EA-NGWCLC ~~2001~~ Box 3

Paul Hart

PROTECTING Groundwater

An International Conference on:
Applying policies and decision making tools to land-use planning

4-5 October 2001 International Convention Centre, Birmingham, UK

Conference Proceedings

ENVIRONMENT AND HERITAGE SERVICE

SEPA
SCOTTISH ENVIRONMENT PROTECTION AGENCY

ENVIRONMENT AGENCY

PROTECTING GROUNDWATER

Applying policies and decision making tools to land-use planning

CONFERENCE PROCEEDINGS

National Groundwater and Contaminated Land Centre Project NC/00/10

Environment Agency
National Groundwater and Contaminated Land Centre
Olton Court
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National Groundwater and Contaminated Land Centre Project NC/00/10

PROTECTING GROUNDWATER
4 & 5 OCTOBER 2001

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Evaluation Form
(Please deposit completed forms in the collection box)

1. What was your objective in attending this conference?

2. On a scale of 1-5, how useful was each session?

		Not useful		(please circle)		Very useful
(i)	Contexts	1	2	3	4	5
(ii)	International experiences	1	2	3	4	5
(iii)	Sectoral views	1	2	3	4	5
(iv)	Parallel session: Science	1	2	3	4	5
(v)	Parallel session: Policy	1	2	3	4	5
(vi)	The way forward	1	2	3	4	5

3. For the conference as a whole, please indicate an overall rating for the various aspects listed below:

		Unsatisfactory	Weak	Satisfactory	Good	Excellent
(a)	Overall conference quality	1	2	3	4	5
(b)	Success in meeting your objectives	1	2	3	4	5
(c)	Conference facilities	1	2	3	4	5
(d)	Refreshments	1	2	3	4	5
(e)	Content of delegate pack	1	2	3	4	5
(f)	Conference organisation	1	2	3	4	5

4. What were the three most useful things that you have gained from this conference?

1 ______________________________

2 ______________________________

3 ______________________________

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5. How will the messages / tools / experiences you have learnt about be of use in your job (background information, aid policy development, etc)?

6. How did you first learn about this conference? (please tick)

- E-mail ❑
- Mailshot ❑
- Personal contact ❑
- Journal advert/flyer ❑
- Web site ❑
- Other ❑ ______________________________

7. What magazines and journals do you read in this field?

____

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8. Any other comments you may wish to make? (e.g. suggestions for future topics).

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(Optional information)

Name: ....

Job title: ....

Organisation:..

(Please tick box if you do <u>not</u> wish your details to be held on our contacts database. ❑

PROTECTING GROUNDWATER

Applying Policies and Decision-making Tools to Land-use Planning

THURSDAY 4TH OCTOBER (HALL 9 all day)

08:30 Coffee/Registration.
09:30 Delegates welcome: Colin Beardwood on behalf of the Environment Agency.
09:35 Chairman's introduction: Tricia Henton, Chief Executive Officer, SEPA.
09:40 "The Environment Agency's approach to groundwater protection: a backwards and forwards look", Bob Harris, Head of National Groundwater and Contaminated Land Centre, Environment Agency.
10:10 "Planning for water resources: the Catchment Abstraction Management Strategies (CAMS) process", Giles Phillips, Head of Water Resources, Environment Agency.
10:35 "Water Framework Directive and the importance of groundwater", Dave Foster, Water Framework Directive Manager, Environment Agency.

11:00 Coffee (view posters in Hall 11)

11:25 "The land-use planning perspective: a Local Authority viewpoint", Dr Elizabeth Street, Environmental planning consultant.
11:50 "The Land-use planning perspective: an Environment Agency viewpoint", Roger Vallance, Head of Local and Regional Relations, Environment Agency.
12:15 "Groundwater issues in Celtic countries", Tricia Henton, Chief Executive Officer, Scottish Environment Protection Agency.
12:40 Discussion.

13:00 Lunch (view posters in Hall 11)

14:15 Chairman's introduction: Andrew Skinner, Regional Environment Protection Manager, Midlands Region and Secretary General International Association of Hydrogeologists.
14:20 "Co-operative agreements between agriculture and water supply in Germany", Prof. Wilhelm Urban, Darmstadt Univ. of Technology, Germany.
14:45 "Groundwater protection in Denmark", Richard Thomsen, Head of Groundwater Department, County of Aarhus, Denmark.
15:10 "An industrial viewpoint on groundwater protection", Gordon Lethbridge, Shell.

15:35 Coffee (view posters in Hall 11)

16:05 "A view from agriculture", Michael Payne, Consultant to the National Farmers Union.
16:30 "The groundwater/ecosystem link: the case for wetlands", Rob Cunningham, The Wiltshire Wildlife Trust.
16:55 "A view from the water supply industry", Jacob Tompkins, Water UK.
17:20 Discussion and close at 17:45.

19:30 for 20.00 Dinner in Hall 11, with after dinner speech from Dr Paul Younger of Newcastle University.

FRIDAY 5TH OCTOBER

Morning parallel sessions in Hall 10a and 10b
08:30 Registration.
09:00 Parallel sessions start **(see table overleaf).**

14:00 Chairman's introduction: Dr Stephen Foster, British Geological Survey and World Bank/Global Water Partnership GW-MATE Leader.
14:05 "Defining groundwater protection zones in England and Wales", Dr Andrew Lovett, University of East Anglia.
14:30 "Integrating groundwater protection policy with land-use planning and site specific risk assessment", Tony Marsland, Environment Agency.
14:55 "Linking groundwater and surface water management", Steve Fletcher, Environment Agency.
15:20 "Making groundwater visible – the key to quality protection", Dr Stephen Foster, BGS.

15:45 Coffee/Tea
16:00 Final discussion & close by 17:00.

FRIDAY 5TH OCTOBER

Morning parallel sessions

Time	**Science** 09:00 – 13:00 Hall 10a Chairman: Prof David Lerner	Time	**Policy** 09:00 to 13:00 Hall 10b Chairman: Bob Harris
09:05	"The potential of artificial tracers for aiding groundwater protection and risk assessment", Dr Tim Atkinson, University College London.	09:05	"Groundwater protection and planning policy", David Hickling, The Planning Co-operative Ltd.
09:25	"Biosolids to land: Thames Water's GIS-based methodology", Dr Keith Baxter, Thames Water.	09:25	"The legal framework and technocratic versus democratic issues for groundwater protection", Dr Peter Howsam, Cranfield University, England.
09:45	"Groundwater pollution risk assessment methodology", Steven Howe, Vivendi Water Partnership.	09:45	"Groundwater protection in Western Australia", Anthony Laws, Water and Rivers Commission, Australia.
10:05	"Tools to delineate Source Protection Zones for borehole and adit systems", Prof. David Lerner, Groundwater Protection and Restoration Group, University of Sheffield.	10:15	"Groundwater in Ontario, Canada: policy issues and potential solutions", Dr David Neufeld, Ontario Ministry of the Environment, Canada.
10:25	"Methodology for wellhead protection areas implementation in urban water supply catchments located in detritic and carbonated formations in Spain", Carlos Martinez-Navarette, Institute of Geology and Minerals, Spain.		
10:45	Discussion.	10:45	Discussion
11:00	**Coffee (view posters)**		
11:20	"Groundwater protection based on an integrated, dynamic flow and particle tracking approach", Anders Refsgaard, Danish Hydraulic Institute, Water and Environment, Denmark.	11:20	"Practical implementation of groundwater protection policy: development of supporting tools in England and Wales", Dr Rob Ward, Environment Agency.
11:40	"Probability-based protection zones in fractured aquifers: implications for land-use Planners", J Nicky Robinson, WS Atkins.	11:40	"The groundwater protection scheme in Ireland: a risk-based tool for effective land-use planning", Donal Daly, Geological Survey of Ireland.
12:00	"Viral and tracer movement through contrasting soils", Malcolm McLeod, Landcare Research, New Zealand.	12:00	"Groundwater remediation and monitoring for urban areas, East Siberia, Russia", Dr Larisa Auzina, Irkutsk State Technical University, Russia.
12:25	"Groundwater protection in karstic areas: an update", Simon Neale, Environment Agency.	12:25	"Lessons learnt from the Foot and Mouth disease crisis: the problems of carcass disposal and the need for strategic planning", Tony Marsland, Environment Agency.
12:45	Discussion.	12:45	Discussion.
13:00	**Lunch (view posters in Hall 11)**		

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List of delegates

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PROTECTING GROUNDWATER
Applying Policies and Decision-making Tools to Land-use Planning

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Posters on display in Hall 11

'Monitoring point construction as a constraint for vulnerability mapping with GIS'. Mark Betson, University College London. Andrew Lovett, University of East Anglia.

'Predicting the impact of land cover change on groundwater recharge'. Jon Finch, Centre for Ecology & Hydrology.

'Planning non-mains sewerage discharge to ground'. B.A.Fretwell and J.A.Heathcote, Entec UK Ltd. A.Hart, Environment Agency.

'Devastating effects of oils on our environment'. Stella Howell, Euro Environmental Containers.

'Urban water management: an integrated approach'. Holger Kessler, British Geological Survey.

'CIRIA Research Project RP625. Biological treatment for contaminated land-case studies'. Chris Meek and David Barr, WSP Environmental Ltd.

'LandSim: Release 2.0'. Golder Associates (UK) Ltd and Environment Agency.

'The inter-relationship between civil engineering works and groundwater protection'. Martin Preene, Arup Water and Rick Brassington, Consultant Hydrogeologist.

'Groundwater source and resource protection - policy evaluation in England, Wales, Scotland and Northern Ireland'. N.S.Robins, D.W.Peach, B.É.Ó.Dochartaigh, D.F.Ball, British Geological Survey. P.McConvey, Geological Survey of Northern Ireland.

'UK Water Industry Research Limited: Diffuse pollutants in groundwater: economic appraisal'. Produced by Metcalf & Eddy Limited.

'The use of an environmental tool for the protection of groundwater in planning applications'. K.Stagg, J.Whittaker, A.Herbert and M.Fermor, Environmental Simulations International.

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'Benchmarking groundwater risk assessment modelling tools'. J.Whittaker, S.R.Buss, A.W.Herbert, M.Fermor, Environmental Simulations International. J.W.N.Smith, Environment Agency.

'Urban Rivers: our inheritance and future'. Prof Geoff Betts, University of Birmingham. Dr John Heathcote, Entec UK Ltd. Dave Martin, Environment Agency.

'A strategy for groundwater protection from nitrate leaching using spatial and geostatistical analysis'. Sarah Evers, Steve Fletcher, Rob Ward and Bob Harris, National Groundwater and Contaminated Land Centre, Environment Agency.

'The Resource Assessment and Management (RAM) Framework'. Environment Agency.

'Methyl Tertiary Butyl Ether (MTBE) in groundwater in England and Wales'. Jane Dottridge and Mark Hall, Komex, UK. Lamorna Zambellas and Alwyn Hart, Environment Agency. Soil / Waste / Groundwater Group, Institute of Petroleum.

'Impacts of contaminated land and groundwater on surface water quality, Birmingham, UK – planning implications'. P.A.Ellis, A.Thomas, M.O.Rivett and R.Mackay, University of Birmingham. R.Ward and B.Harris, Environment Agency.

'The natural quality of groundwater in England and Wales: the BASELINE project'. British Geological Survey and Environment Agency.

'Monitored Natural Attenuation: Environment Agency guidance on its application'. M.A.Carey, Entec UK Ltd. J.W.N.Smith, Environment Agency.

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AN INDUSTRIAL VIEWPOINT ON GROUNDWATER PROTECTION

Gordon Lethbridge

Contaminated Land, HSE Consultancy Group, Shell Global Solutions, P.O. Box 1, Chester, United Kingdom, CH1 3SH

INTRODUCTION

The oil industry takes its environmental protection responsibilities very seriously. The industry's technical body, the Institute of Petroleum (IP), produces guidance documents on best practises on such topics as: the safe handling, storage, transportation and retailing of petroleum products, response to spill incidents, how to carry out robust, technically defensible risk assessments and how to investigate sites for soil and groundwater contamination and how to remediate contaminated sites. The IP works very closely with the Environment Agency, carrying out many projects jointly.

In addition, the oil companies produce their own internal guidance documentation to support the operation of their HSE (Health, Safety and Environment) Management Systems for their various businesses.

Within Shell, environmental performance is an integral part of the business, with its own measurable KPIs (Key Performance Indicators) and a commitment to continuous measurable improvement. We produce an annual externally audited Environmental Report. Each Operating Unit (Shell operates in approximately 130 countries worldwide) has its own team of HSE advisors backed up by a central group of approximately 100 HSE specialists within Shell Global Solutions. This pro-active approach to environmental protection is viewed as a vitally important part of doing business as we have moved from the "trust me" which prevailed up to the 1980s, through the "show me" world of the 1990s to the "involve me" world of the 21st century.

Challenges for the oil industry in protecting groundwater

Within the UK, Shell owns 675 retail petrol filling stations and markets the brand through a further 410 dealer owned sites. This represents 10% of the estimated 11,000 retail petrol filling stations currently operational in the UK. In addition, we operate a refinery, six distribution terminals, a chemical manufacturing plant, three natural gas terminals, several small distribution depots and a number of cross country pipelines. These facilities, with their manufacturing plants and above ground and below storage tanks and pipelines, represent a potential risk to groundwater resulting from accidental leaks and spills of product. The aim of this presentation is to demonstrate how these risks are managed.

Operating large numbers of sites presents some special challenges with respect to environmental protection. Since it is not possible to investigate all sites for contamination, or to upgrade the containment and leak detection facilities within a short time due to resource constraints, some form of site prioritisation is required.

Risk assessment

The potential risks to the environment posed by a specific Shell site are assessed in a desk-top exercise using a proprietary GIS (geographical information system) based tool called Network

Environmental Risk Assessment (NERA). NERA addresses a range of environmental risks (e.g. groundwater, surface water, residential and commercial properties), but for the purposes of this presentation, discussion of its use will be restricted to assessing risks to groundwater.

NERA ranks sites in terms of their potential risk to groundwater by assessing: groundwater usage, the distance to groundwater abstractions wells in the vicinity and the aquifer vulnerability. This results in a site being given an environmental Sensitivity Indicator Value (SIV).

NERA also ranks sites in terms of the likelihood that underground facilities are leaking, or will leak in the future within a given time frame, by assessing: the age, construction and composition of tanks and pipelines, whether or not corrosion prevention measures (e.g. cathodic protection) have been used and the corrosivity of the soil. This results in a site being given a Condition Indicator Value. CIVs can be superimposed on SIVs to get an integrated assessment of risk or the two scores can be assessed in isolation depending on the objective of the exercise.

The information from NERA can be used to:

- Prioritise sites for investigation of soil and groundwater contamination.
- Prioritise sites for upgrading of facilities, before their integrity has started to fail.
- Cost-effectively match the containment (tank and pipeline type) and leak detection systems installed when upgrading a site to match the level of risk posed by that site.
- Gain a rapid feel for the potential environmental liabilities associated with sites acquired from third parties as a result of purchase, exchange or joint venture.
- Identify sites which pose an unacceptably high risk (even with the most sophisticated containment and leak detection systems) and earmark them for closure during network rationalisation programmes.
- Aid decision making in the location of new sites.

NERA was designed to assess environmental risks from underground storage tanks and product transfer lines at retail petrol filling stations. The same principles have been used to develop tools to assess the environmental risks from above ground facilities, especially tanks, at distribution and manufacturing facilities. These tools can be used to assess the potential risks posed by the whole site, part of a site (e.g. one plant in a large manufacturing facility) or a single tank. Our GIS-based Tank Risk Tool is particularly useful for large manufacturing sites. A risk ranking of tanks can be used to:

- Match products with tanks, so that high risk (from an environmental perspective) products (e.g. gasoline) can be stored in low risk (from an environmental perspective) tanks and low risk products (e.g. lube oil) can be stored in high risk tanks. An example of high and low risk tanks is best illustrated at one of our manufacturing facilities which is located on a sandstone aquifer. Over two thirds of the site, the aquifer is protected by several metres of clay. There is no clay protecting the aquifer in the remaining third of the site. Tanks located in the former area are ranked low risk, whereas those located in the later are ranked high risk.
- Match the frequency of inspection to the risk posed by the tank (i.e. inspect a high risk tank more frequently than a low risk one).

Prevention

In order to minimise the impact of our operations on groundwater, the Shell Group has developed a series of minimum environmental standards which apply to all countries in which we operate. They are tailored to the level of risk posed by a particular site. They are far too extensive to describe in detail in this presentation, but a few examples are given for retail petrol filling stations in Tables 1 and 2.

Soil and groundwater contamination

Historically, some form of soil and/or groundwater contamination has been found at up to 50% of retail petrol filling station sites investigated. However, at half of these sites, the level of contamination is minor and insignificant. Prior to the adoption of risk-based approaches to soil and groundwater contamination in the mid 1990s, some form of remediation was carried out at approximately 25% of sites. Application of risk assessment methodologies has now reduced the percentage of sites where some form of remediation is required to protect human health and the environment to around 12%. At the vast majority of sites where groundwater has been impacted, the impact is restricted to non potable perched or shallow groundwater.

Some key points regarding the sources of this contamination include:

- Major leaks (e.g. catastrophic system failure) and spills are very rare. By their very nature, they are detected and acted upon immediately (emergency response).
- The vast majority of leaks are minor ones which in the past could go undetected for long periods of time.
- Underground pipelines are a far greater source of leaks than are underground storage tanks.
- When problems do arise with underground storage tanks they can usually be traced to sub-standard manufacture or poor installation technique. This can be avoided by good QA/QC and supervision of tank installation contractors.
- The technology is now available to minimise tank overfills, which were probably a significant source of contamination in the past, although human error can never be entirely ruled out.
- Despite automatic pump cut-offs, customer overfills still occur.

