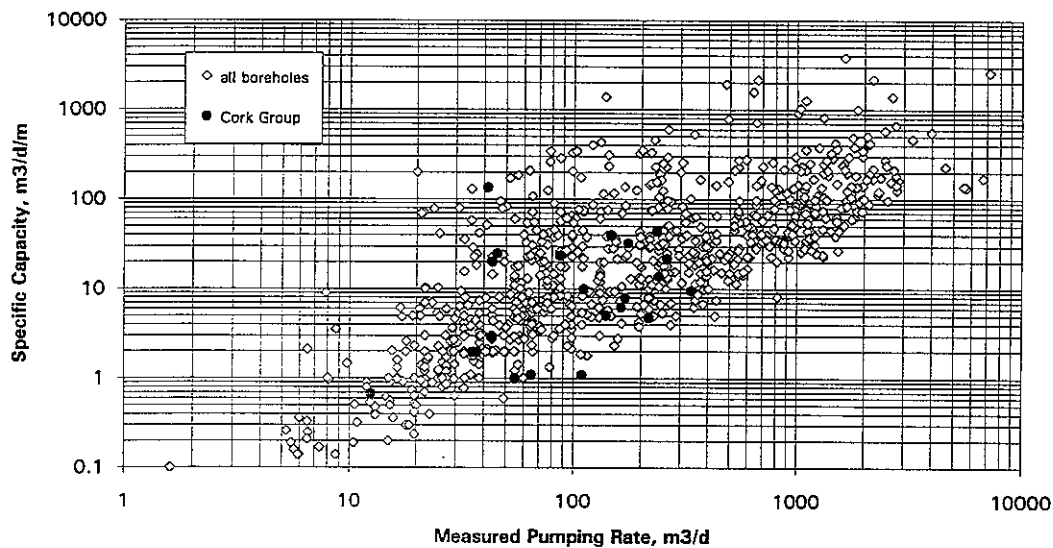
This is the name used on the old geological maps which remains a useful way of encompassing a number of variable and rather thin formations, including the Mellon House Beds, Ringmoylan Shales, etc. They include thin limestones, shales, mudstones and sandstones. They generally outcrop along the flanks of the limestone synclines, where, being rather easily eroded, they tend to occupy the lower ground and are often covered by alluvium and other Quaternary deposits. For hydrogeological purposes, the overlying Ballysteen Limestone Formation can be included with them. Yield/specific capacity data are too few to plot. In general, they seem to have a low permeability and are classified as poor aquifers.



## The "Cork Group"

The "Cork Group" is the name for the succession of mudstones, sandstones and slates found across south and west Cork. Chronologically, they are equivalent to the limestones of north and east Cork but were laid down in a different environment. On the recent GSI maps they are divided into a number of formations, mainly the Kinsale and Courtmacsherry formations. In the GSI well records we have records of many hundreds of wells in these rocks, especially in the southern parts of Cork, around Bandon, Clonakilty and Kinsale, almost all for small domestic supplies, and almost all recording 'yields' of 200-300 gallons per hour. (*Incidentally, for those hydrogeologists who have spent time dredging through the GSI records without much enlightenment, I may say that in recent years they have proved their value, not so much for the 'yields' they record but for their depth-to-bedrock information, which is so important in vulnerability assessments.*) However, we do have a few decent records of pumping tests on wells in these rocks, summarised on Figure 3, indicating that the aquifer is generally "poor".

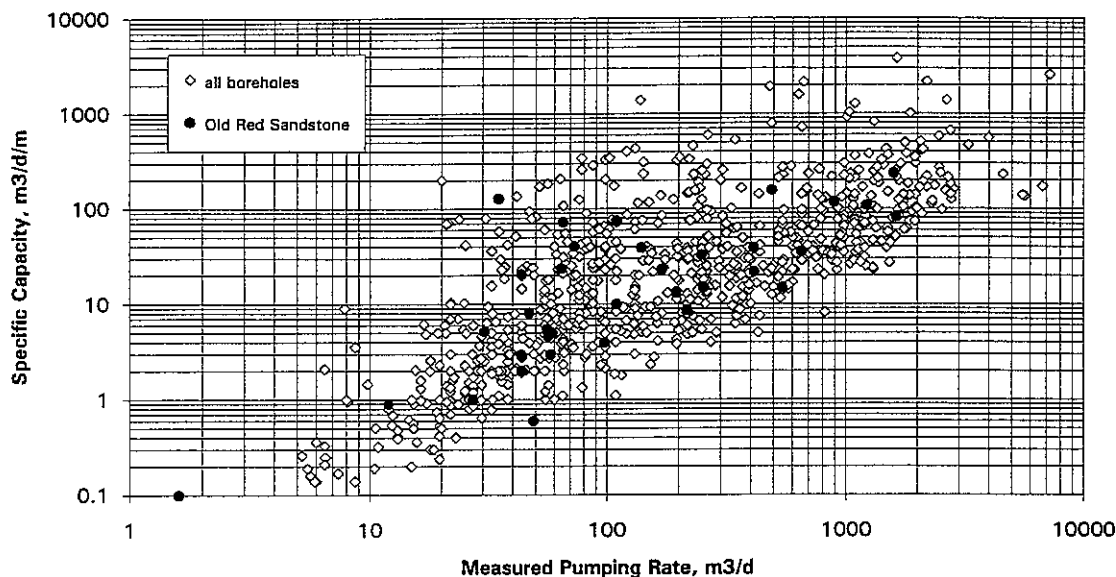
**Figure 3: Yields and specific capacities of boreholes in the "Cork Group" formations**



