Section 1: Groundwater pollution: policy and legislation in the UK

The UK has often been described as the ‘dirty old man’ of Europe: its environmental policies have been seen as too pliable and polluter-friendly by many European neighbours. Defenders of the UK policy cite a pragmatic, rather than obstructively ideological, stance and a willingness on the part of regulators to co-operate with industry to solve groundwater pollution problems. The UK is also playing a leading role in developing a European framework for the use of risk assessment techniques which are acceptable to both industry and regulators (see e.g. Quint et al. 1996). It is also the case that the UK Environment Agency represents one of very few European regulatory agencies which have realised the EU’s objective of integrated river-basin management of both the quality and quantity of surface water and groundwater resources. Some of the UK’s fiercest critics, such as the ideologically rigid Norway, are still years from achieving such a goal. Readers can judge for themselves, as Bob Harris explains how the UK implements European groundwater protection policy, Kathy Mylrea guides us through the Byzantine labyrinths of the UK legal system and highlights the apparent perversity of some judgements (e.g. that storage of chemicals can constitute a ‘natural’ use of land, as in the case of ‘Cambridge Water Company versus Eastern Counties Leather’. See Misstear, Ashley & Lawrence, and Bishop, Lerner & Stuart for further details in section 5). Finally, Paul Ashley examines one of the implications of the ‘Eastern Counties Leather’ case, namely that liability for a historic groundwater pollution incident rests upon forseeability of damage.

Protection of groundwater quality in the UK: present controls and future issues

R. C. HARRIS

National Groundwater and Contaminated Land Centre, Environment Agency, Olton Court, 10 Warwick Road, Solihull, West Midlands B92 7HX, UK

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.

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 realization 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⁻¹ as NO₃) 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⁻¹ 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 utilize 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. Figure 1 shows a typical trend for a groundwater source abstracting from the Triassic sandstones in Shropshire.

**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 & 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 μg l⁻¹ for trichloroethylene and 10 μg l⁻¹ 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 μg l⁻¹ (i.e. 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

![Fig. 1. Extract from the National Groundwater Nitrate Database showing increasing nitrate concentrations in groundwater from a source abstracting water from the Triassic sandstones in Shropshire.](http://sp.lyellcollection.org/)
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 were derived from limited sources, the results give the best available 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 are biased towards those land use categories which are more highly regulated. However, 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 localized contamination at some locations can be significant with percentage levels of some soluble compounds encountered at some distance below the 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 (e.g. cutting oils, a variety of raw chemicals). Other sources relate to the deposition of waste chemicals, e.g. 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 specialized 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, e.g. a borehole or spring. 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, that 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. The UK still awaits an example on the scale of Love Canal, which did so much to raise public awareness in North America and galvanize 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, which 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 that are prescribed under the Environmental Protection Act 1990 are controlled by authorizations granted by The Environment Agency. 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 minimizing 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 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 is a good example. (The Nebraska Groundwater Foundation is a non-profit-making educational foundation dedicated to educating the public about the conservation and management of groundwater.) 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

**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 & 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 & 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. (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.) 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 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 recognize 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 has been published in both paper and CD Rom formats 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 planning of sewage sludge application to agricultural land and in routeing 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, giving 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 must also take into account the risk limitation that 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 completed in 1998, is the most ambitious of any European country. Around 2000 individual sources have had their zones defined and published. Manuals have been 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 recognized that there are many deficiencies in it; not the least that by 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 (European Union 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 as follows:

(i) to maintain the quality of polluted groundwater,
(ii) to prevent further pollution,
(iii) to 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 unrecognized 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 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). 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 recognizes 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 Agency 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.
### Table 1. Relative ease of clean-up for a range of contaminants in different geological environments (after National Research Council 1994)

<table>
<thead>
<tr>
<th>Hydrogeology</th>
<th>Contaminant chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mobile, dissolved (degrades/ volatilizes)</td>
</tr>
<tr>
<td></td>
<td>Mobile, dissolved</td>
</tr>
<tr>
<td></td>
<td>Strongly sorbed, dissolved (degrades/</td>
</tr>
<tr>
<td></td>
<td>volatilizes)</td>
</tr>
<tr>
<td></td>
<td>Strongly sorbed, dissolved</td>
</tr>
<tr>
<td></td>
<td>Separate phase LNAPL</td>
</tr>
<tr>
<td></td>
<td>Separate phase DNAPL</td>
</tr>
<tr>
<td>Homogeneous, single layer</td>
<td>1*</td>
</tr>
<tr>
<td>Homogeneous, multiple layers</td>
<td></td>
</tr>
<tr>
<td>(Triassic sst)</td>
<td>1</td>
</tr>
<tr>
<td>Heterogeneous, single layer</td>
<td>2</td>
</tr>
<tr>
<td>Heterogeneous, multiple layers</td>
<td>2</td>
</tr>
<tr>
<td>Fractured (Chalk)</td>
<td>3</td>
</tr>
</tbody>
</table>

*Relative ease of clean-up, where 1 is easiest and 4 most difficult

**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, 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 that are continuing to affect controlled waters and also groundwaters that 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 that 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 or 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, or 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 (i.e. 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 that 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 & Harris 1996). As landfill design has become increasingly 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 recognized 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 conceptualization 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 visualization 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 21st 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 minimize 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 19th 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.

References


ANON, 1993b. Key ruling on civil liability by House of Lords. ENDS Report, 227, 43–44.