Regulatory concerns

The industry has a number of concerns surrounding current and pending future legislation related to groundwater protection:

- Is groundwater a pathway or a receptor? Early drafts of the contaminated land legislation (Part IIA, EPA 1990) defined groundwater solely as a receptor. Industry, primarily in the form of SAGTA (Soil and Groundwater Technology Association) argued long and hard that groundwater was a pathway, the receptor being an individual who drinks the groundwater, or an ecologically sensitive area into which the groundwater discharges. The final form of the legislation states that groundwater can be either a receptor or a pathway, but it is our experience that regulators on the ground treat it only as a receptor. The problem lies with the term "controlled" water and its definition. In groundwater terms "controlled" water appears to be any water in the ground from the smallest pocket of perched water through to a major aquifer. Under the legislation, if controlled waters have been impacted, a pollutant linkage has been demonstrated and the site is classified as contaminated and would require some form of remediation. Taken at face value, this will apply to the majority of industrial sites that have handled chemicals in the UK. This is clearly not very helpful as it removes the focus from targeting those contaminated sites which pose real risks (as opposed to perceived ones) to human health and the environment for priority action. Indeed it could be counter productive by diverting limited resources away from sites posing real risks to human health and the environment towards those posing perceived risks. I think at least two things are needed to solve this problem:

1. A definition of what the Environment Agency (EA) considers to be useable, potable groundwater.
2. Guidance on when groundwater should be considered to be a pathway and when it should be considered to be a receptor.

- Once groundwater has been contaminated it is extremely difficult from an engineering perspective to clean it up to drinking water standards. Desorption limited pump and treat systems have to be run for decades, if not indefinitely. It is unlikely that aggressive in situ technologies such as air sparging and chemical oxidation will find widespread application in the UK, because of the complexities and heterogeneity of our hydrogeology. Permeable reactive barriers show promise, but are likely to be limited in their application to specific niches. We must recognise that monitored natural attenuation (MNA) will be the only cost-effective means of managing groundwater contamination at the majority of sites contaminated with biodegradable chemicals such as petroleum hydrocarbons. However, there is a real danger that its use will be severely restricted unless we can address the problem raised above concerning the definition of groundwater as a pathway versus a receptor. Since MNA is effectively a pathway blocking technology, that is only appropriate when a receptor has not been impacted (and impact is not imminent), if groundwater is the receptor then, at face value, this precludes the use of MNA. However, this is clearly not the case, since the EA recognise the value of MNA in the groundwater contamination risk management toolbox as witnessed by their detailed technical guidance on the subject. There is however a need for straightforward guidance on the practical application (as opposed to its technical demonstration) of MNA for regulators on the ground.
- Most of our contaminated soil (which can act as a source for groundwater contamination) in the UK is either disposed to landfill or treated ex situ by technologies such as bioremediation, soil washing or thermal treatment prior to re-use. With the advent of the EU Landfill Directive the amount of soil treated by ex situ technologies will increase. There is a danger that the Landfill Directive will severely restrict the cost effective risk-based approach to dealing with contaminated land. For example, ex situ treatment may be very successful in cleaning soil to the risk-based site specific target level (SSTL), but this may be above the limit for disposal to a non hazardous waste landfill. Under the Directive, if the remediated soil is re-used on site, the site would be classified as a landfill. This will hardly help brownfield redevelopment.
- Unlike the contaminated land regulations, the IPPC (Integrated Pollution Prevention and Control) regulations are not risk-based. Thus all contamination of soil or groundwater arising from the operation of an IPPC licensed plant must removed as a condition of the surrender of the license. This is technically impossible. It seems odd that Part IIA recognises this, but IPPC does not. The EA's thinking on this one is understandable. They feel that a risk-based approach to IPPC could be construed as a license to pollute. However, I feel the approach to baseline definition and remediation under IPPC needs some careful rethinking.
- On all but special sites, regulatory responsibility for soil and groundwater contamination lies with the local authorities rather than the EA. This regional approach could derail a nationwide risk assessment of a company's network of sites to identify potentially high risk sites and prioritise them for action. Sites which rank as medium or low risk on a nationwide basis may be identified for action by a particular authority. This will divert limited resources from tackling some of the potentially high risk sites and will be counter

productive, in that the longer potentially high risk sites go uninvestigated, the greater the potential risk to human health and the environment.
- We have experienced significant inconsistencies between the different EA regions in their response to remediation strategies and goals. We should strive for consistency.

Many of the concerns highlighted above are not restricted to the UK and have been voiced by NICOLE (Network for Industrially Contaminated Land in Europe) in a wider European context.

Table 1. Minimum standards for new (NTIs, rebuilds, upgrades, additional developments) retail petrol filling stations

Area of concern	Environmental risk posed by site	Minimum standard
Underground storage tanks	High	Double wall (coated) tanks with interstitial monitoring system.
	Medium	As above OR single coated wall with electronic leak detection.
	Low	Single coated wall tanks
	Aggressive soils	Use corrosion resistant materials OR provide additional leak detection
Tank overfill protection	High	Install overfill protection device
	Medium	Install overfill protection device
Tank fill points	All	Provision of spill collection capacity
Product pipelines - suction systems	All	Single wall. Check valve installed at pump end of line.
Product pipelines - pressure systems	High	Double wall with interstitial monitoring in pressure systems
	Medium	Double wall with interstitial monitoring in pressure systems
	Low	Single wall with electronic leak detection device
	All	Under dispenser shear valves.
Dispensers	All	Integral containment base and check (suction) or shear (pressure) valves
Pavements	All	Leak-proof construction
Drainage	All	Forecourt and car wash drainage in separate systems.
	High	Leak-proof sealed system. Oil/water separator installed.
	Medium	Leak-proof sealed system. Oil/water separator installed
	Low	All discharges to public drainage systems, ditches or open water to be pre-treated.
Wetstock management	All	Daily check to reconcile deliveries, stocks and sales. Compare trends over time to identify losses or gains.

NTI = new to industry

Table 2. Minimum standards for existing retail petrol filling stations

Area of concern	Environmental risk posed by site	Minimum standard
Risk assessment	All High	NERA completed by end 1999. All potentially high risk sites to be intrusively investigated for soil and groundwater contamination. Corrective action should be taken at those sites posing actual unacceptable risks.
Upgrading	High Medium	First priority Second priority All upgrades to comply with requirements for new installations
Underground storage tanks	All High Medium	Tanks over 30 years old to be replaced Install overfill protection device. Reconstruct fill point to prevent spills entering soil. Reconstruct fill point to prevent spills entering soil.
Suction systems	All	Remove check valve from tank end of line to under pump
Pressure systems	High and medium	Leak test. Upgrade poor condition systems. Good condition systems - replace mechanical leak detection system with automatic electronic version.
Dispensers	High and medium	Replace with unit that has an integral containment tray or install under unit containment trays
Forecourt surfaces	High	Replace with leak-proof pavement and appropriate drainage collection system.
Drainage systems	High	Test existing unit and repair or replace all leaking components. Replace poorly performing oil/water separator systems that discharge to public sewers, open water or ditches.
Wetstock management	All	Daily check to reconcile deliveries, stocks and sales. Compare trends over time to identify losses or gains.

THE GROUNDWATER-ECOSYSTEM LINK: THE CASE FOR WETLANDS

Robert Cunningham

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WHY WETLANDS?

The action of the water cycle as a force of nature, constantly recycling water through rivers, groundwater, sea and air is one of the first lessons that we learn about the way the Earth functions to maintain life. However the very familiarity of the concept as a physical, inviolable process can lead us to overlook the role that ecosystems play in regulating the movement and quality of water in our aquifers, lakes, rivers and seas.

In this cycle the most obvious link between ecosystems and groundwater is where the two meet in wetland habitats. Increasingly the conservation community looks to policy makers and water resource managers not only to protect wetlands but also to seek opportunities for their restoration and creation. In a world of competing demands for resources why should wetlands be seen as a priority?

THE VALUE OF WETLANDS TO BIODIVERSITY

Globally wetlands represent a tremendous resource for biodiversity, holding more than 40% of the world's species but covering less than 1% of the Earth's surface (Ramsar 2000). In the UK freshwater wetlands are known to support over one third of Britains higher plants, some 660 species, (EN & EA 1999) and in excess of 3,500 invertebrate species (Merritt 1994). Our rivers, lakes and waterways are home to some of the UK's best known mammals such as the otter and water vole.

As well as supporting a wealth of species diversity wetlands are also highly productive, supporting large numbers of individuals such as waterfowl with freshwater sites like the Somerset Levels and Ouse Washes hosting 100,000 and 60,000 wintering birds respectively (*persn. comm* Phil Burston, RSPB).

THE VALUE OF WETLANDS TO PEOPLE

The importance of wetlands goes far beyond their intrinsic value to biodiversity. Increasingly it has become clear that the narrow focus of mans activities on making wetlands "productive" through their drainage and destruction have ignored many of the functions they perform in regulating the terrestrial side of the water cycle to the benefit of society.

A recent study by Costanza *et al* (1997) estimated the value of the world's natural wetland ecosystem function at 4.9 trillion dollars, over 25% of the wealth generated by global economies. While studies that attribute monetary value to natural systems are open to

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[1] The Wildlife Trusts are a unique national partnership of 46 independent charities, the Urban Wildlife Partnership and Wildlife Watch, the junior branch. Collectively, The Wildlife Trusts manage approximately 2,250 wetland habitats and 595 river reaches. Outside of our reserves our officers deliver advice and practical expertise to riparian and wetland managers supported by the UK Water Policy Team

significant uncertainty the vast sum attributed to wetlands reflects the wide array of functions they perform (see Figure 1).

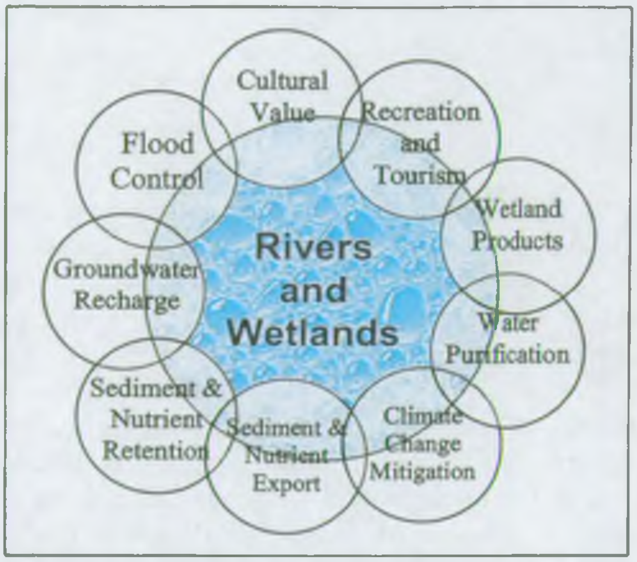

Figure 1 The multi-functional benefits of wetland ecosystems

For example wetland ecosystems can play an important role in nutrient and pesticide removal, protecting both surface and groundwater quality. In Florida studies have shown that the cypress swamps have nitrate and phosphate removal efficiencies that exceed 97% before water recharges the aquifer. In another study the restoration of the Swedish Gotland wetland system was shown to be the more cost-effective for the removal of nitrate than the expansion of sewage works (Gren, 1995).

As well as removing pesticides and nutrients wetland systems act as the "throttle" of the terrestrial water cycle attenuating peaks and troughs in pollutant and hydrological loading.
By soaking up precipitation in the upland bogs and mires and storing floodwaters in extensive floodplains wetland ecosystems can play an important role in reducing the severity of flood peaks. Over time these systems can release water to surface and groundwater bodies supporting river base flow and abstraction.

Wetlands are also prized for their amenity value providing opportunities for quite and active recreation. With tourism playing a major part in supporting the rural economy maintaining a diverse, high quality, is as important for people as wildlife[2].

Therefore the demand for resource to protect, restore and create wetlands made by environmental groups should be viewed in the context of benefits they deliver not only to wildlife but people as well.

WETLAND LOSS

It has been estimated that as much as 25% of Roman Britain was wetland (Rackham 1986) ranging from the vast lowland fens of East Anglia to extensive upland bogs of Scotland &

[2] "Valuing our Environment" a study by the National Trust (2001) reports that up to 70% of employment in tourism is dependent on a high quality environment.

Northern Ireland. As we enter the 21st century less than 5% remain intact, often as isolated fragments in a "sea" of drained, engineered and essentially dry land.
The UK is not unique; it has been estimated that in many European countries 50-60% of wetland habitats have been lost in the early-mid 20th century (Dugan 1990) through pressures of land drainage, flood defence, abstraction and pollution.

Land Drainage & Flood Defence

Although the large-scale drainage of UK wetlands dates back to Roman times, our recent history has seen a dramatic increase in the efficiency and extent of human intervention. The drive for land drainage was given great impetus by concerns about the UK's ability to feed its population and a drive for self-sufficiency in the post-war years. More recently the Common Agricultural Policy of the European Union has been the central force for encouraging agricultural production at the expense of other land use values.

At the same time in the urban environment drainage systems have developed to move water off impervious surfaces to the nearest watercourse as efficiently as possible with little opportunity for groundwater recharge or attenuation of pollutants.

In the UK alone 19,000 hectares of wet grassland have been drained (RSPB *et al* 1997) while in low-lying Eastern England as much as 7000km^2 have been lost (Williams 1990). The loss of habitat extent and quality has led to the decline of bird species such as snipe (now confined to nature reserves in England) and lapwing (48% decline in the 1990's).

The long history of policies that treat rainwater as a problem to be moved off land, into rivers and out to sea as quickly as possible have not just had a devastating impact on wildlife. The wholesale straightening and deepening of river channels and the construction of flood banks has led to the disconnection of rivers from their floodplains reducing catchment storage, increasing downstream flood risk and reducing groundwater recharge.

The legacy of land drainage and flood defence policies have compromised the natural regulating function of wetland ecosystems at a time when the threat of global climate change promises greater flood frequency and more frequent periods of drought.

> *"……the most immediate source of increased flood risk from flood and erosion arose, not from environmental or climate change, but from a heritage of hard engineered defence structures……"*
>
> (Agriculture Select Committee Report into Flood and Coastal Defence, 1998)

Abstraction

Despite strict regulatory controls in England and Wales the level of abstraction has risen significantly since the 1960's. In its water resource strategy the Environment Agency (2001) has reported that abstraction from many river basins and aquifers in England & Wales is already at, or beyond sustainable levels. This is not only putting enormous pressure on wetland habitats but also risking the saline intrusion in some of our major aquifers where groundwater levels have been at, or below, sea level for a number of years.

In England alone 26 of our most important wetland sites designated as Sites of Special Scientific Importance (SSSI) are known to be adversely impacted by abstraction with a further 286 currently undergoing evaluation or monitoring (EN & EA 1999). These figures represent only a small part of the picture with many undesignated wetlands already lost or under threat. Damage is not restricted to drought years but reflect an ongoing problem that must be addressed.

Pollution

Probably the most widespread threat to groundwater quality in the UK is diffuse pollution from intensive of agriculture, a process that is synonymous with a dramatic increase in nutrient and pesticide inputs and an equally dramatic loss of biodiversity.

For example local Wildlife Trusts are typically reporting a 90% loss of species rich unimproved grasslands to fertiliser and pesticide application and arable conversion in the past 20 years. The leaching of nutrients from agricultural sources is a major factor in the eutrophication of inland and coastal waters, disturbing the fragile balance of natural ecosystems and encouraging algal blooms that reduce dissolved oxygen concentrations, smothering fish and invertebrate life.

Nitrate pollution is also a major problem for water companies who are required to spend £16 million achieving drinking water standards (Petty *et al* 2000). This cost is of course passed onto the consumer. However the costs of nitrate removal pale into insignificance when compared to the problem of pesticide contamination. In England and Wales water companies have invested £1 billion over the past 10 years in pesticide removal technology with operating costs currently running at £100 million per year (Water UK, 2001).

The impacts of pesticides are equally dramatic on wildlife. In 1998 up to 1200km of rivers in upland Wales were contaminated by sheep dip (EA 1999) just one type of pesticide that has devastating effects on invertebrate communities.

THE FUTURE FOR UK WETLANDS – DRIVERS FOR REFORM

The decline in European and UK wetland biodiversity has been encouraged by a fragmented institutional, economic and regulatory framework that evolved in response to very different social imperatives to those that operate today. These systems have been slow to respond to growing public concern about the state of the natural environment, the threat of global climate change and growing evidence that the current system is failing both people and wildlife.

However opportunities for change do exist, the UK Biodiversity Action Planning process (BAP) has given conservation groups, local authorities and government departments a framework for habitat creation. Action recently reinforced by the CROW Act (2000) which requires all government departments and statutory agencies to further the achievement of BAP targets when carrying out their functions.

There is also evidence that government is waking up to the new challenges it faces. In its recent rural white paper (DETR 2000a) the government laid out its vision for the future of the rural economy, a vision that included:

> *"....payments for environmental "goods" that the nation wants – flourishing wildlife, living landscapes, a protected heritage and opportunities for leisure."* [Chapter 8] and
>
> *"More sustainable water management and an approach which safeguards environmental capital"* [Chapter 10]

Details of just how the Government intends to deliver these commitments remain sketchy but to date the process of change appears to have been driven by circumstance rather than any coherent vision. For example Catchment Abstraction Management Strategies (CAMS) were developed in response to the 1995 drought when the Government directed the Environment Agency to develop a publicly accountable, transparent methodology for water resource management on a catchment scale.