## "Old Red Sandstone"

The "Old Red Sandstone" occurs right across the region, generally on the higher ground. It forms the core of the mountains, from the Ballyhouras in North Cork to the MacGillycuddy's Reeks of Kerry, and makes up most of the big peninsulas of the west. The succession is divided into a number of formations, which vary across the region, including the Ballytrasna, Knockmealdown, Caha Mountain formations.

As with the Cork Group, we have many well records but very few 'yields' above 200-300 gallons per hour. However, we do have a few significantly higher yields and a couple of exceptional yields in the Dingle area. Figure 4 summarises the data.

**Figure 4: Yields and specific capacities of boreholes in 'Old Red Sandstone' formations**

The exceptional yields were obtained in boreholes drilled for a fish farm, and in the absence of other indications, were assumed to be due to drilling in a major fissure zone, perhaps a major fault. There have been attempts to repeat this success in a couple of areas, by using air photos and/or geophysical surveys to identify suitable zones, and these have met with some limited success, although the Dingle yields have not been repeated. To some extent, there are indications that yields are higher in the coarser formations (conglomerates and coarse sandstones) and poorer in the finer formations (mudstones, siltstones and fine sandstones).

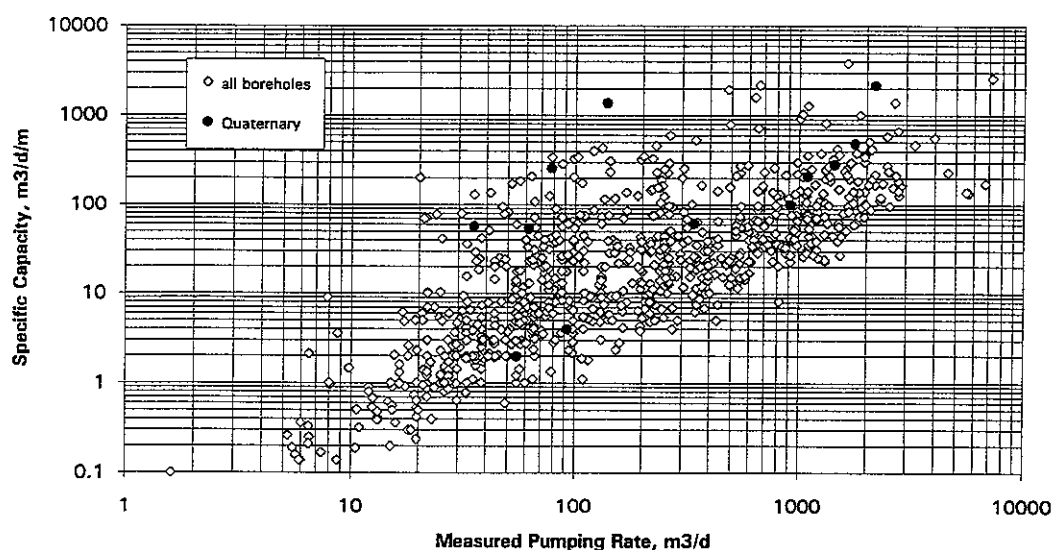
In County Waterford, most of the medium-sized public supply sources draw from this aquifer, and it has been classified as locally important, as also in South Tipperary, under the groundwater protection schemes prepared by GSI for these counties. If we can get some confirmatory evidence, it may be possible in time to be more discriminating and to classify the coarser formations as 'Lm' or even 'Rf'.

### Quaternary Sands & Gravels

As elsewhere in Ireland, Quaternary deposits are very widespread and very variable in composition. Gravelly deposits thick enough and extensive enough to constitute aquifers have been investigated and/or developed in several places:

- Brinny, near Inishannon, Co. Cork, boreholes for industrial use
- Carrigtwohill, Co. Cork, boreholes for industrial use
- Ardfert, Co. Kerry, for public supply
- Minane Bridge, Co. Cork, for public supply (infiltration gallery)
- Enniskean, Co. Cork, for public supply (infiltration gallery)
- Ballyvourney, Co. Cork: exploration for industrial site.