At the other hydrological extreme the catastrophic floods of winter 2000/2001 prompted DEFRA[3] and the Environment Agency to develop Catchment Flood Management Plans (CFMPs) as a means of identifying "sustainable" flood risk management options at a catchment scale.

While The Wildlife Trusts and other conservation bodies welcome these initiatives and their attempts to protect and enhance biodiversity, they represent a piecemeal approach to reform operating within, and restricted by, existing regulatory and funding regimes.

Such measures are likely to be eclipsed by the requirements of the Water Framework Directive (WFD). The WFD is arguably the single most important piece of European environmental legislation enshrining the concept of holistic water resource management on a river basin scale.

Under the directive member states are required to prevent the deterioration of water bodies (including groundwater bodies) while "aiming to achieve good status" by the year 2015. For groundwater the definition of "good status" includes the balancing abstraction with recharge while protecting/restoring dependent river and wetland ecosystems, preventing or reversing any sustained upward trend in pollutants and preventing saline intrusion.

The reforms required to meet these obligations will have impacts that extend far beyond river corridors or even national borders, touching all aspects of land use management.

ACTIONS FOR CHANGE - THE WILDLIFE TRUSTS PERSPECTIVE

If the UK is to secure the future of its wetlands and maximise their economic and social value we must act now to reform outmoded legislation, policies and practices. The Wildlife Trusts will be working alongside other conservation groups to ensure the Government implements not only the letter but also the spirit of holistic river basin management enshrined in the Water Framework Directive. Our priorities for action include:

- Ensuring the CAMS process establishes the water resource needs for internationally important sites (SAC/SPA/Ramsar) and SSSIs and the water resources required to meet BAP wetland restoration and creation targets.
- Giving water resource planners the power to reduce the risk posed to wetlands by unsustainable abstraction[4] in the face of historic over-allocation and climate uncertainty by:

[3] The Department of Environment, Food and Rural Affairs is the body that subsumed elements of the Department of Environment Transport & Regions (DETR) and the Ministry of Agriculture Fisheries and Foods (MAFF) in recent government re-organisation.

[4] Although the Environment Agency has powers to compulsorily vary or revoke abstraction licences (Water Resources Act, 1991 s52) the requirement to pay compensation appears to have discouraged any action being taken. The Government proposed to tackle this problem by bringing forward legislation would remove

- Revoking/varying licences that are damaging wetlands or preventing them from meeting conservation objectives.
- Converting licences granted in perpetuity to time-limited status, thus giving greater flexibility in the face of uncertainty over climate change and environmental impacts.
- Regulating proposed markets in abstraction rights to prevent increased uptake of under-utilised (sleeper) licences while encouraging trading for environmental protection.

- Revising the economic regulation of the privatised water industry to create incentives for taking a long-term vision to sustainability. Key to this will be freeing up the industry to invest in the restoration/creation of large-scale wetlands.
- Funding research and pilot studies schemes to establish the benefits of floodplain and wetland restoration.
- Reducing run-off from urban development by using a range of techniques commonly referred to as Sustainable Drainage systems (SuDs). SuDs can play a valuable role in creating wetland habitats in an urban setting, encouraging infiltration, breaking down or trapping pollutants and reducing flood risk.
- Ensuring the strategic planning of flood defence through CFMPs identifies all opportunities for flood risk management. In particular wetland creation and managed re-alignment through the abandonment or removal of flood defences should be given a high priority as a potentially cost-effective method of providing flood storage.
- Reforming agricultural policy to reflect the new economic realities of farming and the wider rural economy. Policies should be tested for cross compliance with wider objectives of biodiversity planning and the UK's obligations under the Water Framework Directive.

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compensation payments for damaging abstractions (DETR, 1998). Despite these measures making the draft Water Bill (DETR 2000b) the process of translating this to statute appears to have stalled.

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PRACTICAL IMPLEMENTATION OF GROUNDWATER PROTECTION POLICY - DEVELOPMENT OF SUPPORTING TOOLS IN ENGLAND & WALES

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INTRODUCTION

The Environment Agency and its predecessor the National Rivers Authority developed a series of tools in the 1990s to support the implementation of the "Policy and Practice for the Protection of Groundwater" (PPPG) in England & Wales (Environment Agency, 1998). These tools enable the policies contained in the PPPG to be put in to practice by ensuring that there is a consistent and practical framework for groundwater protection.

The tools include 53 groundwater vulnerability maps at a scale of 1:100 000 and modelled groundwater source protection zones (SPZs) for nearly 2000 groundwater abstractions. The successful adoption of these tools within England and Wales has led to further developments including procedures and generic modelling packages to assist with the assessment of applications for permits to discharge, landfills and other disposal operations, and for the assessment of the potential impact of contaminated land on groundwater. This suite of decision support tools, which is readily available, has enabled the PPPG to be implemented in an increasingly effective manner within the areas of development planning, management and remediation of contaminated land and regulation of potentially polluting activities.

The original driver behind the development of the PPPG was a requirement to introduce a common policy on groundwater protection that addressed the requirements of environmental legislation and protection. It also enabled the regulator at that time (the NRA) to influence other agencies involved in the control of pollution, in the absence of a comprehensive legislative framework for the protection of groundwater. Since the publication of the second edition of the PPPG in 1998, extensive further groundwater protection legislation has been introduced and sweeping changes in our approach to groundwater management and protection are resulting from, for example, implementation of the Groundwater Regulations, and the Part IIA Contaminated Land and Integrated Pollution, Prevention and Control (IPPC) regimes. Further extensive changes will also arise from the transposition of the Water Framework Directive into UK law over the next few years. This will drive continued development of decision support tools. New data sets and ways of combining these with existing information will be needed, together with clear guidelines on the use of these tools.

This paper outlines some of the existing tools and their purpose with a particular focus on their scope. It also considers the drivers that underlie the need for change and identifies the direction the Agency is taking for the development of new and improved tools.

PROVISION OF TOOLS

The range of tools currently available to support the PPPG is shown in Table 1 in relation to land use planning and the risk assessment framework adopted by the Agency (DETR, 2000). The **groundwater vulnerability (GWV) maps** and **source protection zones (SPZ)**, are described in detail in the PPPG, having been developed in parallel with it (Environment Agency, 1998). The other tools have been subsequently developed to address more specific groundwater protection needs. These needs have emerged as priorities in recent years as new legislation has emerged and/or concerns over the impacts of certain activities has required more detailed attention. As a result, the Remedial Targets Methodology for soils and groundwater (RTM) (Environment Agency, 1999a), and the software packages LandSim (Environment Agency, 2001a) and ConSim (Environment Agency 1999b) have been developed, with accompanying guidance.

For the tools to be effective and have widespread adoption, they need to be readily available, relatively easy to use (taking into consideration the complexity of the problem being addressed) and, where necessary, are provided with adequate support. The Environment Agency has widely promoted the tools developed and made them readily available through a range of outlets. The PPPG and the GWV maps were first published, on behalf of the Agency, by the Stationery Office in paper format. Subsequent data digitisation enabled the GWV maps to be packaged in digital format for use in GIS.

Source Protection Zones have only recently been made widely available. Previously only available for inspection by visiting Agency Offices, they are now published on the Agency's web site (www.environment-agency.gov.uk). This enables users to view the SPZs in relation to other geographic information and download the data set for use in the users own GIS free-of-charge. A simple registration procedure will enable users to be notified in the future of any updates.

The **Methodology for the derivation of Remedial Targets (RTM)** provides a framework for deriving targets for remediation of contaminated land sites or assessing the potential impacts of activities, spillages or incidents on groundwater. The methodology is supported by detailed guidance and a MS Excel97 spreadsheet that enables site specific remedial objectives to be derived for contaminated sites. This is a product of the Agency's R&D Programme with the spreadsheet available for download from the Agency's web site. The methodology adopts a tiered, risk based approach that tailors the degree of effort and resources in assessing and managing risks to the seriousness of the potential consequences of the pollution. It is applicable for all substances and takes account of not only the particular approach to contaminated land assessment in the UK but also existing water quality standards and other statutory UK requirements.

LandSim and **ConSim** extend the capability of the site specific assessment tools by utilising probabilisitic methodologies developed for assessing the risks posed to groundwater and other receptors by the leaching of contaminants from landfills (LandSim) and other potential sources, e.g. contaminated land (ConSim). The outputs are is thus in the form of probabilistic plots that can be used in performing tiered assessments under the RTM. Both LandSim and ConSim have been developed in collaboration with an industry partner to provide robust, user-friendly methodologies that are readily available with dedicated support and training.

One of the key drivers for the development and use of these latter procedures has been the need for consistent and auditable approaches. Although many decision support tools such as spreadsheets, models etc. are commercially available or are derived for site-specific purposes, they can be difficult to audit on a case-specific basis and are not necessarily fit-for-purpose as far as the UK regulatory environment is concerned. Developing, testing and making standardised tools widely available facilitates the regulatory assessment process. Whilst the

Agency does not rule out the use of alternative decision-support tools, it needs to be satisfied that these have been adequately tested and benchmarked, that the results can be readily audited, and that the model approach is consistent with UK legislative requirements. Guidance on the interrogation of risk assessment models and robust problem formulation and simulation has also been prepared to support the appropriate application of these models (Environment Agency, 2001b, 2001c).

APPLICATION OF TOOLS WITHIN THE CONTEXT OF PLANNING AND RISK ASSESSMENT FRAMEWORKS

The development of the GWV maps and SPZ alongside the PPPG presented a simple risk-based approach for the protection of groundwater, with the objective of influencing, within a land-use planning context, the location of potentially polluting activities. The tools enabled the risk to groundwater, as a whole, to be considered (via GWV maps) as well as the risks to a number of specific groundwater sources - principally public water supplies (via SPZ maps). In combination, the tools and the PPPG provide a clear indication to planners, developers and operators etc. of the likely risks to groundwater and the Agency's response to prospective developments or activities.

With an increasing understanding of risk and its broader acceptance within the environmental protection and decision-making process, the Agency in conjunction with the UK Government's Department for the Environment, Transport and Regions (now DEFRA) produced a risk assessment framework (DETR *et al*, 2000). The tiered approach provides a logical process for risk assessment and management by allowing information optimised and priority-based assessment of risks.

At each tier, an increasing level of information is needed. This requires both data provision at the required scale and accuracy and tools for the assimilation and analysis of these data to enable the necessary risk assessment and inform decision making. Although the map based tools fit into this framework, it is primarily at the initial risk screening (first) tier, and additional tools are needed to support the second and third tiers of the risk assessment framework. The more specific tools – RTM, ConSim and LandSim – extend the capability, having been developed to address risk assessment needs at a site-specific scale. The resulting outcome is that a suite of tools is now available to deliver regulation and environmental protection.

Each of the tools developed for the protection of groundwater, and outlined above, has a specific purpose within the framework of decision-making and risk assessment. Each is designed to be complimentary to the others and applied at a different spatial scale to inform decision making at the required level of detail. Within the risk assessment framework, the tools are linked and enable the appropriate risk assessment procedures to be adopted, whether that be regime-specific, e.g. to control discharges and disposals, or more generic.

However, there is the danger that, in using the available tools in a variety of circumstances, the underlying assumptions made during their development are overlooked; their application may not be "fit-for-purpose".

GWV maps and SPZ maps should only be regarded as risk screening tools. They have been developed at a scale that can only provide an initial indication of the risks of pollution if a pollution source were present (Figure 1). Because of the scale of mapping and the precision of the data used in their generation, they cannot be used for detailed site-specific assessment. They must therefore be restricted to application in risk screening activities providing an indication of the risks to groundwater and the need for potentially greater protection in some areas than in others. This filtering mechanism can lead to considerable improvements and efficiencies in dealing with environmental (groundwater) issues within land use planning. Additionally the maps are extremely useful in enabling the prioritisation and guiding pollution prevention activities and the need for more detailed risk assessment.

As the process of decision making transfers to more site-specific assessments the methods become more process-based and data intensive. At the site-specific level detailed knowledge of local hydrogeology, characteristics of the contaminant source term and behaviour of the contaminant(s) in the sub-surface are needed. The level of detail required is beyond that which is, and can be, incorporated in the risk screening tools. However, although the assessments made are in more detail there is also the potential for considerable uncertainty to remain. At any stage of assessment, certain assumptions are made and here, the uncertainties may relate to lack of detailed knowledge of contaminant behaviour or inadequate site investigation data to parameterise the models used or support the assumptions made by the models. It is therefore essential that application of the tools is supported by high quality data and a good conceptual model of the scenario being modelled is available. Selection of the appropriate tool(s) is also important at the site-specific level to ensure that the objectives of the assessment are met and the necessary outcomes achieved.

FUTURE DEVELOPMENT OF TOOLS

The tools have been developed to support a range of legislation and groundwater protection initiatives in a practical and easy-to-use format. As a result, they may not include some of the more complex processes or factors due to the absence of an adequate level of information or knowledge. This has meant that the tools may not necessarily represent 'state-of-the-art' but instead, 'state-of-practice' at the time of their release. For example, although it is recognised that the thickness of the unsaturated zone is an important factor in groundwater vulnerability assessment, insufficient data at the time when the GWV maps were first produced meant that it had to be omitted.

However, as information technology, professional experience and knowledge advance, what was once 'state-of-the-art' becomes 'state-of-practice' and so the tools should be refined to take advantage of these advancements. In terms of the map-based tools (GWV and SPZ maps), increased use of Geographic Information Systems (GIS) has meant that information can be more readily updated, assimilated and analysed. The versatility of GIS enables better visualisation of data and customised products to be produced. This has been demonstrated through the application of the GWV maps, along with other data, to produce pollutant specific risk maps (e.g. Evers *et al*, 2001). The approach used involved combining process-based simulation models with the vulnerability maps to identify groundwater at risk from agriculturally derived nitrates and pesticides (Figure 2). By undertaking these developments further needs and opportunities are identified and can be developed.

The use of GIS will also enable the various layers, that were by necessity combined on paper maps, to be presented individually or in combination in order that activity-specific vulnerability maps can be generated, e.g. where an activity results in the soil layer being removed or deep excavations are envisaged. Combinations of layers and additional information, including land use data, natural baseline hydrochemistry and geochemical properties will further improve the ability of the catchment scale tools and provide a better constrained framework for the site specific tools.

Other new developments will be needed to address the requirements of the Water Framework Directive. The move towards an integrated water policy will require groundwater quality and resources to be addressed simultaneously along with their links to other aquatic media and associated ecosystems. A requirement of the Water Framework Directive is to undertake characterisation of groundwater bodies. This will require the development of conceptual models for each groundwater body and the identification of the degree to which they are at risk. It is anticipated further enhancements to the existing map-based tools will be needed including the incorporation of additional factors, such as hydrogeological behaviour in terms of water balances, and interactions between groundwater and surface waters, stratification characteristics and recharge estimates. It is likely, for example, that the current aquifer system used in the GWV maps – major, minor and non-aquifer – will need to be revised to ensure that these factors are incorporated. The existing classification is principally focussed on the significance of aquifers as water supply resources and does not necessarily emphasise the significant role that groundwater plays in maintaining baseflow to rivers and associated ecosystems. The Agency is currently considering how our new needs can be incorporated within a new suite of tools.

The outputs from research work commissioned by the Agency and others will also need to be incorporated into the tools to improve their predictive capabilities and

Further refinement and development of the modelling tools, such as ConSim also continues. A second release of LandSim has recently taken place and it is proposed to develop the functionality of ConSim Version 2 to allow more robust assessment of the risks from soakaway discharges and land-spreading, and to facilitate the assessment of parameter sensitivity in the model.

CONCLUSIONS

The Environment Agency has developed a suite of tools that can be applied at a range of scales to address multi-functional issues. By being both complementary to the risk assessment framework adopted in England and Wales and to each other the tools are being widely applied. They enable consistent and cost-effective decision making by enabling Environment Agency policies to be put into practice at a range of scales. When applied properly within the risk assessment and planning process, groundwater protection issues will be adequately addressed and the necessary priorities met.

Widespread adoption of the tools is being achieved and this is leading to consistent and better-informed decision making. Additionally, as experience has been gained through the application of the tools further opportunities for development have been identified and the understanding of groundwater protection issues enhanced.

Recently, the decision-support tools described in this paper have been used during the Foot and Mouth epidemic for disposal site selection and risk assessment. Without an existing suite of procedures, both the Environment Agency and others would have been placed in a much more difficult situation in terms of the resources and timescales needed for site assessment, with the potential for increased risk of environmental damage arising from the carcass disposal operations.

Although this pragmatic approach has been applied in England & Wales it will have to be re-assessed within the context of the Water Framework Directive, other initiatives and scientific and technological developments. This will enable us to continue to have an evolving, workable and reasonable approach to groundwater protection in England & Wales in future years.