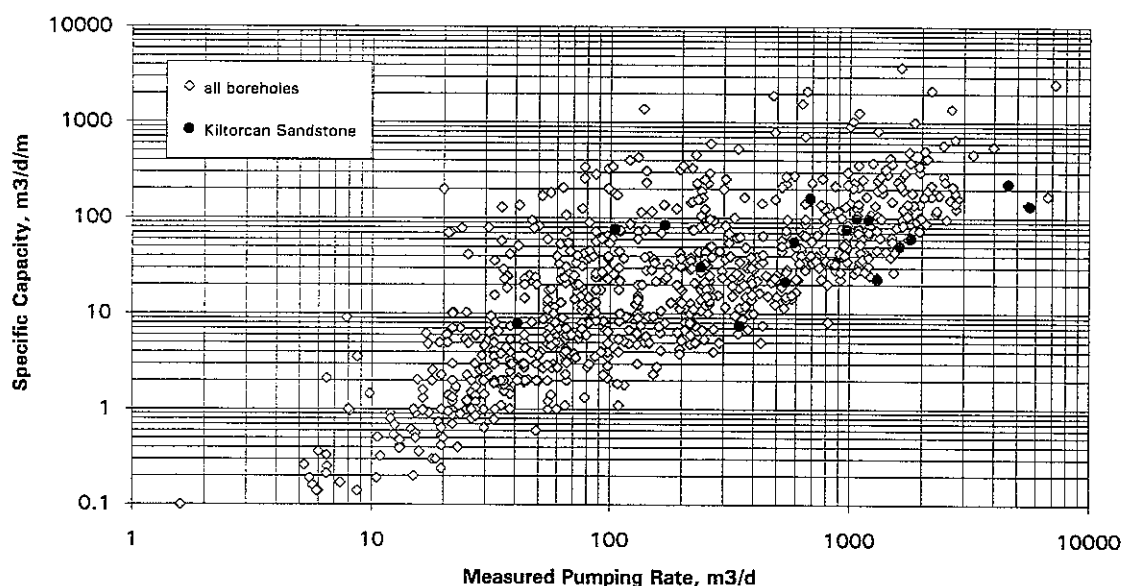
The thickness of the Quaternary deposits can range up to perhaps 60 metres or more in coastal areas. Where they are rather thin and shallow, the use of infiltration galleries can allow successful development where boreholes are impractical. Undoubtedly these deposits hold considerable potential. Figure 5 summarises the yield/specific capacity data for the Quaternary aquifers.

**Figure 5: Yields and specific capacities of boreholes in Quaternary deposits**

### The Kiltorcan Sandstone

In 1979 we had just a few hints about the aquifer potential of this formation, mainly from three boreholes drilled for the Rathluirc water supply. Since then the aquifer has been explored, tested and developed, particularly in North Cork, and has earned its place as one of the major aquifers in the country, not only in South Munster but also in the Southeast and the Midlands.

The graph in Figure 6 summarises the available yield/specific capacity data for the aquifer in Cork and Waterford, and shows that, provided you get the geology right and also drill deep enough, it is one of our more predictable and reliable aquifers. The one relative failure was a rather shallow well (80 feet) in the more shaly upper part of the Kiltorcan. Compared with our limestone aquifers it also has other advantages: it yields a softer water, it is often artesian or sub-artesian, and it generally has a lower vulnerability.

**Figure 6: Yields and specific capacities of boreholes in the Kiltorcan Sandstone**

## The Waulsortian and other clean limestones

My 1979 talk was exclusively concerned with the Carboniferous Limestones of the "Southern Synclines", and it is true that these remain the focus of groundwater exploration and development in the region.

The abundance of groundwater in the southern limestones has been evident since pre-history, from the numerous springs, large and small. The region includes many of Ireland's largest springs, such as Kedrah (Co. Tipperary), Dower (Co. Cork) and Ballymacquin (Co. Kerry).

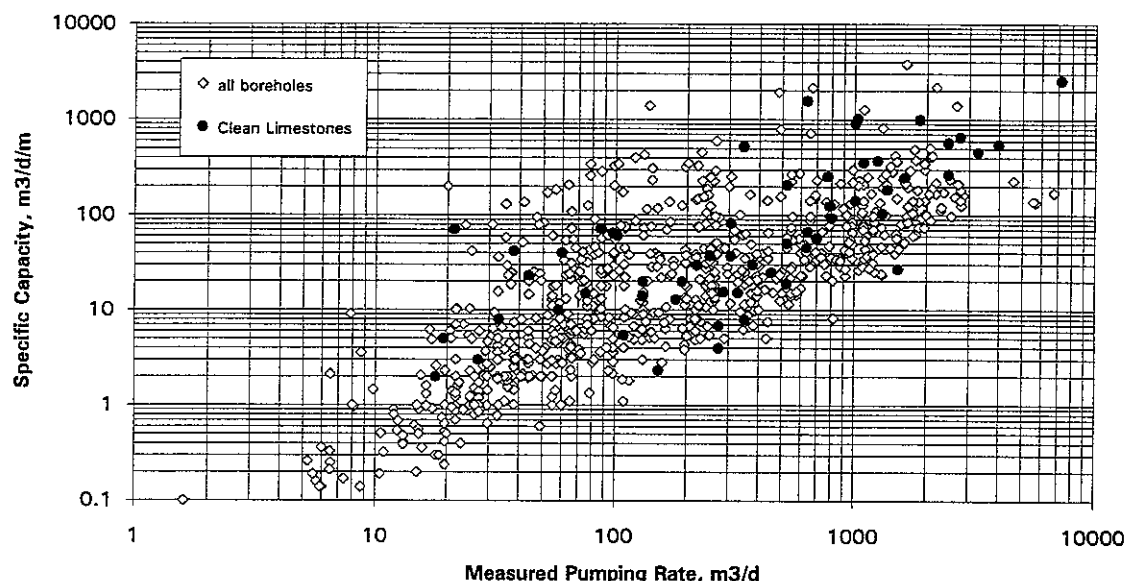
These springs ensure that the flow in the rivers of the limestone valleys remains relatively constant. Examination of the annual flow hydrographs of rivers such as the Suir and Munster Blackwater and their tributaries shows that these rivers are characterised by relatively small ranges in flow, relatively high summer flows, and rather smooth recession curves. Using the technique of base-flow separation, it can be deduced that the base-flow component of total flow in most of these catchments can be as high as 50 to 70% in a dry year such as 1975. Another useful parameter is the "specific dry weather flow" (i.e. flow per unit catchment area) and the ratio of dry weather flow to mean annual flow. Many of the catchments ranking highest for these indices are found in the South Munster region, and it is the presence of the limestone aquifers, with their large groundwater storage, which accounts for their position.

Beside these springs, the region has many caves, swallowholes, sinking streams, and other features of karstification. Many of Ireland's best known caves are in this region, such as Mitchelstown Caves (Co. Tipperary), Crag Cave (Co. Kerry) and Castlepook (Mammoth) Cave, Co. Cork.

The southern region is not an obviously karstic region in the manner of the Burren or Cuilcagh. Nevertheless, many of the limestone formations are highly karstified, and their karstic nature is extremely important in considering both groundwater development and groundwater protection. Although large areas of bare limestone are uncommon, there are many small outcrops and the subsoil cover is often very thin. Sinking streams are common. Even where there is a thicker subsoil cover, this often consists of gravels or gravelly till and gives little real protection. Hence much of the limestone would be classed as highly to extremely vulnerable under the GSI's guidelines.

Within the limestone succession of South Munster, several different limestone formations have been mapped, as the new GSI bedrock maps indicate. The most widespread is the Waulsortian, comprising coalescences of calcareous mud-mounds. Other limestone formations are more recognisably bedded. In general, investigations so far have not allowed us to make detailed distinctions between the hydrogeological properties of the various clean limestone formations. Bridget Scanlon's short study of the Castleisland area, Co. Kerry, suggested that the main aquifer was the Waulsortian, while the more shaly bedded limestones and an upper 'reef' formation were less productive. However, over much of the region, the upper part of the limestone succession is absent, having been removed by erosion.

Figure 7 shows a yield/specific capacity graph for the limestone aquifers of South Munster. The region includes many of Ireland's highest-yielding wells, including the 'supreme champion' at Ballynamuck, Dungarvan, yielding 7900 m<sup>3</sup>/day. Other notably high-yielding wells are recorded at Cloyne, Mallow and Ringaskiddy, Co. Cork. Where transmissivities can be calculated or estimated, they are generally in the range of 100-2000 m<sup>2</sup>/day.

**Figure 7: Yields and specific capacities of boreholes in Waulsortian and other clean Limestones**

The key to the aquifer characteristics seems to lie in the regional geological structure. The anticlines are cut by series of shear faults, trending approximately north-south (in fact, varying from north-northeast/south-southwest to north-northwest/south-southeast). The mapped spacing of these north-south faults is typically 1 to 5 km. These faults are paralleled by a very well developed system of near-vertical north-south joints, which can be seen in the field (e.g. in quarries) and are commonly spaced at intervals of about 0.5 to 2 metres.