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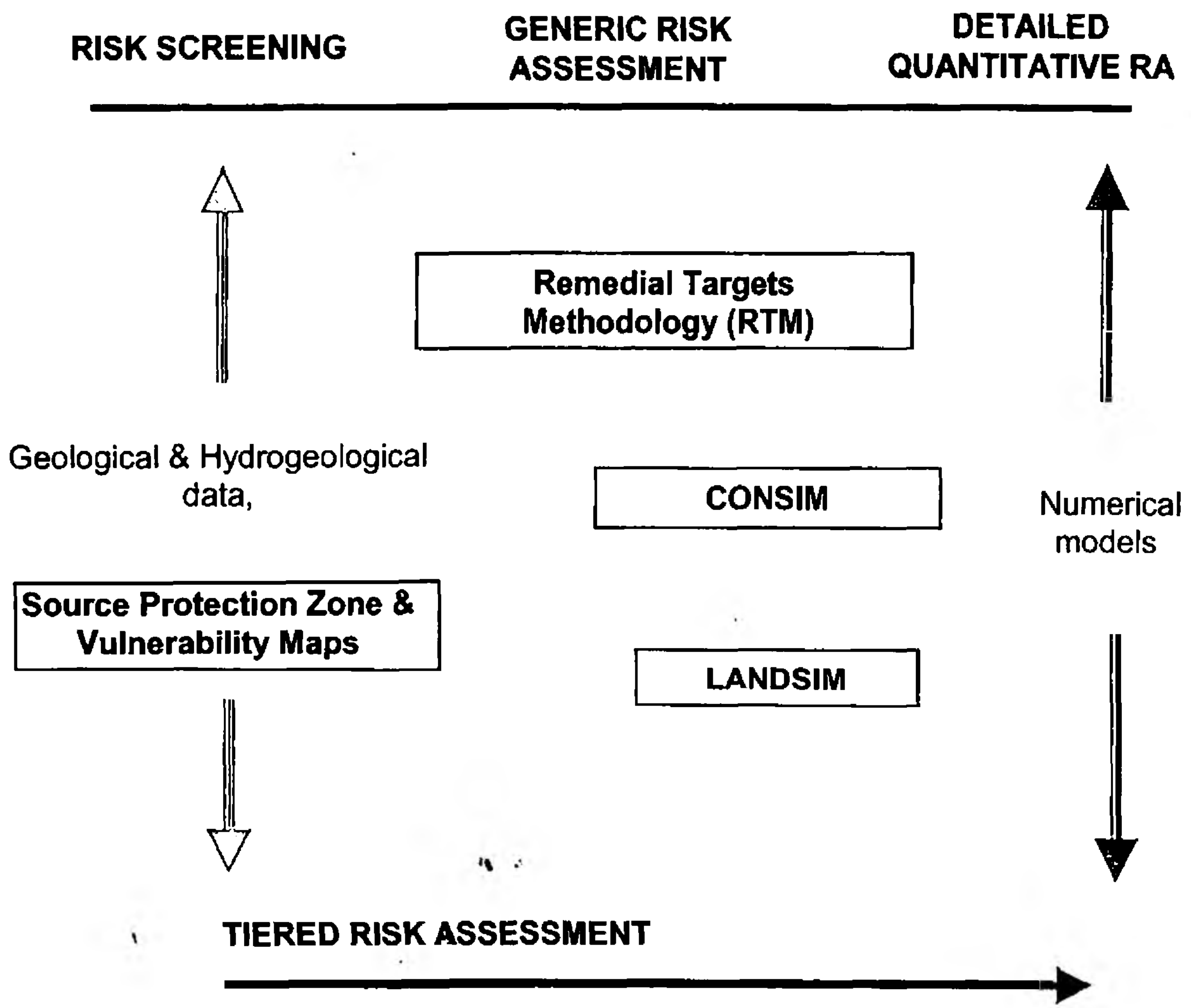
DEVELOPMENT PLAN FRAMEWORK	AGENCY POLICY AND TOOLS	RISK ASSESSMENT TIERS	EXAMPLES OF DEVELOPMENT AND ACTIVITIES WITH POTENTIAL FOR IMPACT ON GROUNDWATER
Structure Plans Unitary Development Plans Local Plans Metropolitan Borough Council Plans Welsh District Council Plans Minerals Local Plans Waste Local Plans	"Policy and Practice for the Protection of Groundwater" (PPPG) (1998). + **Groundwater vulnerability maps (GVM)** + **Source Protection Zone (SPZ) maps.**	Risk Screening TIER 1	• Landfill sites & other waste management activities. • Industrial development, especially involving chemicals. • Discharge of septic tank, treated sewage effluent or surface water to soakaways (private) and, sewage works, foul sewers and storm overflows (utilities). • Spreading of sheep dip and other agricultural wastes • Graveyards and animal burial sites. • Kennels, catteries, stables etc. • Oil and petroleum storage and transport via pipelines. • Mineral workings, oil & gas exploration and land restoration. • Major infrastructure developments. • Timber treatment plants. • Development of potentially contaminated sites.
Pre-planning assessments e.g. scoping opinions	As above + Environmental Impact Assessment (EIA) Scoping Guidance	Generic Quantitative TIER 2	
Planning applications and Operating Environmental Permits/Authorisations.	As above, but with site-specific data and assessment with analytical tools, e.g. **Remedial Targets Methodology (RTM), ConSim, LandSim**	Detailed Quantitative TIER 3	

Table 1. Assessment tools within land use planning framework

Figure 1. Assessment tools within risk assessment framework.



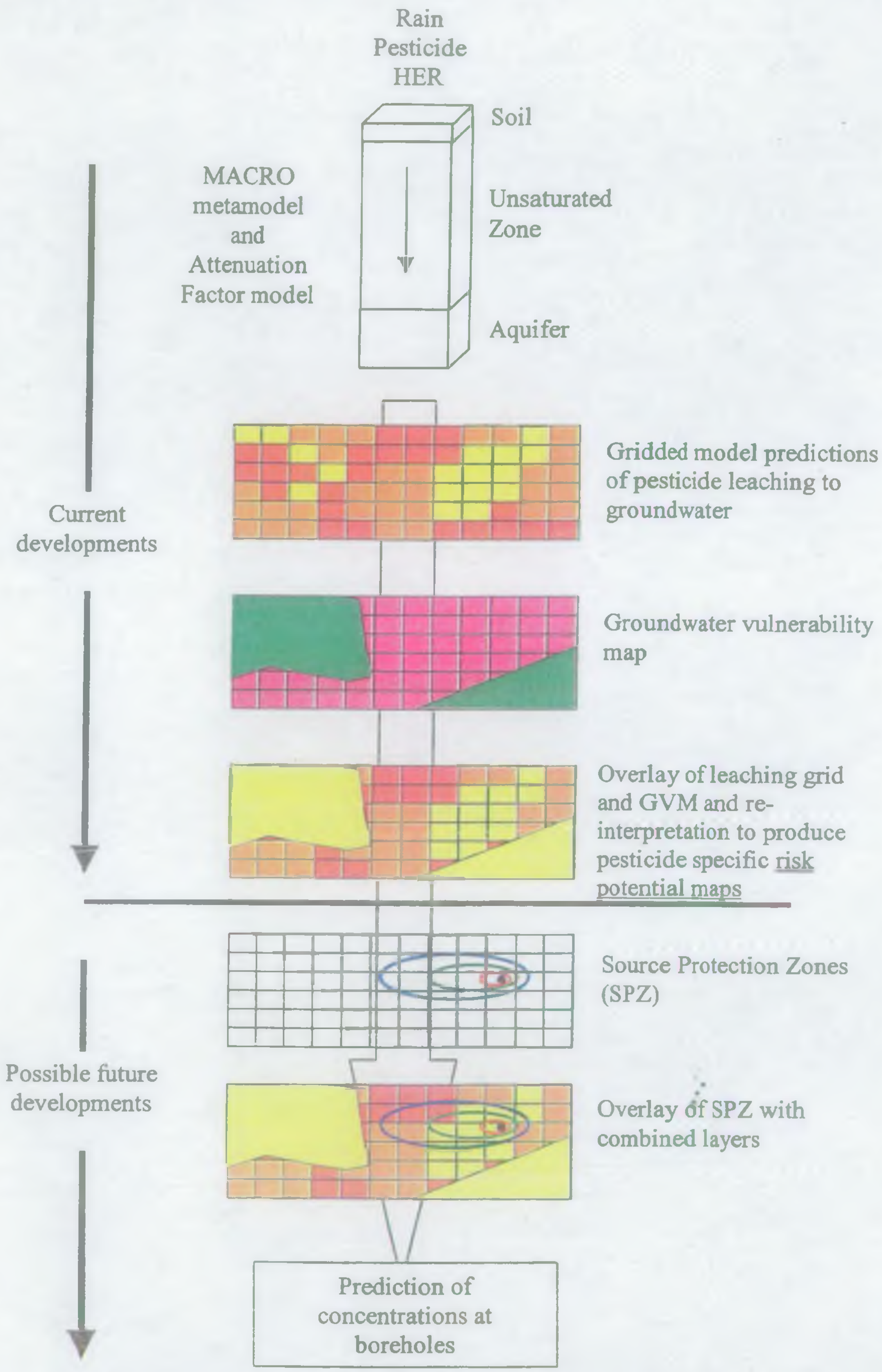


Figure 2 **Overview of the methodology for prediction of pesticide pollution of groundwater.**

Table 1 Current estimate of groundwater usage (based on various national statistics and other data)

	% groundwater in public supply	Approximate total groundwater use per capita (l d^{-1})*	Volume of groundwater in public supply – all uses (Ml d^{-1})	Volume of groundwater in private supply – all uses (Ml d^{-1})
England	33	50	6500	500
Wales	8	12	250	95
Scotland	5	7	150	134
Northern Ireland	8	12	77	31

*Based on average per capita consumption of 150 l d^{-1}.

Meanwhile Scotland and Northern Ireland had given little attention to either resource evaluation or resource protection, a situation both are earnestly trying to rectify. Historically they have suffered source derogation by pollution and paid dearly as a consequence. For example, the adit supply from the Sherwood Sandstone Group for the Newtownards area of County Down had been abandoned in 1963 when the source was found to be contaminated by gas works waste tipped into nearby quarries. The supply had previously provided a gravity flow of 36 l s^{-1} from 1.6 km of tunnels to the Ballycullen water treatment works. There is a similar example in Scotland, where one of the earliest public water supplies, the spring sources from the volcanic Pentland Hills above Edinburgh, has been abandoned in favour of upland surface water impoundment due to increasing nitrate concentrations in the springs.

It is surprising that even in recent years there have been few initiatives to protect water supplies from sensitive water using industries such as the distillers and water bottlers. Many of the distillers show remarkable ignorance about their 'lifeblood' water supplies and have made little effort to safeguard them from pollution. In the 1980s, however, one company, the Highland Spring water bottlers at Blackford in Perthshire, bought large tracts of moorland above their supply wellfield in order to control land use.

Wales has had a more positive approach to groundwater protection. Falling under the same administrative umbrella as England, problems such as contaminated land, diffuse agricultural pollution and even acid rain have long been recognised. Today a number of issues are common to Wales, Scotland and Northern Ireland who share the problems of dealing with small compartmentalised aquifers, often fractured, and weakly permeable rocks in hilly terrain, and with pollution issues such as sheep dip disposal, fish farm effluent disposal and woodland drainage.

MANAGEMENT EVOLUTION IN ENGLAND

During the 1970s major concern had arisen over diffuse pollution of groundwater by agricultural fertilisers (Young *et al.* 1976). By 1980 there was a growing awareness of the need to deal with groundwater pollution in general, although the concept of groundwater protection was still to be defined. Wilkinson and Gray (1981) reported:

Groundwater in the UK is generally of good quality. However, in recent years, an increasing number of cases of deterioration in quality have been reported. There are many reasons for this decline, but common causes are badly located domestic and industrial waste disposal sites, certain modern agricultural practices and overpumping of resources. Growing awareness of these problems has led to an increasing number of field investigations . . . into both natural and man-made changes that occur in the quality of groundwater. Attention has particularly focused on man's activities that have caused or are likely to cause pollution and on ways in which these can be controlled.

These concerns were not limited to England but were Europe-wide. In 1983 a review of aquifer vulnerability was commissioned by the European Community and the British response remains as an unpublished open-file report with eight accompanying manuscript maps at a scale of 1: 500 000 (Monkhouse 1983). The methodology defines land zones according to the length of time (1 week, 1 year, 20 years, greater than 20 years) taken for infiltrating rainwater to reach the saturated aquifer.

The concept of land zonation according to perceived aquifer vulnerability was taken one stage further during 1986 by the development of nitrate vulnerability maps at a scale of 1: 100 000. These were developed for the Severn Trent Water Authority collaboratively by the British Geological Survey and the Soil Survey and Land Research Centre. The zonation was based on classifying soils according to leaching potential defined by soil texture, porosity and soil water regime and combining them with three geological classifications based on type of drift cover to provide a total of four categories of risk (Robins *et al.* 1994).

Whilst methodology for assessing risk to the aquifer from diffuse pollution was developing, consideration was also being given to the delineation of source capture zones in which land use activity could be controlled. Adams and Foster (1992) described source protection zones as a special additional element of protection for selected groundwater sources based on horizontal flow time and distance from the source. The respective aquifer protection policy statements from the various Water Authorities each defined the zones in slightly different ways. An inner protection zone around a source was based on a travel time of between 50 days and 400 days and designed to safeguard the source from receiving live pathogens. An outer protection zone was generally set at a travel time of 400 days (a metric year) and not less than 25 % of the total resource capture zone. The capture zone was defined as the outer limit of capture for a given source (the limit to which all aquifer recharge will be captured by the source).

The formation of the National Rivers Authority in 1989 paved the way for the rationalisation of groundwater protection procedures and for a standardised protocol to be devised. This was duly published as policy for England and Wales (NRA 1992) and has since become the foundation for current policy and practice in all parts of the United Kingdom.

There remain a number of technical areas which are inadequately understood and which inhibit the value of these policies. They include:

- A lack of understanding of recharge mechanisms and quantities, particularly the role of weakly permeable drift;
- A lack of understanding of groundwater flow processes and inability to determine accurate travel times;
- The lack of interconnection between source protection and resource vulnerability.

Other specific issues that are not adequately accounted for by present policies include the role of secondary permeability and of karstic flow behaviour in vulnerability and source protection –important considerations, for example, in evaluating risk from *Cryptosporidium*.

LEGAL, HYDROGEOLOGICAL AND SOCIAL DIFFERENCES

There are three significant groups of differences between the administrative regions of the United Kingdom. They are legal, hydrogeological and social, and all are reflected, to a greater or lesser degree, in the respective policies that have been adopted.

Legislative differences are important. Although England and Wales are considered as one from a legal standpoint, Scotland and Northern Ireland are subject to their own Laws and Statutes. The most significant difference is that neither Scotland nor Northern Ireland yet issue abstraction licences, and as a consequence few data are available regarding groundwater exploitation. This will change, as the Water Framework Directive requires abstraction monitoring, a task which can only feasibly be undertaken through a licensing process. One feature unique to Scotland is the Water Order, an instrument designed to protect public supply sources derived from surface water from derogation, but is also used for some groundwater sources.

One of the important local emphases is the need for compatible approaches where aquifers cross national borders in Ireland, and it is important that policy development by the Environment Protection Agency, Wexford and by Environment & Heritage Service, Belfast can work in tandem. Groundwater protection policy in the Republic of Ireland has two fundamental differences to that in Northern Ireland. The first is that given most point pollution sources are situated beneath the soil zone (e.g. septic tank overflows and soakaways) the influence of the soil zone on groundwater protection is disregarded. The second is that the resource protection scheme (land zonation) sits within the source protection scheme by means of an integrating matrix (DELG 1999). Additionally, potentially polluting activities are evaluated as *Protection Responses* according to risk and degree of acceptability. The Protection Responses for different vulnerability zones indicate the acceptability of activity with regard to the potential hazard and outline the design and construction as well as investigation requirements of, for example, landfill sites, septic tanks or landspreading of organic wastes.

Northern Ireland, of similar size to the county of Yorkshire, contains the most compact and diverse range of solid and drift geology and soil types anywhere in Europe. This diversity means that no single groundwater body is extensive in area or regionally important. This same diversity is continued across into the Midland Valley of Scotland, and extensive tracts of Lower Palaeozoic and Precambrian strata form the Highlands to the north and the Southern Uplands south to the border with England. Wales also offers diversity with a central core of basement rocks flanked by younger strata. None of these regions offer regionally important aquifers. The most productive are the Permo-Triassic aquifers south west of Belfast and towards Newtownards in County Down, the Permian aquifers of Dumfriesshire in southern Scotland, the Devonian of the Eden Valley in Fife, and the Permian in the Vale of Clwyd in North Wales.

The regionally significant aquifers in England, Chalk, Permo-Triassic and Jurassic Limestone, are of quite a different magnitude to the main aquifers elsewhere. Even the only locally significant aquifers such as the Carboniferous Limestone are distributed over a much larger scale in England than in Scotland, Northern Ireland and Wales. The key difference is, therefore, that groundwater flow regimes tend to be larger in area and flow paths may be deeper than in the small aquifer units in Scotland, Northern Ireland and Wales. In addition, groundwater resources available in superficial deposits, including glacial outwash features and valley alluvium, offer valuable potential in the Celtic regions but tend to be overlooked in England.

A number of perceptions have developed over time, which are now being dispelled as appropriate data are gathered. The occurrence of high nitrate concentrations was believed, largely throughout the 1980s, to be an English problem and possibly also an Irish one. Monitoring has now shown it to be very much a Scottish problem, particularly in the east. It is less of an issue in Northern Ireland even though there is intensive livestock farming, because of high rainfall and dilution, and because the field moisture capacity is maintained for much of the year promoting active denitrification within the soil zone. In addition, there is a prevailing image of the Celtic countries of green and pleasant glens and vales with springs gushing pristine waters, an image which contrasts heavily with the reality of rising minewaters and industrial wastelands of Central Scotland and South Wales.

Social differences also influence approaches to groundwater protection. Scotland has many dispersed rural and island communities, many of which are increasingly dependent on groundwater supplies, whereas Northern Ireland has a similar rural population but also has near complete reticulation of mains water. In England relatively few rural communities are dependent on small groundwater supplies while in west Wales and other parts of rural Wales many individual properties rely on their own domestic sources. Nevertheless, 70% of the population of south east England is reliant on groundwater for the mains supply.