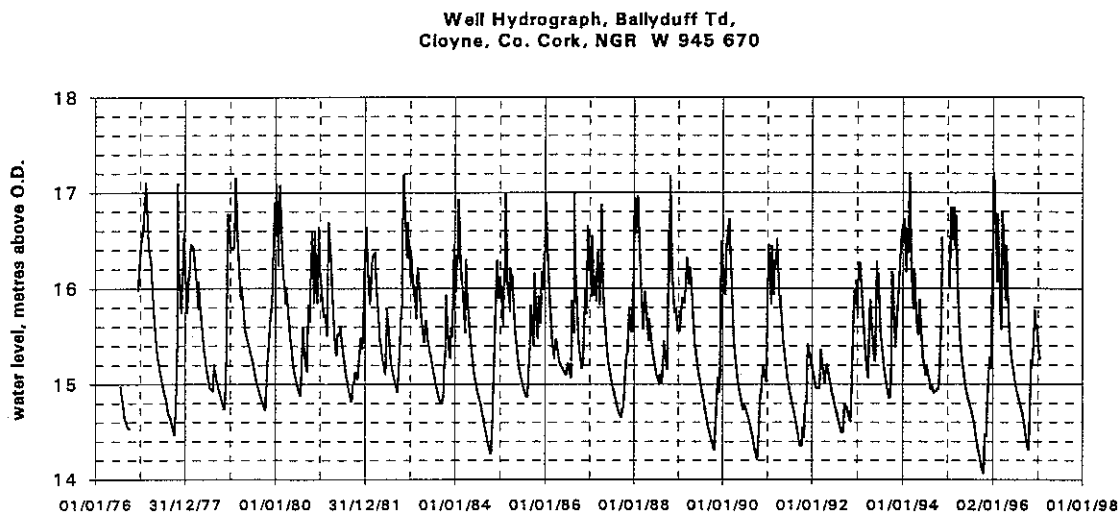
Examination of limestone exposures in many places, especially at the coast (Fenit, Co. Kerry) or on lake shores (Killarney) shows numerous open joints and surface karstification. Evidence of deeper karstification along these joints can be found in cave surveys, which often show main passages or galleries about 1 to 6 metres apart. Cloyne Cave, Co. Cork, is one of the best examples, with a dense maze of passages on a reticular pattern.

Most of the explored caves are either dry or only partially or seasonally filled with water, and thus reflect past, rather than present, hydrology. However, Carrigacrump Cave, Co. Cork, has passages at least 15 metres deep, with over 9 metres depth of water measured. Caliper logging of one of the Cloyne boreholes found a major zone of fissuring at 41 metres below ground (about 20m below O.D.), and at Ringaskiddy major water inflows were encountered down to about -40m O.D. Karstification has clearly extended well below present sea levels, presumably during periods when the sea level was much lower than at present.

There is evidence that sea levels were formerly around 50 to 60 metres below O.D. in Cork City. The deepest river channels were developed along the outcrop of the "Lower Limestone Shale", since these were the rocks least resistant to erosion. The infill to these channels includes the gravel aquifers now found in places such as Carrigtwohill. The karst we find today is therefore a "drowned" karst, in which karst voids and conduits created at a time of lower sea levels have once again been filled with water.

### Groundwater level monitoring

For the past 20 years or so, with the help of Cork County Council we have been monitoring groundwater levels in several wells in southeast Cork, as shown in the example in Figure 8. The long-term monitoring has been limited to the Waulsortian limestone and the Quaternary, but we have shorter records from a few wells in the Cork Group and Old Red Sandstone.

**Figure 8: Example of Well Hydrograph, Co. Cork**

The records show the variability of the annual cycle of recharge and discharge; the annual peak, though usually in January or February, may in fact occur anywhere between October and April, and once, freakishly, in August (1986), while the annual minimum may occur anywhere between August and December, though most often it would fall in September or October.

Detailed examination of the records demonstrates the extreme vulnerability of much of the limestone, with very rapid response to rainfall events, even in summer. This is attributable to the widespread occurrence of sinking streams.

### Groundwater Resources and Protection

In our 1979 report to the European Commission (published in 1982) the GSI estimated that the total available groundwater resources in the 'Southern Region', in the main aquifers alone, amounted to approximately 604 million cubic metres per year, of which about 53 million cubic metres per year were currently being used. Since that time we have become aware that the Kiltorcan Sandstone is much more important than we knew, and there are substantial additional resources in the lesser aquifers. We have not had cause to make new estimates, but we can be sure that the region is still blessed with abundant groundwater for future development.

The GSI has been involved in this region for many years, particularly in County Cork. County aquifer protection schemes have been prepared for South Tipperary and Waterford, and we hope to start on South Cork within the next year. North Cork has had an aquifer protection policy in use for about 10 years, based on the first GSI scheme, i.e. without a vulnerability component.

### Warm Springs

The South Munster group of warm springs includes about 12 springs or spring complexes in five sub-groups:

- The Mallow complex, Co. Cork, chiefly comprising Lady's Well, Mallow
- Carraundulkeen, Gneevgullia, Rathmore, Co. Kerry
- The Newmarket group, Co. Cork: Trinity Well, Newmarket, Ballinatona Springs, Meelin (5,800 m<sup>3</sup>/d abstracted), and Pollnabpiast, Marybrook.
- The Kilmallock group, Co. Limerick: Knocksouna springs, Ballynagoul and Garrane springs.
- The Newcastle West group: St. Bridget's Well, Cregan's Well, Tobergal, and Camas spring.

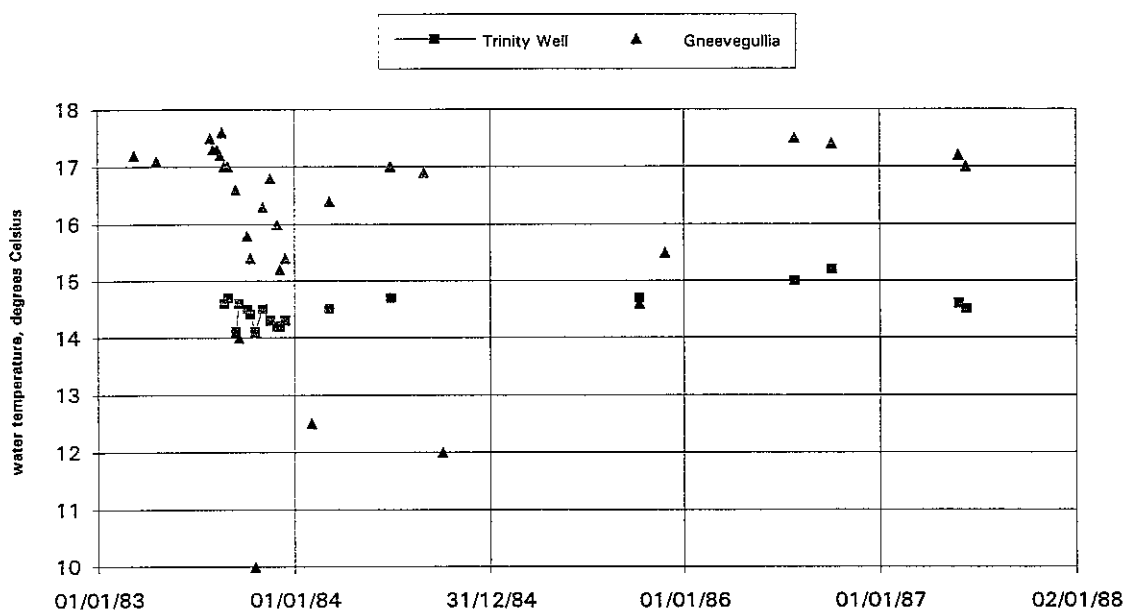
Most of the springs emerge from Carboniferous limestone. Trinity Well is an exception in issuing from Namurian rocks but the hydrochemistry suggests a limestone origin and one can infer that a vertical fault allows the water to rise to the surface from limestone some distance below. However,

the abnormal temperatures of these waters implies that they are quite distinct from normal limestone springs. In at least some cases, the waters may come from a deeper aquifer, probably the Devonian sandstone (Kiltorcan or equivalent). Some details of the warm springs are listed in Table 1, and Figure 9 illustrates the temperature variations in Trinity Well (very little variation) and Carraundulkeen Spring (large variations due to mixing with surface water after rainfall).

**Table 1: Summary details of warm springs in South Munster**

Ref.	Group	Name	NGR	O.S. Sheet	Temperature, °C.			Flow, lps		
					Max.	Min.	Median	Max.	Min.	Median
2001	Mallow	Lady's Well	W 562 986	Cork 33	22.1	16.1	19.5	31.2	1.5	10.1
2005	Newmarket	Ballinatona 1	R 283 124	Cork 14	13.75	13.2	13.6			
	Newmarket	Ballinatona 2	R 283 124	Cork 14	14.8	14.4	14.5			
	Newmarket	Trinity Well	R 299 077	Cork 14	15.2	14.1	14.5			
	Newmarket	Marybrook	R 430 046	Cork 23			(13.0)			
2006	Gneevegullia	Carraundulkeen	W 116 984	Kerry 60	17.5	10.0	16.85	7.9	4.5	5.7
2003	Newcastle W.	St. Bridget's Well	R 265 326	Limerick 36	14.0	12.3	13.1	4.67	0.2	1.7
	Newcastle W.	Cregan's Well	R 266 313	Limerick 36			14.0			
	Newcastle W.	Camas	R 281 288	Limerick 44			13.0			
	Newcastle W.	Tobergal	R 315 279	Limerick 44	14.0		13.2			
2004	Kilmallock	Knocksouna 4	R 566 276	Limerick 47	16.1	15.3	15.6			
	Kilmallock	Ballynagoul 1		Limerick 47			17.0			
	Kilmallock	Ballynagoul 2		Limerick 47			15.7			
	Kilmallock	Garrane		Limerick 47			13.0			