Land use varies around the country according to topography and geology. The two extremes are possibly the flat arable cultivation of eastern England and the small upland hill farming of Wales. Forestry also has an increasing impact on the aqueous environment, and is a feature common to both Scotland and Wales.

DIFFERENCES IN POLICY AND PRACTICE

The respective policy documents issued by the Environment Agency, Scottish Environmental Protection Agency and Environment & Heritage Service in Belfast reflect individual requirements. Each is underpinned by its own set of laws and guidelines, and as a consequence the three policy documents now have their own individual flavour. Apart from the Policy Statements, which must differ according to the administration of each region, the key management tools remain the groundwater vulnerability land zonation map and the source protection zone. However, these too have evolved along different routes to satisfy different needs.

Lewis *et al.* (2000) summarise the different approaches to vulnerability mapping between Scotland and England and Wales:

- The geological formations in Scotland are classified according to permeability alone, and not also on aquifer and yield potential as in England and Wales;
- Low permeability drift aquifers are shown in Scotland (and Northern Ireland) even where they overlie aquifers;

- Where borehole evidence indicates clay beneath a gravel aquifer, any deeper bedrock aquifer is shown as protected by the clay in Scotland, whereas it would be classified vulnerable in England;
- The Scottish maps show nitrate vulnerable zones;
- The soil leaching potential classification used for England and Wales has been modified to suit Scottish soil types.

Source protection zones are now being established for Scotland and will be shortly in Northern Ireland. The protocol adopted for England and Wales will be adhered to wherever possible, but in relatively data-scarce Celtic lands less emphasis can be placed on analytical solutions. The basic premise is that the area of each source protection zone is proportional to the source abstraction rate. Methods of establishing source protection zones are (Burgess and Fletcher 1998):

- Simple application of Darcy's Law where data are scarce;
- Hydrogeological mapping where data are scarce, but the geological framework may be complex;
- Analytical and semi-analytical modelling based on standard hydraulic formulae;
- Numerical modelling typically using code such as FLOWPATH.

Choice of method depends on data availability, hydrogeological complexity and volume of abstraction. There are some 2000 public supply sources in England and Wales yielding between 500 and 10 000 m^3 d^{-1}, whereas there are only a few hundred in Scotland and Northern Ireland, many of which are springs. A risk-based approach is needed for all these important sources to provide greater quantification. Conversely, most small domestic supplies can be dealt with by application of Darcy's Law.

OVERALL FUTURE REQUIREMENTS

The Water Framework Directive influences future groundwater protection policy through the following environmental objectives:

- Implementation of measures to prevent or limit the input of pollutants into groundwater to prevent deterioration of the status of individual groundwater bodies;
- Protection, restoration and enhancement of all groundwater bodies to ensure a balance between abstraction and recharge of groundwater in order to achieve *Good Groundwater Status*, both quantity and quality, by the year 2015;
- Achieving good environmental status of rivers, i.e. baseflow;
- Implementation of measures to reverse any significant and sustained upward trend in the concentration of any pollutant resulting from the impact of human activity;
- Ensuring compliance with the standards and objectives laid down in the Directive for *Protected Areas*.

Good chemical groundwater status is defined by the electrical conductivity of the groundwater as an indication of salinity and of concentrations of recognised pollutants which should not exceed quality standards under other relevant EC legislation. In addition, the quality of groundwater baseflow must be adequate to sustain surface ecological and chemical quality such that it will not damage existing terrestrial ecosystems. Protected Areas are special protection sites designated under the EC Habitats Directive and those surface and groundwater bodies from which abstraction for human consumption exceeds 10 m^3 d^{-1} or serves more than 50 people, i.e. there is no distinction between so called major and minor aquifers.

Good physical groundwater status is a measure of the sustainability of the resource in terms of recharge, abstraction and baseflow, and the maintenance of or restoration of aquatic environment and habitats within a catchment.

Comprehensive monitoring programmes must be established by the year 2006 to ensure good groundwater status. Detailed local evaluation of aquifer vulnerability and possible reassessment of source protection zones will be required. In addition, inventories of potential pollution sources and land use zonation will be prepared. Together these will underpin a series of individual catchment management plans. Water Framework Directive compliance has definite time scales and these have considerable financial implication for upgrading water body status.

These various drivers and legislative requirements mean that:

- There will be an increasing move towards a risk-based approach to groundwater protection and source protection;
- There is a need to protect the whole of the water cycle, i.e. the impact of groundwater bodies on river ecology and on whole catchment hydrology, as well as on water supply sources;
- There is a need to monitor the transport of nitrate currently stored in the unsaturated zone and yet to arrive at source in many Nitrate Vulnerable Zones, and the consequent transport of nutrients to surface waters;
- There is also a need to evaluate the influence that climate change, in particular wetter winters, may have on current models of vulnerability and source protection.

CONCLUSIONS

Devolution is an increasingly significant influence on groundwater management in the UK, whereby Scotland, and probably also Wales, will increasingly seek management policies which better reflect their own needs and requirements. It is probable, therefore, that as time goes on the respective groundwater protection policies will diverge rather than attain uniformity. Policies in Wales may be allied more with those of Scotland and Northern Ireland, which each face similar issues, rather than to England as at present. Similarly the approach in Northern Ireland may be influenced by that taken in the Republic of Ireland so taking Northern Ireland's policy away from that of Scotland and Wales.

The Environment Agency has CAMS to assist in a holistic appraisal of catchments. This will produce a series of CAMS frameworks, which will largely fulfil the requirements of the Water Framework Directive for sustainability of quantity. Scotland and Northern Ireland cannot pursue this same policy as neither have the basic data already in place with which to make such reviews. Major data gathering campaigns of investigation and monitoring will, therefore, be necessary in order to develop appropriate catchment management plans.

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36. UK WATER INDUSTRY RESEARCH LIMITED DIFFUSE POLLUTANTS IN GROUNDWATER: ECONOMIC APPRAISAL

Paper submitted by Metcalf & Eddy Ltd, Birmingham

ABSTRACT

The study presents a methodology for a financial assessment of the environmental impacts of diffuse pollutants on groundwater. The importance of local factors and the need for site-specific controls on agricultural activities are highlighted. The issue of compensating the agricultural community for restricting the usage of nitrate and pesticides is raised.

OBJECTIVES AND METHODOLOGY

This is one of the first studies to attempt to quantify from a financial perspective the environmental impacts of diffuse pollutants on groundwater. The presence in groundwater of nitrate and pesticides has a major cost implication particularly to Water Companies and their customers.

A methodology has been developed for an economic assessment of the impacts of diffuse pollutants (nitrate and pesticides) on groundwater supplies. With appropriate information this methodology can be adopted for use in other examples where groundwater supplies are adversely affected by diffuse pollutants. It is important to recognise that a significant volume of site-specific data is necessary to undertake a rigorous cost benefit analysis. Although the analysis is primarily a financial tool, it is essential that the hydrogeological conditions are understood in order that sensible assumptions can be made in the analysis.

An economic assessment has been carried out in four case study areas based on borehole catchments for water supply sources, which are affected adversely by nitrates and/or pesticides, using information on the land use and likely nitrate and pesticide applications in each study area. The case studies were taken from sources that abstract from three major but different aquifers in the UK in order that variations in regional hydrogeological conditions could be included in the financial analysis.

The data available for the four case studies are detailed and considered appropriate for the cost benefit analysis. Five scenarios have been modelled for each case study in the cost benefit analysis:

- A baseline using the current land use and the existing water treatment measures.
- A change of land-use to organic farming with the removal of artificial fertilisers and pesticides.
- A change of land use to integrated crop management (ICM).

- The impact of additional monitoring on both the Water Companies and the Environment Agency as a result of the implementation of the EC Water Framework Directive and Nitrates Directive.

- The impact of additional monitoring and water treatment, which may be necessary if concentrations of nitrate and/or pesticides continue to rise.

To determine the sensitivity of the analysis to changes in the variables assumed, sensitivity testing was carried out to investigate the effects over the 20 year period of the analysis of variations in gross margins and in changes in water treatment costs as a result of reductions in the application of nitrate and pesticides arising from the modelled changes in agricultural practices.

It is important to recognise that the cost benefit analysis is predominantly a financial assessment of the various scenarios, comparing the gross margins of agricultural operations against the costs of water treatment. Water treatment costs are financial costs but are also used as an indication of society's minimum willingness to pay for clean drinking water. Where possible other environmental costs, such as the potential impact on groundwater-fed watercourses and on private groundwater supplies, have been included but these are generally small in relation to the direct costs. Not all environmental impacts can be costed due to a lack of environmental economics evaluation studies.

Owing to the absence of reliable information on non-agricultural inputs of pesticides and nitrate, it was not possible to include these potential sources in the cost benefit analysis for the four case studies. Non-agricultural applications may be of significance in two of the case studies.

The cost benefit analysis does not consider the environmental arguments for continuing or modifying agricultural operations to protect water quality. Because of the nature of the cost benefit analysis, the effects of subsidies and taxes are excluded as these are transfer payments hence have no net effect on society. The analysis simply identifies that there is a cost to society as a whole associated with the presence of diffuse pollutants in groundwater, which either can be borne by agriculture through reduced gross margins resulting from reductions in pesticide and nitrate applications, or by the Water Companies through water treatment. In practice, it is likely that the availability of agricultural subsidies will play an important role in determining the agricultural practices carried out and the associated nitrate and pesticides usage.

DISCUSSION AND CONCLUSIONS

Whilst much research has been undertaken to investigate the fate and behaviour of diffuse pollutants in the soil zone, there is little information on that fate and behaviour, particularly of pesticides, below the soil zone. Data on nitrate and pesticides suggests that diffuse pollution of groundwater is a medium to long-term process because of the generally slow rates of contaminant movement within the groundwater system. Elevated levels currently recorded may be the result of agricultural operations of several years previously.

The national distribution of groundwater monitoring points for pesticides in England and Wales is poor with a significant majority of the monitoring points within the River Thames catchment. Interpretation of the data nationally is considered inappropriate.

The conclusions of the cost benefit analysis are that a change from current agricultural practice to organic farming has a variable impact on gross margins depending on the cropping pattern within the borehole catchment. For two of the case studies, a change to organic farming provides significantly higher gross margins even if the costs involved with conversion to an organic system are included (Table 1). In contrast, for the other two case studies, the highest gross margins are from the current pattern of agriculture. The two areas, which show the greatest impact of a change to organic farming, have a much higher percentage of grassland within the borehole catchment. For all four case studies a change from the current agricultural operations to integrated crop management (ICM) results in lower gross margins.

Table 1. A summary of gross margins for different agricultural regimes in four case study catchment areas.

Case study	Conventional farming (£/ha)	Organic (£/ha)	ICM (£/ha)	Catchment yield (Ml/ha)
1 Triassic Sandstone	124.72	218.50	118.48	2.808
2 Lincolnshire Limestone	342.71	334.01	325.57	0.730
3 Chalk	131.35	247.72	124.79	2.086
4 Chalk	337.19	271.38	310.26	0.782

The baseline conditions for all of the case studies show that the benefits to agriculture of using nitrates and pesticides currently exceed the costs of groundwater quality monitoring and treatment. The analysis shows a variable result in respect of future water quality monitoring and treatment. For three of the case studies the costs of additional water quality monitoring in accordance with the EC Water Framework Directive exceed slightly the benefits to agriculture of maintaining current application rates of nitrate and pesticides. For these three examples, when additional water treatment that could be required as a result of increasing use of nitrate and pesticides is considered, the costs significantly exceed the agricultural benefits.

For the remaining case study, the analysis shows benefits to agriculture of the current operations even when the costs for additional water quality monitoring and treatment are considered.

From the perspective of the cost benefit analysis, it can be argued that for the case studies where there is an adverse impact on groundwater quality resulting in a net increase in costs, irrespective of changes to agricultural operations, the current use of the land for agricultural purposes cannot be justified. Encouragement should be given to modifying the land use practice to reduce the impact on groundwater, or controls should be placed on the agricultural operations, which could result in significantly reduced gross margins.

The methodology used in this assessment is helpful in costing the impacts of diffuse nitrate and pesticides contamination of groundwater. The methodology can be expanded to consider other sources, which are adversely affected by these contaminants. However, due to the site-specific characteristics of groundwater sources, it is essential that any economic assessment is not isolated from an assessment of the hydrogeological conditions pertaining to each site.

It is considered that improvements to groundwater quality potentially can be achieved by restricting the crop types grown within sensitive catchments to those that require the application of lower pesticide loads and/or those pesticides, which present a lower risk to groundwater. Further work is necessary to establish the relationship between the crop types grown and the quality of the groundwater.

The case studies showed the importance of local factors on the presence of diffuse pollutants in groundwater. It is considered that national policy measures would be too inflexible and inappropriate to address such site-specific factors. Site-specific controls on nitrate and pesticides usage, obtained through land use permits or voluntary agreements restricting the crop types grown and associated pesticide usage within sensitive areas, with compensation arrangements for loss of income could be more appropriate ways of addressing the problem.

This paper is a summary of the report: *Diffuse Pollutants in Groundwater: Economic Appraisal*, UK Water Industry Research Limited (2001). The project was funded by UKWIR and carried out by Metcalf & Eddy Ltd in conjunction with Reading Agricultural Consultants and Economics for the Environment Consultancy Ltd, under the guidance of Thames Water Utilities.

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37. BENCHMARKING GROUNDWATER RISK ASSESSMENT MODELLING TOOLS

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ABSTRACT

A wide range of modelling tools is available in the UK for application to groundwater risk assessments. The models are based on various conceptual models and mathematical assumptions. Many have been developed within the framework of national legislation and policy of other countries, such that their approach may not be appropriate in the UK. In a project commissioned by the Environment Agency, a methodology for benchmarking groundwater risk assessment models for UK applications was developed, together with four case studies to test software functionality. Four frequently-used tools were investigated. A focus for the benchmarking exercise was the risk assessment framework of the Remedial Targets Methodology (R&D Publication 20, Environment Agency 1999a). The report produced by the benchmarking project provides guidance to Agency on points to consider when reviewing risk assessments undertaken with the four modelling tools. It also provides a framework for comparison of other risk assessment tools used in the UK. Many of the findings of the benchmarking are relevant to predictive modelling of groundwater contaminant transport, and the findings highlight the range of distinct theoretical representations of simple processes that are adopted in different tools.

INTRODUCTION

Models are increasingly being used as a tool to aid decision-making in the assessment and remediation of contaminated land, as well as the protection of water resources. When based on thorough site investigation and sound conceptual models, they are able to provide quantification of groundwater flow and contaminant transport characteristics and predict contaminant concentrations at points within an aquifer system. This contaminant transport simulation may subsequently be used to help assess the likely exposure of humans or other receptors to the contaminants, or may simply be used to assess the likelihood of pollution of controlled waters. The assessment of risk may relate to an existing or potential source of contamination.

Many software tools exist for aspects of risk assessment; this paper focuses on models developed for assessing impacts on groundwater quality. The modelling tools vary in complexity: from simple screening tools to complex 2D/3D spatially distributed models. As well as using different solution techniques, they differ in the underlying conceptual models and intrinsic assumptions. These assumptions are important to all stages of risk assessment: data acquisition, model design, analysis approach and interpretation of results. Therefore, a clear understanding of the underlying conceptual models and assumptions is vital for appropriate selection and application of the software tools (Environment Agency, 2001a).

In the area of groundwater protection, the modelling approach has typically focused on advective transport processes, for example applying particle-tracking in the delineation of source protection zones. This type of analysis gives an indication of unretarded travel times and directions of transport. Contaminant transport models may be used to additionally simulate the effects of attenuation of pollutants along the transport pathway. Such models typically incorporate representations of dispersion, sorption and degradation.

Since it is practically impossible to characterise the subsurface sufficiently to make precise predictions, there is inevitably uncertainty in the magnitude of processes occurring, representative parameter values, and even conceptual models. Many of the recently developed modelling tools incorporate probabilistic approaches for dealing with uncertainty. Probabilistic approaches provide a rational alternative to the 'worst case scenario' as a basis for decision-making. Being the combination of many unlikely values, particularly when conservative ranges of uncertainty are used, the latter may represent an extremely unlikely scenario. Decisions based on the outcome of this scenario may be unnecessarily cautious (and consequently restrictive or costly), or unduly optimistic (and not protective of the environment) if a 'best case' approach is taken.

BENCHMARKING RISK ASSESSMENT TOOLS

Groundwater risk assessments are performed in the UK using a variety of software tools. These include two tools developed by the Agency: the Remedial Targets Worksheet (which accompanies the R&D Publication 20 *Methodology for the Derivation of Remedial Targets for Soil and Groundwater to Protect Water Resources* (Environment Agency 1999a)) and ConSim (Environment Agency, 1999b). Many of the available software tools were not developed in the UK and are designed to comply with other regulations or assessment frameworks, such as BP Risc (BP, 1997) and GSI RBCA Toolkit, which are based around the Risk-Based Corrective Action (RBCA) standard; (ASTM 1995, 1998). They also differ in the underlying assumptions and levels of complexity.

The project '*Benchmarking and Guidance on the Comparison of Selected Groundwater Risk-Assessment Models* ' was commissioned by the Environment Agency's National Groundwater and Contaminated Land Centre (NGWCLC) in order to develop a methodology to benchmark such models, and to provide a comparison of four commonly-used software tools:

- The Remedial Targets Worksheet v1.1
- ConSim v1.05
- The RBCA Tool Kit for Chemical Releases from Groundwater Services Inc v 1.2 (Groundwater Services Inc. 1998)
- BP RISC v3.09 (BP Oil 1997)

The accompanying report (Environment Agency 2001b) also includes guidance on the use and potential misuse of the modelling software for those reviewing risk assessments performed with these modelling tools.