**Figure 9: Temperature variations in warm springs: Trinity Well, Newmarket, Co. Cork and Carraundulkeen Spring, Gneevegullia, Co. Kerry**



## Conclusion

In terms of its groundwater resources, the South Munster region vies with the Southeast region as Ireland's richest. The Southeast has more extensive aquifers but South Munster tends to have the highest productivity and is aided by a more abundant recharge, which also tends to improve prospects in the poorer aquifers. As yet, these abundant resources have been developed only to a fraction of their potential and we can expect that in the years to come, the region will come to make much more use of this exceptional resource.

*Acknowledgements: I would like to express my thanks to the many people who have contributed information used in this paper, including Bob Aldwell, Brian Connor, Kevin Cullen, Eugene Daly, Harry McEvoy and many local authority engineers, but especially to Michael Cogan of Cork County Council. Finally, I must acknowledge my debt to the late Dr. David Burdon, who contributed so much to hydrogeological work in South Munster, and who was, in this as in many things, a source of great encouragement.*





## **COSIMA CONTAMINATED SITES MANAGEMENT SUPPORT SYSTEM**

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*The COSIMA project is being developed as part of the Telematics Application Programme for the Environment Sector, under the aegis of DGXIII. It is part-funded by the E.U.*

### **ABSTRACT**

*The COSIMA consortium comprises of five cities: Cologne (D), Cork (IRE), Bologna (I), Amsterdam (NL) and Katowice (PL). Moreover, three software development firms are involved: ESBI (IRE), ESRI (D) and ESRI (Italia), and these firms are acting as the Industrial Partners of Cork, Cologne and Bologna respectively. This group is developing a computerised integrated Contaminated Sites Management Support System (CSMSS) to assist environmental, planning and other experts in identifying, assessing, registering and remediating sites which may have been contaminated through previous use - e.g. industrial or landfill sites.*

*Sites must be investigated to assess the nature and extent of contamination, if any, and may require remediation to make them safe and suitable for further use. The COSIMA consortium is developing and agreeing a common approach for the investigation, analysis and remediation of contaminated sites, and is further developing and implementing an appropriate support and analysis system on two different Geographic Information System (G.I.S.) platforms: Intergraph and ArcInfo.*

*The developed system will handle graphics, maps, photographs, etc. and databases including testing and analysis methods as well as results, remediation methods, and cross references to standards for investigation into, remediation and re-use of sites.*

*The final system and methodology will be standardised across the consortium as far as possible, and will provide a user-friendly map based tool to support contaminated sites management. The standardisation, based on five cities facing common problems, will ensure that the developed CSMSS will be a useful tool to any body in the management of potentially contaminated lands.*

### **OBJECTIVE:**

The objective of the COSIMA project is to develop a G.I.S.-based Integrated Contaminated Sites Management Support System (CSMSS) to assist environmental, planning and other experts in registering, assessing and remediating sites. This is necessary for environmental and economic reasons as follows:

- Contamination caused by industrial and other activities may present a danger to human beings and to the natural and built environment.
- The continuing spread of urban areas demands more and more green field sites. It is desirable to recycle/redevelop historic industrial sites (Brown Field) which may be derelict.
- These Brown Field sites, because of their locations, are often high quality sites for investors. Therefore their development is an important factor in urban development and planning, and in attracting inward investment.

- There is a lack of an appropriate support system for contaminated sites management. The in-house data necessary for checking potentially contaminated sites is held in different areas in the cities and is not integrated. Investigations are presently carried out and analysed manually, and are time-consuming.
- COSIMA will develop a new product which will be marketable across the European Union.

## **METHODOLOGY:**

A methodology has been developed by the cities to carry out Risk Analysis on any potentially contaminated site.

### **1. Initial Investigation:**

There must be an initial evaluation of the site history through examination of old maps, aerial photographs and archival records to identify/quantify previous site use. If the results of the initial investigation indicate that a risk may exist the investigation moves to the *Screening Phase*.

### **2. Screening Phase:**

In this phase the decision is made as to what we must investigate for in general terms, and to what initial extent. It comprises three steps:

- Programme of Testing
- Actual testing
- Evaluation of test results and risk analysis

If after the *Screening Phase* the site is found to be a possible risk and further examination of the extent of the contamination is needed then the investigation moves to the *Detailed Investigation Stage*.