Benchmarking Methodology

The methodology comprises a structured series of questions and four hypothetical case studies involving typical scenarios of contaminant transport along groundwater pathways. Both the questions and the case studies are designed to explore the functionality of the four selected software tools, and to provide an approach for comparing further tools. Further software capabilities in terms of transport via other pathways, or risk to humans, were not examined within the exercise.

The context for the comparison was the tiered risk assessment framework for contaminated soils, as laid out in the Remedial Targets Methodology (Environment Agency 1999a). Thus, the comparison considers whether it is possible to represent partitioning at a soil source (Tier 1), dilution processes in the groundwater, at an abstraction borehole, or at a surface water receptor (Tier 2), and attenuation processes, such as dispersion, retardation and decay, within the aquifer (Tier 3). However, the findings of the study are relevant to all aspects of predictive modelling of contaminant transport, since the study highlights the conceptual models representing the source, pathway and receptor and the underlying assumptions.

Case Study Scenarios

The four case studies constitute typical contamination scenarios involving sources above or below the water table. The scenarios are designed to explore different aspects of typical risk assessments in turn. Due to the limited capability of software tools to model fissure flow systems, the case studies focus primarily on intergranular flow in porous media. However, one case study examined the representation of the unsaturated zone of the Chalk via a dual porosity approach. As an example of a case study scenario, Figure 1 shows a schematic diagram of the conceptual model of the third case study. The source is a shallow waste dump at a paint factory, which has led to contamination of the soil zone by cadmium, benzene and trichloroethene. The site lies above a deep sandstone aquifer, and the site is situated within the catchment area of a public water supply borehole. In addition to the transport of the contaminants in the aquifer, the case study is designed to examine (a) the calculation of depth of mixing below the site (b) dilution by abstraction borehole in a Tier 2 analysis, and (c) the inclusion of unsaturated zone attenuation processes in a Tier 3 analysis.

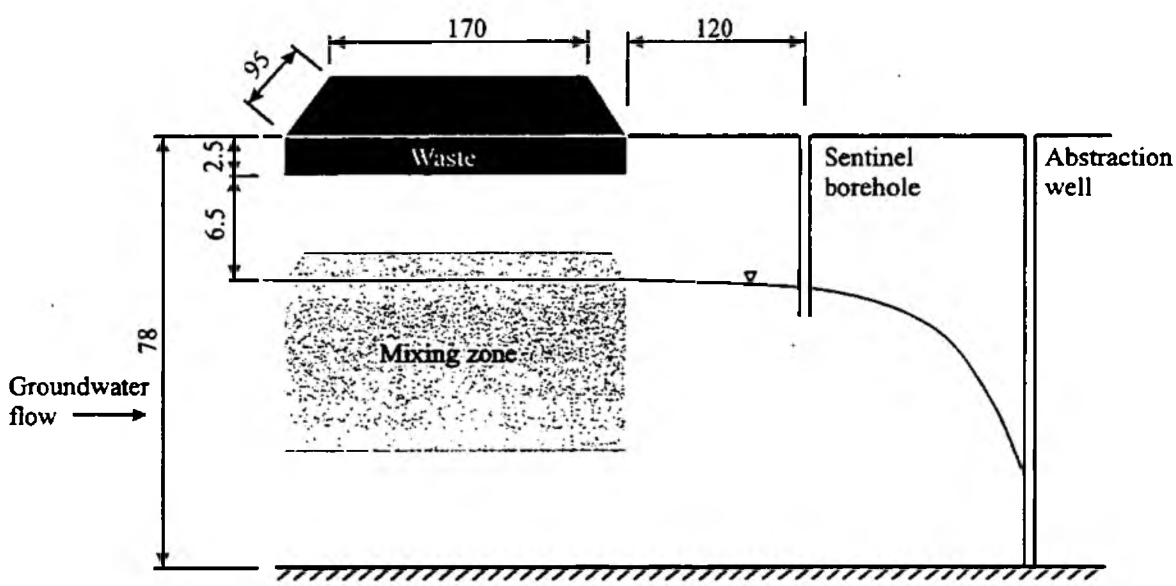

Figure 1. Case Study 3: contamination from a shallow waste dump at a paint factory (dimensions in metres)

Outcome of the Benchmarking Exercise

All four benchmarked tools follow a source-pathway-receptor approach to assessing risk, and apply analytical models of groundwater flow and contaminant transport for the prediction of the migration and fate of contaminants. ConSim v1.05 is designed specifically for sources in the unsaturated zone, whilst the other models are able to consider sources above or below the water table. All models apply a simplistic water balance approach to represent infiltration through soil zone to the underlying groundwater. Some models may also be used to simulate contaminant attenuation in the unsaturated zone. The benchmarked software tools may all be used deterministically (producing a single prediction); ConSim may also be applied probabilistically to derive a range of predicted outcomes.

It is possible to use each of the models to undertake a risk assessment at Tiers 1 to 3 of the Remedial Targets Methodology. With some of the software tools extra care needs to be taken at Tier 2 to ensure that whilst dilution is considered, no attenuation processes are included. The results of the predicted concentrations at the receptors were found to be largely consistent for simple scenarios involving partitioning in the source, dilution in the aquifer below a soil source, and transport due to dispersion and retardation in the aquifer. Results tended to diverge when including biodegradation and/or attenuation in the unsaturated zone. Some of the issues raised by the case studies were:

- Differing conceptual models for decay/degradation. BP RISC applies first order decay to the dissolved component only, whilst the other three apply first order decay to both the sorbed and dissolved components. The appropriateness of the assumption depends on individual contaminants (e.g. based on nature of sorption and availability to biomass), and the source of decay rates (experimental or modelling). For readily sorbed contaminants the two approaches may lead to significantly different predictions of concentrations at a receptor.
- The importance of reporting a mass balance. Not all of the models include an analysis of the masses into and out of the system. Therefore it was not immediately apparent that some of the software tools (Remedial Targets Worksheet and RBCA Tool Kit) contained an inconsistency in the treatment of groundwater fluxes out of the mixing zone under a soil zone source and into the down-gradient region of the aquifer. This results in differing groundwater velocities and, by implication, differing residence times and availability for degradation. The types of scenarios that are affected by this inconsistency involve soil sources and (a) steady-state Tier 3 assessments that include degradation and (b) transient Tier 3 assessments. The effects are particularly notable for cases where the recharge volume is not insignificant in comparison to the groundwater flux through the mixing zone in the aquifer below the site.
- Mode of application. The location and time at which concentrations are evaluated can have a great effect on the quantification of risk. For a source represented by a constant contaminant concentration (i.e. assuming infinite mass) the most conservative decisions for protection are based on concentrations predicted at locations on the centreline of the plume, and at late times. Due to a limit in assessment times, not all of the models were able to predict the maximum concentrations of highly retarded contaminants that might be possible at a receptor. BP RISC is unable to predict the long-term risk beyond 100 years, which is often important in the UK regulatory context.

Being aware of these issues, the experienced user can generally make appropriate parameter choices to overcome these potential limitations.

CONCLUSIONS

Risk assessment models are valuable tools for decision-making, aiding the quantification of risks posed by actual or potential sources of contamination. There are already a wide number of tools available, each with its own approach to simulating contaminant transport.

The project '*Benchmarking and Guidance on the Comparison of Selected Groundwater Risk-Assessment Models* ', commissioned by the Environment Agency, developed a methodology to compare risk assessment tools, with a focus on their applicability to tiered assessments consistent with the Remedial Targets Methodology. A structured series of questions and four case studies allow the testing of software functionality for predicting contaminant transport along subsurface pathways. The benchmarking exercise provides guidance primarily for Agency staff involved in reviewing groundwater risk assessments, but also for consultants and software publishers who are involved in the development and application of tools for such assessments

Key to making reliable interpretations and decisions on the basis of modelling results is a thorough understanding of the conceptual models and inherent assumptions applied in the software tools, combined with an appreciation of the regulatory constraints in the UK. Faced with inevitable uncertainty, probabilistic techniques provide an approach for practical consideration of the range of outcomes from many plausible events or scenarios.

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PARALLEL SESSION: SCIENCE

PAPERS NOT INCLUDED IN PROCEEDINGS

WELCOME

Groundwater has traditionally been viewed as a drinking water resource. In the UK its highest usage for water supply is in the south and east of England where the greatest pressures from intensive agriculture, current and historical industrial development, and general pressures on land use occur. Similar areas occur throughout Europe and the developed world. Groundwater must be protected for future generations so that we are not forced to develop more costly and radical solutions to rising water supply demands. However, the focus is shifting away from groundwater primarily as a water supply resource. Better knowledge about the large influence that groundwater has over rivers and wetlands has presented us with the additional need to protect groundwater in order that surface water ecosystems are preserved. Such an integrated understanding is the foundation of the European Water Framework Directive, which will provide the legislative cornerstone for driving future water and land quality management.

The Environment Agencies in the UK are the primary regulators for the groundwater environment but Local Authorities manage the main controls over land use. Both parties must work in concert, to ensure that risks to groundwater resources from potentially polluting activities and developments are minimised.

In 1998 the Environment Agency re-published the 1992 NRA policy document on groundwater protection - "Policy and Practice for the Protection of Groundwater". In 2000 it completed the production of: 52 maps in a national map series relating to groundwater vulnerability, and over 1800 modelled groundwater source protection zones (SPZ). It has made these widely available to regulators, planners and developers, including the SPZ maps being available for download from the Agency's web-site. The Agency has also produced a number of more detailed decision-support tools for application in a risk-based, site-specific context. The other regulatory agencies have also adopted similar approaches with both the Scottish Environment Protection Agency (SEPA) and more recently the Northern Ireland Environment & Heritage Service (NIEHS), publishing groundwater protection policies.

It is timely to explore the ways in which technical people can work with land-use planners to achieve the long-term protection of water resources. This is particularly relevant as we move into the implementation of the European Water Framework Directive which requires statutory River Basin District Management Plans to be drawn up by December 2003. We also need to explore the changes ahead as we try to integrate our approaches to water management on a whole river catchment basis.

We hope this conference will help in the discussions we need to have and the approaches we will need to develop and adopt, which will be both technical and which will deal with issues that are common to most developed countries. Furthermore, since the European Union Member States, in particular, share common legislation, it is important that we learn from each other and adopt / take ideas from best practice wherever it may be.

We therefore welcome delegates from other countries and hope that we can mutually gain from the debates and make this a successful event.

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1. GROUNDWATER MANAGEMENT AND PROTECTION IN ENGLAND AND WALES - A BACKWARDS AND FORWARDS GLANCE

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INTRODUCTION

Taken as a whole, groundwater may seem to provide a smaller proportion of the drinking water supply in the UK than many other European countries. Although this proportion is only around 33% overall, there are many towns and cities which totally rely on groundwater as the sole source of supply, and for some regions it is a strategically important resource. To the south and east of a line drawn between the Rivers Tees and Exe groundwater accounts for at least 50% of the potable water needs and in Southern England this rises to nearly 80%. These areas coincide with those where there are most pressures in terms of: lowest recharge, most intensive agriculture, densest population and, historical manufacturing industry. Groundwater resources here are therefore highly vulnerable and often under a degree of stress.

Groundwater management and protection has traditionally focused on public drinking water supplies. In the past we have therefore mostly concentrated on the main UK aquifer systems, the Chalk, Triassic sandstones and to a lesser extent, the Jurassic and Carboniferous limestones. However, this focus is shifting, away from the major aquifers, towards a better understanding of the role of groundwater as part of the water cycle. This is happening as a result of a more holistic consideration of the water environment, which has recently accelerated due partly to the introduction of the European Water Framework Directive.

This paper describes some of the history behind groundwater protection in the UK, culminating with the publication of the Environment Agency's Policy and Practice for the Protection of Groundwater. The policy is a risk-based approach to groundwater protection begun at a time when risk was not so readily understood. However, the paper is produced at a time when we are in the midst of a major transition; changing from the main consideration of groundwater as a pure and sustainable source of drinking water, to a better understanding of its importance to the (water) environment as a whole. It outlines the drivers for this change, the new ways in which we will have to develop our thinking and the new tools we will use in refining the risk-based decision-making process.

BACKGROUND

Understanding the need for, and then promoting, the protection of groundwater is not a modern phenomenon in the UK. From a very early age local communities were concerned about their local wells and by the beginning of the last century many water authorities had been empowered by Parliament to make local bylaws (e.g. the Margate Act of 1902 and the Brighton Corporation Water Act of 1924). These gave local water undertakings powers to prevent pollution from particular land use activity in order to protect the quality of drinking water abstracted from boreholes. At that time the concerns were about bacteriological pollution from septic tanks and general unsewered development, although the focus latterly has largely switched to chemical contaminants from both diffuse and point sources.[1]

There were many such local initiatives but no opportunities were taken to combine them nationally. One reason was that the post-war Town and Country Planning Acts had made it a requirement for many of the types of development that could give rise to groundwater pollution to require planning consent. Since the local authorities administered this planning system and the water supply arrangements were largely in the hands of closely related public bodies (e.g. local water boards), there were often informal exclusion zones around water supply boreholes, which applied to unacceptable development on an ad-hoc basis. Land use planning remains a critically important control mechanism for groundwater protection.

In 1963 the first Water Resources Act introduced controls on all water abstraction. For groundwater it provided the legislation to control the impact of new abstractions on existing abstractors. Until the implementation of the Water Resources Act, we did not even know how much groundwater was being abstracted. It is difficult to manage and protect a resource if there is no monitoring of volumes abstracted levels and quality. However, there was little requirement to consider the impact of the abstraction on the environment *per se* and indeed "licences of right" were issued to existing abstractors even though their abstractions may have been unsustainable and were having an adverse affect on surface water features.

It was not until 1974 that the opportunity arose to co-ordinate aquifer protection and develop approaches, firstly on a regional basis. In England and Wales local Water Companies were amalgamated into ten Regional Water Authorities (RWAs), which were geographically based on river basins. At this time some RWAs, in areas where there are considerable land-use pressures coinciding with high groundwater abstraction for public drinking water supplies, began to draw-up and publish Aquifer Protection Policies. There was an added driver because the same year also saw the publication of the Control of Pollution Act 1974. This gave an effective right of veto to the RWAs over the issuing and conditioning of Waste Disposal Licences by County or Metropolitan Local Authorities. Hence some RWAs felt they needed to inform both these Waste Disposal Authorities and the waste industry of their broad objectives in aquifer protection. Severn-Trent Water Authority published their policy in 1976 with accompanying maps showing simple 1 kilometre radial circles around each public water supply borehole as Zone 1, the area of highest risk and therefore where there was likely to be the most stringent objection to development. Other zones were identified according to the importance of the underlying geology as an aquifer. Thus Zone 2 was the outcrop of the Triassic sandstone and the Carboniferous limestone; Zone 3 minor aquifers, such as the Coal Measures sandstones and, Zone 4 those rocks where groundwater was not present in significantly extractable quantities.

Southern Water Authority followed this lead, but had more sophisticated protection zones around boreholes, in different size groupings, according to the volume of the licensed abstraction, and different orientations, based on the direction of groundwater flow.

1980 saw the introduction of the European Groundwater Directive and the start of the European legislative influence on the (ground)water environment. It dealt exclusively with the

[1] However, "new" microbiological pollutants, such as *Cryptosporidium* and *Giardia*, and latterly problems thrown up by agricultural diseases (e.g. the Foot and Mouth disease virus and the BSE prion), have thrown the potential vulnerability of groundwater into sharp relief.

protection of groundwater quality in its own right and not necessarily the protection of water supplies, although this was the implication. The philosophy was, and remains, to protect the raw material first and foremost so that there is little need to subsequently treat the abstracted water before supply.

Around 1981 the increasing recognition of the importance of the soil zone in protecting groundwater from diffuse pollution and a growing understanding of the need to protect all groundwater led to the next step forward. In the late 1970s and early 1980s RWAs were becoming concerned about the growing importance of diffuse agricultural pollution (particularly the leaching of nitrate) on their long-term ability to supply potable water. The European Drinking Water Directive had introduced a nitrate limit of 50mg/l for potable supplies, which for groundwater under much of central and eastern England was rapidly being reached, or had already been exceeded. It therefore made it important that those areas of land most vulnerable to nitrate leaching were identified if proactive measures were to be taken. With the aid of the Soil Survey and Land Research Centre (SSLRC), groundwater vulnerability maps were drawn up and published, pioneered again by Severn-Trent Water Authority, and then later by others. These maps showed, by colour coding, a division of the main aquifers into three, according to the protection afforded by overlying Drift deposits and soils. However, they were not heavily promoted since the RWAs had no powers to control agricultural land use. Their main use became that of a tool to inform the sewage sludge disposal business, also run by the RWAs, with regard to suitable places to spread sludge for agricultural benefit. Unfortunately the more preferred permeable soil areas almost invariably coincided with the Major Aquifer outcrops. The maps therefore helped inform the internal business conflicts.

DEVELOPMENT OF THE NRA GROUNDWATER PROTECTION POLICY

The privatisation of the water industry in 1989 gave rise to the creation of the National Rivers Authority (NRA) in England and Wales. For the first time south of the Scottish border there was a national body with a responsibility for protecting groundwater. The Water Act of 1989 also brought in legislative controls designed specifically for the control of diffuse pollution from agricultural land use. Areas could be defined for the purpose of protecting water quality and the Secretary of State could ban or prescribe relevant activities. In the event this legislative opportunity was not taken for groundwater, the voluntary/persuasive route outlined below being preferred.

The NRA was able to progress with the production of a national groundwater protection policy, building on the existing RWA documents and drawing on experiences from other countries. To help it in this task it engaged the British Geological Survey (BGS) who examined the variety of international approaches and possible alternatives for adaptation to the UK environment.

What was agreed was a combination of protection for specific vulnerable abstractions and protection for groundwater as an overall resource. It therefore effectively melds scientific data (vulnerability) with a societal factor (resource importance). A key facet was the visual demonstration of the defined areas by the publication of maps.

The approach is an improvement on that of the RWAs, combining source protection with the added dimension of relatively detailed aquifer vulnerability for the whole land surface. The classification of vulnerability involved an appreciation of the characteristics of both aquifers and the overlying soils. The source protection zone definition improvements employed the identification of the whole catchment areas of abstractions through modelling, together with their sub-division into travel time zones.

A policy document (Policy and Practice for the Protection of Groundwater in England and Wales) was published in 1992 by the NRA. This set out in one section the principles that were being used and a second section incorporated a set of policy approaches in the form of statements and matrices. The categories of groundwater vulnerability and source protection thus defined were matched with common land uses that could give rise to groundwater pollution (e.g. waste disposal, septic drainage, contaminated land remediation etc). These stated what the NRA's likely attitude would be to developments, in terms of its concerns over groundwater pollution, and therefore informed both developers and fellow regulators alike.

The policies thus set out in very general terms what the NRA's attitude would be to particular developments situated on various categories of aquifer vulnerability or within a specific source protection zone. Although the attitude was highly precautionary within Zones 1 and 2, it was highly laced with caveats for the rest of the areas because of the uncertainties that always need to be understood at the site-specific level. The Policy document and its tools were therefore promoted as an initial filter for the assessment of risk. Hence it was most useful in its application to land-use planning, particularly at the strategic level.

TOOLS - GROUNDWATER VULNERABILITY MAPS

The groundwater vulnerability mapping approach was developed in conjunction with the Soil Survey and Land Research Centre (SSLRC) and the British Geological Survey (BGS). A series of 52 maps at the 1:100000 scale covering the whole of England and Wales, show in general terms where the safest and most risky areas are located with respect to informing the possible 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. The latter is divided into three broad categories: Major, Minor and Non-Aquifers[2]. These represent the importance of particular rock types for both their water resource current and potential use and the intrinsic permeability of the strata. The system thus combines the two separate factors of drinking water potential and inherent vulnerability. This simple system had its detractors within the scientific community but was adopted because of the simplicity of the approach. The maps and their use had to be explained and adopted by non-experts, such as the land use planning community.

Of course many other factors also affect groundwater vulnerability in any particular location, such as the depth of unsaturated zone, the presence and nature of any overlying Drift deposits, and the nature of the contaminants themselves. 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 planning new development in detail.

TOOLS - GROUNDWATER SOURCE PROTECTION ZONES

[2] The mapping system employed in Scotland and N. Ireland uses essentially the same categories, but labels Major, Minor and Non-Aquifers, Highly, Moderately and Weakly Permeable Aquifers respectively.

Protection for individual public water supply (and other such sensitive) abstractions under the groundwater protection policy is affected by the definition of three annular zones around each borehole. Two are based on travel times, and the third on the whole catchment area. In order of decreasing risk to the abstraction they are:

- Zone I (Inner Protection Zone) - defined by a travel time of 50-days or less from any point within the zone at, or below, the water table. Additionally, the zone has as a minimum a 50-metre radius. It is based principally on biological decay criteria and is designed to protect against the transmission of toxic chemicals and water-borne disease.

- Zone II (Outer Protection Zone) - defined by the 400-day travel time, or 25% of the source catchment area, whichever is larger. The travel time is derived from consideration of the minimum time required to provide delay, dilution and attenuation of slowly degrading pollutants.

- Zone III (Total catchment) - defined as the total area needed to support the abstraction or discharge from the protected groundwater source.

- Zone of Special Interest - For some groundwater sources an additional "Zone of Special Interest" has been defined. These zones highlight areas (mainly on non-aquifers) where known local conditions mean that potentially polluting activities could impact on a groundwater source even though the area is outside the normal catchment of that source.

The zones were drawn up using proprietary steady state, two-dimensional model codes (FLOWPATH and latterly MODFLOW for the majority of 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.

Because of this uncertainty about the precise position of the zones and the variation in borehole pumping rates, which could also lead to temporal changes, a strict legislative approach to the definition of zones was not adopted. The exact delineation of the zones themselves were therefore not enshrined in statutory documents (i.e. in the form of formal maps), although there is reference to them in terms of Zone 1 etc. The provision of additional or better data and the subsequent remodelling may well provide more accurate shapes. Also in heavily exploited aquifers, changes in borehole pumping rates can have dramatic knock-on consequences throughout a series of abstraction sources over a wide area. The data sets are therefore updated at appropriate frequencies to ensure that the SPZs remain current.

THE ENVIRONMENT AGENCY AND GROUNDWATER PROTECTION

The Environment Agency was formed, from the NRA and other environmental protection agencies (notably HMIP and the Waste Regulatory Authorities), in 1996. The Policy and the maps and zones previously published by the NRA were adopted and re-published in an up-dated version in 1998. In accordance with the Agency's practice it was given to other environmental regulators but sold to commercial interests, such as environmental consultancies, through the Stationary Office. It is interesting to note that it was the NRA's, and remains one of the Agency's, best selling publications, indicating the degree of interest in the regulation of the sub-surface environment.

THE USE OF THE TOOLS

Vulnerability maps

The 5-year programme of production of the groundwater vulnerability maps spanned the period during which the Environment Agency was created. The final map in the series was published in 1999, with the marketing and distribution for all being undertaken on behalf of the Agency by The Stationary Office.

An additional stage was to produce digitised versions of the maps for better assimilation into Geographical Information Systems. All maps were digitised and made available through a single CD ROM. Customers can purchase as few or as many maps as they like, although for Local Planning Authorities the use of the appropriate maps for their area is free.

Source Protection Zones

By 1996 the modelling programme for nearly 2000 Source Protection Zones, relating to public water supplies and other sensitive uses, had been completed but not finally co-ordinated into a national data-set. The Environment Agency was keen to make the zones as widely available as possible and decided to use its web-site for this purpose. It therefore had to quality check the modelling carried out in the Regions and assemble the data-sets into a consistent format, particularly where the zones abutted one-another. This was eventually undertaken using a simplified vulnerability map background and loaded onto the "In your backyard" part of the Agency's website. Here there is the ability to search according to either grid reference or postcode and an ArcView shapefile can be downloaded for use in a GIS. The most up to date reference set is available through the web-site. (see the paper by Ward, Smith and Marsland in these Proceedings for further information about the tools and how they will be developed further)

Making the source protection zones accessible in this manner has had several effects. On one level it has raised the profile of groundwater protection and freed up staff resources from responding to external requests for data. On an operational level it has facilitated more rapid responses to the need to identify high-risk areas quickly. A recent example was the need to respond rapidly to the disposal of carcasses in the Foot and Mouth Disease outbreak. (see paper by Tony Marsland in these proceedings).

NEW LEGISLATION AND CLOSER FOCUS ON GROUNDWATER

The introduction of a raft of new legislation in the UK in 1999 and 2000 relating to groundwater and contaminated land has meant that the re-published policy has become out of date with respect to its legislative context. The move towards a more prescriptive regulatory approach has also meant that the toolkit has had to be stocked with more complex tools that will assist decision-making at the site-specific level. Models such as LandSim and ConSim have therefore been developed within the Agency's research and development programme, along with detailed guidance relating to specific techniques and practices. (see posters for further information).

THE EUROPEAN WATER FRAMEWORK DIRECTIVE

There is beginning to be a more integrated technical approach to water management. A key driver for this is the European Water Framework Directive (WFD). Having been under discussion for some years, this Directive was published at the end of 2000. It is designed to prevent further deterioration and to protect and enhance the quality and quantity of aquatic ecosystems. Its key objectives include:

- the focusing of environmental water policy on water as it flows naturally through river basins towards the sea;
- consideration of both surface waters and groundwater, taking into account the natural qualitative and quantitative interactions between them;
- the objective of achieving good status of all waters within 15 years, in particular the good ecological status of rivers and;
- the designation of "protected areas" with special requirements.

The WFD is a modem and integrated Directive that encompasses water quality, quantity and ecological issues. Uniquely, the Commission and Member States are attempting to ensure that a common approach to implementation is taken across Europe. Annika Nilsson's paper in these proceedings addresses the WFD in more detail. Suffice to say here that its overriding objective is to achieve "good status" for both surface water and groundwater. Applying to all waters; inland surface waters, groundwaters, transitional waters and coastal waters, improvements must be achieved through a River Basin Management Planning process for which Statutory River Basin Management Plans must be drawn up and consulted on through a public participation process.

Integrated Directive

The integrated approach of the Directive will challenge us to think across traditional disciplinary and legislative boundaries, such that a conceptual model of the river basin catchment will be essential. But do we know enough about "how rivers work" and what drives their ecology? It may be that for some situations the pressures that we have traditionally thought are the most important are not, because of the lack of our basic understanding of the connection between land/soil, groundwater and the river. In some urban areas therefore, where the groundwater provides the majority of the base flow to the river, it may be that the legacy of land contamination leaching into the underlying groundwater is the primary factor influencing river water quality. In such situations the quotation "rivers are simply outcrops of groundwaters" will be very true. In other situations it may be that the pollution legacy is preserved within the river sediments and it is this source which is affecting the whole surface water ecosystem and not diffuse run off or groundwater inflow.

INTEGRATED WORKING/THINKING

Regulators and planners will be forced to consider the needs of water protection for groundwaters and surface waters within the broader context of land use planning. We will therefore have to be better at ensuring that the risk-based decision-making tools that have developed are better understood and used. It will also mean that hydrogeologists, ecologists, chemists, hydrogeologists and other technical disciplines will need to work with each other in a way that many may find difficult at first.

As the impact of point source discharges on surface water quality diminishes due to action by regulatory bodies, the problems of diffuse pollution will become more to the fore. Further improvements in river water quality and the achievement of ecological quality objectives will only come about if the diffuse impacts can be identified, quantified and prioritised for action. This will require local authorities and regulatory bodies to understand, for example, the influence of historically contaminated land within urban areas on the underlying groundwater, and the influence of groundwater discharges on river systems. Where the latter is significant, particularly at times of low flow when surface run-off is low, then the requirement for river quality improvement will need to relate back to the land and the associated groundwater. Hence for those regions with large industrialised urban areas the Water Framework Directive may well be a significant driver for polluted land and groundwater remediation.

THE FUTURE

The way forward for groundwater protection has to address both the technical complexity surrounding groundwater flow, the fate and transport of pollutants and also the inter-relationship with surface water and the land surface.

Adopting a risk-based approach to groundwater management is essential but we will have to understand more about the importance of groundwater within the water cycle and the particular river basin catchment. We cannot afford to protect **all** groundwater, in the strictest sense of the term. We will need to clear about the value of groundwater either as a resource for today's and future generations or as a critical component in surface water ecosystems. Future groundwater management and protection strategies will therefore need to be more closely integrated with whole catchment strategies and in particular to the land-use planning system.

The tools we use to aid our decision-making will need to be transparent and based on sound scientific understanding. At the planning level they must be relatively simple in order to be understood and be owned by the non-specialists, whilst at the site-specific level they should be sufficiently robust to give confidence without being over prescriptive.

Decisions about groundwater protection are difficult but can be very costly to rectify if wrong. Over-protection or under-protection will involve costs, both in risk mitigation or remedial action respectively. The latter particularly may impose a huge legacy and burden on future generations if we do not get it right.

ACKNOWLEDGEMENTS

The long development of the groundwater protection philosophy in the UK to the Environment Agency's current position cannot have been carried out without the vision and leadership of a few and the involvement of many. There are too many to mention each one, but some key people stand out. In the time of the RWAs; Andrew Skinner, Keith Selby and Howard Headworth; in the development of the NRA's policy, Andrew again, with Stephen Foster, Bob Palmer, Steve Fletcher, Tony Marsland, Chris Thomas, Brian Morris, Mike Packman and many others in the Regional offices and the contractors who undertook the modelling and mapping playing an essential part; in moving through to the roll out of the tools by the Agency and the future thinking, Rob Ward and others. Thanks to them all.

2. PLANNING FOR WATER RESOURCES: THE CATCHMENT ABSTRACTION MANAGEMENT STRATEGY (CAMS) PROCESS

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INTRODUCTION

Water resources management in England and Wales involves a number of bodies, and is of interest to everybody. Good management can ensure a sustainable balance between the needs of society to use water to support health, employment and economic activity; and the needs of "ecology" and the environment. The Environment Agency has some very broad "overseeing" duties and responsibilities, including to contribute to sustainable development, and to act to "secure the proper use of water resources". The Agency is the body responsible for licensing abstractions from the ground or surface waters.

This paper outlines some of the planning activities which contribute to or impinge on water resources management, and describes a particular initiative, launched this year, which will address at a local level and in public the decisions about achieving sustainable management of groundwater and surface water resources.

The paper will focus on quantitative aspects of water management. It is of course well understood that quantity and quality are intrinsically linked in that quantity, level and flow of water will impact on chemical and ecological quality. The Agency seeks to ensure that decisions are integrated or holistic ones; but for discussion purposes, my purpose in this paper is to explain the foundation to quantity management.

WHO PLANS WATER RESOURCES IN ENGLAND AND WALES?

There are several different perspectives on water resources management, which drive different approaches and plans. In addition of course, there are many "external" drivers which impinge on, or must be taken into account in, such plans.

Private water companies are responsible for ensuring adequate and economical supplies of water in what we still call the public water supply network. This provides for most domestic use of water and much industrial and commercial use. Government requires water companies to produce and update Water Resources Plans, and asks the Agency to approve them. Progress with and currency of plans are reviewed annually by the Agency.

A key issue for the environment and for use of water, is what happens in a drought. The Agency has a set of drought contingency plans, and has also seen and agreed in appropriate terms a Drought Contingency Plan from each water company. Our aim is to ensure proper planning of resources and hence a balanced response, when a drought – or threat of drought - approaches.

The Agency itself produced in March 2001 a set of national and regional water resources strategies. These aim to provide a framework of information and expectations about safeguarding supplies to all sectors and the environment for the next 25 years. The strategies choose a "twin track" of resources development and leakage and demand management, and include for some water resource recovery in broad areas where the environment is believed to be suffering from over abstraction.

The Agency has also published over the last 5 years, a set of Local Environment Agency Plans (LEAPs) covering the whole of England and Wales. LEAPs have been developed consultatively on a river catchment basis and aim to identify issues and opportunities and to plan progress against them, on this local basis. They cover all aspects of environmental management: some include identification of over-abstraction issues.

The Agency is planning to publish later this year a document identifying its "Restoring Sustainable Abstractions" (RSA) programme. This will gather together all perceived or possible over-abstraction issues, including some already being dealt with by water companies, and some arising from the Habitats Directive implementation. The document will indicate plans to investigate or deal with these issues over the coming years.

The Agency's general duties make it essential that we ensure compatibility between these various plans and perspectives, and with other plans. For example local authority plans and population forecasts, Habitats Directive and Biodiversity Action Plans, Fisheries Action Plans and Flood Management Plans all need to be taken into account consistently.

Plans are of little benefit unless they influence decisions. The Agency is the licensing authority for all abstractions of water (there are some exceptions, planned to cease with enactment of the draft Water Bill). We have indicated to all parties that we expect applications for any new abstractions to reflect the content of the various Water Resource plans or strategies. Exceptions would require some particularly rigorous justification.

To add to – but ultimately integrate with and contribute to – this range of plans, the Agency has recently launched and begun to use the process of developing Catchment Abstraction Management Strategies (CAMS). The process and how it will contribute is described shortly.

GROUNDWATER AS A RESOURCE IN ENGLAND AND WALES

It is worth just touching here on the nature and importance of groundwater as a resource in England and Wales.

Abstractions from major chalk, limestone and sandstone aquifers, as well as from more local gravels and other minor aquifers account for a substantial and highly important (40%) of water available for use. For such a heavily populated part of Europe this is vitally important; reliable sources of water are in short supply. As a bonus, of course, ground water has historically been of excellent quality, often requiring minimal treatment.

It often has the character of being readily available all the year round, unlike surface water in clay or "hard rock" catchments for example; and its dispersed nature means that it is frequently relied on as a local and therefore cheap source for relatively remote villages or farms.

What has not always been respected (or indeed adequately understood) in the past is the vital dependence of many streams and rivers, on the drainage from aquifer systems. We all acknowledge that many, perhaps all, groundwater abstractions will have an effect at some time and location, on the flows in streams. Many of the stream habitats which have suffered from low or no flows in England and Wales, have arisen because of groundwater abstractions some distance away. The same goes for wetland sites. We now acknowledge -and so does the Water Framework Directive, by and large! – that supporting flows and ecology in our streams, rivers and wetlands is a key role for groundwater. The paper by Steve Fletcher on "Linking Groundwater and Surfacewater Management" addresses this issue at more length.

BACKGROUND TO CAMS

The idea of developing Catchment Abstraction Management Strategies arose in the course of the Government's review of abstraction licensing legislation and practice in England and Wales.

The UK Government has been moving, since 1997, towards much more open regulation, with a view both to regulator accountability, and to facilitating clarity for those being regulated. CAMS will contribute to this theme.

The notion in the review of moving licences towards being on a time-limited basis, rather than in perpetuity as most historical ones are, was developed to help water resources management to adapt to future uncertainties (e.g. climate change) and future pressures on water. However time limiting also introduces abstractor uncertainty and therefore a public statement by the regulating authority (the Agency) would provide a clear context assisting abstractors to plan their arrangements for and their reliance on water.