### **3. Detailed Investigation Stage:**

This will normally be undertaken to define more accurately the extent of contamination/contaminants - e.g. Hot Spots etc. - and again consists of

- Planning a programme of testing
- Carrying out tests to establish in detail the extent of the area contaminated and the levels of contamination.
- Evaluation of test results.

Based on the results of the detailed examination an expert evaluation is carried out and a decision on whether or not to remediate is taken. Where remediation is necessary the target levels of remediation are set and after remediation these are checked before any development is allowed.

## **APPROACH:**

- The approach in COSIMA is user-led development, where the personnel who will use the CSMSS in each city specified their needs and these were integrated into the system. Compliance with these needs is subject to ongoing verification through the project.
- The existing G.I.S. (Geographic Information Systems) platforms in each city are being used for the development of the system.
- The consortium standardises where possible on terms, symbols and data storage tables across the cities.

## **WORK PLAN:**

In order to achieve the aims of the project and to fulfil the contract with the European Union the project was divided into a number of work packages together with 'deliverables' to be supplied to the Commission. There were six key work packages identified by the consortium as essential to complete the contract with the Commission. These workpackages are at various stages as outlined below.

- **WP0 Harmonisation of Terminology and Methodology**

This is now complete.

This was necessary so that all cities in the consortium would have common terms and definitions. It forms a 'Handbook for Contaminated Sites Management' in English-German, English-Dutch, and English-Italian. We hope to have an English-Polish version also by the end of the project. The handbook includes definitions of expert terms in the field of contaminated sites, explanations of limits, threshold values, target values, background values for toxic substances, remediation and examination techniques, and definitions of medical terms.

- **WP1 Analysis of Users Needs**

This is now complete.

This was developed through face-to-face interviews, questionnaires and discussions between the personnel that will use the system and the industrial partners. The resulting 'deliverable' document identifies data required, system functions required, existing data, locations and formats etc.

- **WP4 Uniform Data Model (UDM)**

This is now complete.

The UDM defines all the objects, attributes and relationships necessary to deal with all areas associated with contaminated sites management including Registration, Risk Assessment and Remediation. While the UDM is an overall comprehensive model, each of the cities may choose to develop their system based on a sub-set of this model.

- **WP5 Harmonised Presentation Model (HPM)**

Work on this is ongoing and is due for completion by the end of July 1997.

The graphical presentation of data (e.g. contamination type, well locations, historical industrial site) will be the same in each city as far as possible - i.e. Colour codes, Line styles, symbols, levels/layers etc. for presentation of map and analysis data, will "look" the same where possible across the cities. However, the developed system must be flexible in presentation because of varying national and local standards.

The deliverable is a document defining in detail how data is to be represented.

- **WP6 Integration of Existing Data Infrastructure**

Work on this is ongoing and is due for completion by the end of September 1997.

The objective is to identify and describe in detail the existing Data Processing systems and/or Digital data in each city which is to be integrated into the CSMSS. To date we have identified the full extent of the Data and/or Systems Infrastructure, sources and formats to be integrated in each city.

Examples of these for Cork would be:

- Planning Register
  - Water records
  - Derelict Site Register - Drainage records
  - Census information
  - W.E.P.S. system
  - Ordnance Survey Maps
- among others.

Work has also started on the examination of the interface of the required data.

The deliverable is a document defining in detail the Data Infrastructure to be integrated into the CSMSS.

- **WP7 User Interfaces**

Work on this is ongoing and is due for completion by the end of January 1998.

In this work package our industrial partners will detail the design of the software and will code, document and unit test it. The User Interface must fulfil the function defined in the User Needs Analysis (WP1) and the Harmonised Presentation Model (WP5).

The deliverable is CSMSS - a turnkey G.I.S. application providing user-friendly access to and analysis of data for the management of potentially contaminated lands.

#### **FUTURE PLANS 1998:**

- Towards the end of COSIMA two 'Demonstrators' will run in the Environment Departments of Cork and Cologne. These Demonstrators will test the CSMSS using real data from selected (suspected) Contaminated Sites.
- Using these Demonstrators, the success of the developed CSMSS will be assessed on the basis of a detailed Validation Plan. Direct and indirect impacts on various appraisal groups will be assessed as far as practicable during the Demonstrators, but due to time and financial restrictions, these assessments will be incomplete.
- Bologna and Katowice at a future date hope to implement their own CSMSS systems.
- The software partners will, on the basis of the prototypes developed in Cork and Cologne, market COSIMA on a European wide basis.

We would like to thank Mr. J. Higgins, Cork City Manager and Mr. W. A. Fitzgerald, City Engineer, Cork Corporation, for allowing us to present this paper to the I.A.H., and also to thank Mr. Donal Daly and the I.A.H. for their kind invitation.