Also, the Government has been party to the formulation and then enactment of the European Water Framework Directive (WFD) and the concepts and mechanisms of CAMS fit very well (we hope and believe!) with those which will arise from the Directive.

The process for developing a CAMS, and the nature of consultation and of documentation, are outlined in "Managing Water Abstraction – the Catchment Abstraction Management Process" published by the Agency in April 2001. The process itself has been the subject of a great deal of (interest and) consultation with a range of stakeholders over the past two or three years. No CAMS has yet been produced – indeed, each is expected to take some two years, and there are 129 of them to be developed – but the Agency has published its timetable and work has begun on the first 26 of them.

PURPOSE OF THE CAMS PROCESS

The objectives for CAMS are:

- To make information publicly available on water resources availability and licensing within a catchment;
- To provide a consistent and structured approach to local water resources management, recognising both abstractors' needs for water and environment needs;
- To provide the opportunity for greater public involvement in the process of managing abstraction at a catchment level;
- To provide a framework for managing time-limited licences;
- To facilitate licence trading.

Just as we expect others to respect and act in the context of their (and our) plans and strategies (paragraph 2.8 above) so we ourselves are making a commitment through our CAMS. In particular, a CAMS will indicate our expectations (and any concerns) regarding any new licence applications in the catchment (groundwater or surface water) and any actions we may see as necessary regarding existing abstractions, including towards any expiring time limited licences. To do this, a CAMS must address the same issues as a licence determination; the legislation requires us to consider

- whether there is a reasonable requirement for the water;
- whether the proposed abstraction could impact on any existing abstractors' rights;
- and the effect the proposal could have on "downstream" uses and users of water.

This last clause effectively includes fisheries and ecology, water quality, and recreation including angling and navigation. For proposed groundwater abstractions, impacts on rivers, streams and their character and uses are also included.

NATURE OF THE CAMS PROCESS

The CAMS process is focussed on a specified area. This is based largely on the surface water catchment, but because it has to cover groundwater abstractions too, the boundary may reflect the boundaries of groundwater units that feed the surfacewater catchment. Major catchments have been sub-divided, but of course the interdependencies within the catchment have to be taken into account.

The technical part of the process provides the core of the final CAMS. The process is designed to ensure that it includes not only the collection and analysis of "hard" data about the catchment, its flows and character and existing abstractions, but also the views, perceptions and values of stakeholders. 'Stakeholders' here means anyone having an interest in the catchment.

The development of a particular CAMS will include considerable stakeholder involvement – some on a selected basis, some through public documents. In all, five different points of consultation are specified in the process for each CAMS. The process will finish with a final published CAMS.

One benefit already in developing a CAMS process is that it has forced out into the open some historical differences in methodology round the country. Using inconsistent methods or values will not be defensible in future; so the CAMS process will use consistent approaches. I will flag three broad areas:

- resource assessment and management
- resource availability status
- sustainability appraisal

Resource Assessment and Management

Resource assessment and management is a key area for the success of the process. It will be based on the collection and analysis of a full range of hydrological data (including abstractions, effluent returns), to produce a baseline assessment of the catchment. In practice this will be structured by dividing the catchment into "water resource management units" each of which is designed to comprise the largest subdivision of the catchment which can be managed in the same way.

To define a sustainable water management regime, the Agency must balance the needs of abstractors with those of the environment. To do this, we have adopted some principles, including:

- to protect the environment by:
  - identifying a minimum flow or groundwater level below which abstraction may be curtailed or augmented;
  - protecting flow and level variability across the full range of regimes from low to high conditions
  - protecting the critical aspects of the water environment including habitats that are dependent on river flows or water levels (recognising that some sites are more sensitive than others)
- to be able to incorporate existing and future requirements such as flows to estuaries
- to take account of quality considerations in both surface waters and groundwater; and
- to protect established rights and uses, and to respect all purposes including environmental ones.

The balance will be represented, in some circumstances, in a "tiered" basis for water availability and environmental protection, rather than a simple and more traditional "minimum flow" requirement.

Resource Availability Status

The analysis will culminate in a resource balance, on a timescale reflecting the local sensitivities and variability. This will finally be summarised in a classification (for each water resource management unit) of the "resource availability status". The categories are:

- water available;
- no water available;
- over-licensed; and
- over-abstracted

These labels will give an indication of what a new applicant for a licence for consumptive use of water may expect; and for the last two, of the desire by the Agency to reduce current licensed and maybe actual abstractions.

Sustainability Appraisal

To assist in identifying an appropriate future resource availability status and how it can be achieved, a sustainability appraisal will be carried out. This will consider the Government's four elements of sustainability i.e. economic, environmental and social aspects, and resource use.

Initially a qualitative assessment of options will be carried out for each resource management unit. Subsequently, for units where some degree of resource recovery is being considered, recovery options are identified and assessed in more detail, including some quantification of costs to abstractors.

ROLE OF CAMS IN WATER RESOURCES MANAGEMENT

The development of a set of CAMS has a number of benefits. In the first instance, it has propelled the Agency into addressing some significant inconsistencies in method and approach, practices which were inherited from the old Water Authorities at the time of water privatisation in 1989. With a public approach, such inconsistencies became obvious and would not be defensible in the medium term.

An integral part of this is the role of groundwater. While CAMS endpoints are to a degree focussed on rivers and streams, the dependency on groundwater of many surface waters (including wetlands) cannot be avoided or "brushed under the carpet". Stakeholders are entitled to expect a scientific approach from the Agency, when the conclusions and decisions are potentially a matter of significant economic, environmental and sometimes social significance. In anticipation of this, the Agency has been working systematically at enhancing the adequacy of groundwater modelling, with priorities and level of detail reflecting the local sensitivity and need.

The Government wishes to encourage the trading of abstraction licences where it can lead to more economically efficient use of water without posing any environmental threat. The recent publication, 'Tuning Water Taking', sets out expectations and some tasks for the Agency to support the aspiration. For trading to be accessible to possible new entrants, they will need information about licence availability ('unavailability would be a better indicator; since trading will presumably only be considered when an extra licence may be refused).; the publication of CAMS is explicitly expected to support the development of a possible market in abstraction licences (although environmental protection and practical/physical aspects will place limits on how far this is likely to go).

The Water Framework Directive is insisting that the "status" of groundwater and surface waters is planned and managed, to standards which are specified but which need considerable discussion and interpretation. Water quantity or level is an explicit status target for groundwater, as well as being a specific relevant element of achieving adequate ecological status in surface waters. The need to consider groundwater management in addressing surface water issues is explicit.

The CAMS process has been designed in a way I believe to be fully in harmony with the spirit and general approach of the WFD. The six-yearly time intervals between reviews of each CAMS, the catchment focus, the commitment to public consultation, and the aim of achieving a sustainable approach to water resources management, are all entirely consistent.

Having said that, the development of a CAMS is a significant effort. A complete set of CAMS for England and Wales will take the equivalent of 70 or 80 people across the Agency some eight years to establish (i.e. 600 person years!) Once a CAMS is established, the licensing process for that catchment should be simpler; but the resource needs set a serious challenge. We believe CAMS catchments; if we are right, the WFD with its much wider remit is a daunting challenge.

CONCLUSIONS

This paper has only discussed water quantity elements of water resources management in England and Wales. Various initiatives, including the Water Framework Directive, will serve to reinforce the need for water quantity and water quality to be appraised in harmony.

The CAMS process offers a model which can help inform us as to how River Basin Management Plans can be developed. Its resource needs, particularly 'first time round', also sound a warning. Our hope is that the process we have constructed and published, and the experience we will gain from implementing it in England and Wales, will make a positive contribution to our efforts to implement the WFD, and may also offer some useful ideas to others.

3. PROTECTING GROUNDWATER: LAND-USE PLANNING PERSPECTIVE - A LOCAL AUTHORITY PLANNING VIEWPOINT

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ABSTRACT

Town and Country Planning has been guiding development within England and Wales since 1949. The planning system has taken on board the concept of sustainable development as best it could, given existing legislation since the government report 'This Common Inheritance (1990)' and the Rio Conference (1992). This paper examines how the Environment Agency and Local Authority Planners have been working together in the past five years since the Agency was formed. Of particular interest is the question of who is responsible for determining Best Practical Environmental Option? Some recommendations are made for better working arrangements.

INTRODUCTION

In some ways it could be said that I am here under false pretences. I no longer work for Kent County Council and some of my colleagues at Kent would argue that I never truly developed the Royal Town Planning Approach to Planning. For this I never apologized, having studied for my undergraduate and planning degrees in Canada in the late sixties and the early seventies. My thesis was based on the concept of "Limits to Growth" proposed by Meadows *et al* (1973). The book begins with a quote from U Thant, Director General of the United Nations made in 1969, Meadows goes on to say:

The problems U Thant mentions, the arms race, environmental deterioration, the population explosion, and economic stagnation, are often cited as the central, long-term problems of modern man. Many people believe that the future course of human society, perhaps even the survival of human society, depends on the speed and effectiveness with which the world responds to these issues.

The thesis went on to explore how to work out the carrying capacity for an area of Canada looking at economic, social and environmental criteria. Looking at this with the thirty years of planning experience in England, this looks a very naïve approach. It would certainly not work for Kent, where all environmental resources would be considered overstretched. No town in west Kent would be considered economically self sufficient since half the labour force works in London and commutes each day. The towns in Thanet, east Kent have such high unemployment that there are families where two or sometimes three generations have not had a job, and the area holds "objective two" status under the European Community Aid programme.

This paper seems to be wandering a long way from the title, but I am trying to explain that a town planner has to consider many different factors besides groundwater protection. In England and Wales, there is a statutory development plan for every area of the country. In the more urban areas, there will be a unitary development plan. This is true of the Medway Towns in Kent. In the rest of Kent, the Structure Plan is prepared by Kent County Council and is the statutory development plan for the county and the districts prepare local plans, which have to conform with the structure plan. The Environment Agency is a statutory consultee on both Structure and Local Plans, which includes the plan for Medway.

THE STATUTORY PLAN PROCESS

The existing Kent Structure Plan (adopted 1996) has a very simple policy for ground water protection:

> Policy NR 4: Development will not be permitted which would have an unacceptable effect on the quality or potential yield of groundwater resources.

Subsequently, the Environment Agency have produced a report on the Policy and Practice for The Protection of Groundwater (1998) that states clearly their policy about proposed development, which may have a detrimental effect on groundwater:

B.1 For any proposal which would physically disturb aquifers, lower groundwater levels, or impede or intercept groundwater flow, the Environment Agency will seek to achieve equivalent protection for water resources and the water resources and the water environment as if the effect were caused by an abstraction controllable under the resources the Water Resources Act 1991.

If this was not clear enough, the Kent Office of the Environment Agency have produced a document which is simply called the Kent Area Planning Guidance. This guidance sets out, in 21 pages, all the main polices that Local Authorities should use in their Structure and Local Plans to cover the environmental issues that are the remit of the Environment Agency. This was presented to KPOG (The Kent Planning Officers Group) in March as a 'fait accomplis'. Needless to say, it was politely accepted by the chief planning officers from Kent County Council, Medway Council and the 12 District Councils present and will probably be filed away carefully. The Environment Agency needs to remember that Planning Authorities have been protecting the Environment since 1949 and the 1996 Structure Plan is the third review of the Kent Structure Plan, which plans development within the county until 2011. The Structure Plan includes a total of 134 policies. Furthermore this plan has been subject to a strategic environmental appraisal that won a national award from the Royal Town Planning Institute in 1994. The year before the legislation that set up the Environment Agency was enacted.

THE ENVIRONMENT AGENCY'S ROLE IN DEVELOPMENT CONTROL

I am going to talk about only two case studies that have considerable importance to Kent County Council and the future of the County of Kent, namely Ebbsfleet – a development of offices and housing on a new station on the new rail link between London and France for Eurostar; and an incinerator proposal at Allington in Maidstone.

Ebbsfleet

The planning application for Ebbsfleet describes the development as follows:

Development up to 790,000 sq metres comprising residential, hotel and leisure uses supporting retail and community facilities and provision of car parking, open space, roads &

infrastructure land at ebbsfleet bounded by the a2, southfleet road, springfield road & the north kent railway line, excluding blue lake, springhead enterprise park & ctrl alignment, swanscombe/northfleet

The application was received in March 1996 and was accompanied with an environmental statement. This meant that the planning authorities, Dartford and Gravesham, since the application straddled the boundary between the two Thamesside local authorities, would have 16 weeks rather than 8 weeks to process the planning application. It was also clear that the application was of major significance for the county and for the nation. It was a very long time since a new railway line had been built in England. Kent wanted a new station with the trains stopping in Kent. From Ebbsfleet to Kings Cross, the journey would only be 20 minutes by high-speed rail link. This would mean the site would be as attractive for development as Greenwich or Chelsea. But Kent County Councilors had learnt about environmental assessment through the channel tunnel and the rail link and they would not grant planning permission for a development that was not environmentally assessed as sound. It was important that the environmental assessment was sound. Further more all three authorities would have to be completely satisfied that objections to the development could be overcome before planning permission could be granted.

The development proposal was so big and important that it soon became apparent that the best way for the local authorities to undertake the environmental appraisal of the application was to form a series of working groups looking at different aspects of the development. Working groups were formed on transport, social and community development, economic impact, design and master plan, and environment impacts. Each group had representatives from the developer or an appropriate consultant, a local authority representative, a county council representative and any other representative who seemed appropriate and could contribute to the work being undertaken by the group.

The Environment group invited the Environment Agency to attend the first meeting since their letter suggest that there were several problems that needed to be resolved concerning the application although in general they had:

> "no objection to the outline planning application submitted. However, the indicative layout proposals enclosed are unacceptable, and the EA advocates discussion with the Applicant prior to additional details being submitted to the local planning authority for consideration."

On the day of the meeting the group waited half an hour before ringing the Environment Agency to be told the Environment Agency had decided not to attend meeting of the working group. The group had to hire consultants to resolve the concerns we could identify considering the water environment which may not have been the ones that the Environment Agency considered important.

Later on towards the end of the year when most of the work of the groups was completed we managed to hold a meeting with all the statutory consultees about the revised environmental statement. English Heritage, English Nature and the Environment Agency did attend and they had the opportunity to discuss any outstanding issues with the environment group. The application was finally granted planning consent about 18 months after it was submitted. The planning agreements took another three years to work out.

Waste to energy plant at Allington, Maidstone

This was an application to burn up to 500,000 tonnes of domestic and commercial waste and generate electricity of less that 49 MW, supported with an environmental statement. The application was processed by Kent County Council as the competent authority. The Environment Agency lodged a holding objection to the application on the basis of the possible effect of ash at this location on groundwater protection. At that stage, the Agency also informed the planning authority that it would be unlikely that they would extend the list of acceptable wastes being disposed at the site which was for clean inert fill only and therefore the applicant would need to demonstrate any ash disposed at the site fell within this category. The planning authority wrote for further guidance from the Agency following a public meeting when the Environment Agency representative had stated that the holding objection was dependent on further information likely to be included in the IPC Authorisation.

It should be pointed out here, that the Environment Agency will often write stating that it has no objection to a planning application to a major planning application, if the Agency is aware that an Integrated Pollution Prevention Control (IPPC) license will also be required. This for the simple reason that the Agency gets paid by the developer for processing an IPPC license and does not get paid for responding as a statutory consultee to a planning application.

The planning authority pointed out the holding objection was based upon groundwater issues and that the technical aspects of this would be dealt with via a waste Management License. The planning authority also pointed out that although the height of the stack would be dealt with by the IPC application, it had already been included in the environmental statement and this was the application before the planning authority. If the Environment Agency could not accept the validity of the work submitted with the planning application, the planning authority sought confirmation that the Agency would comment further once the IPPC application was made.

In these circumstances, the county council would intend to defer reporting to Members until final views on the height of the stack was available as this was considered a material planning consideration, and to report to members without a recommendation from the Environment Agency would be premature. The views of Maidstone Borough Council and Tonbridge and Malling Council indicated that the application did not represent the Best Practicable Environmental Option (BPEO) for dealing with the waste types specified to be disposed of.

Kent County Council wrote to the Environment Agency asking whether the Agency considered the application to be the best practical environmental option (BPEO) quoting the Kirkman Case where the High Court decision held that air emissions are capable of being a material planning consideration and that in considering this issue the planning authority is entitled to take account of the IPPC regime as discharged by your Agency. In essence, the County Council is entitled to reach a favourable decision on BPEO as long as it is certain the proposal is or is likely to be acceptable to the Environment Agency.

At this point, the County Council sought Counsel's opinion on BPEO. On the basis of this advice, BPEO is clearly capable of being a material consideration and therefore in reaching a decision the local planning authority has to have regard to it and be guided by the views of other authorities more directly responsible. In essence, BPEO needs to be considered in the assessment of alternatives in the Environmental Statement. The County Council therefore wrote to the applicant asking them to prepare information demonstrating that their application represented BPEO. The Environment Agency needed to respond to the planning application, not the IPPC authorization, whether this represented BPEO. A further letter emphasized the need for the polluting effect from the development on air and water to be a planning issue to be resolved before planning consent could be granted.

At this point the application had been lodged with the planning authority for over a year and the planning authority were concerned about the cost to the developer of further delays if the Environment Agency could only consider BPEO through the IPPC authorization process rather than the planning process. The Environment Agency finally withdrew its holding objection, originally lodged on 25 September 1998 on 5 November 1999.

CONCLUSIONS

It would seem that there is clearly a miss match between expectations and delivery on the role of the Environment Agency in Town and Country Planning. Town Planners regard the new boys as experts that have a duty as statutory consultees to comment on Structure and Local Plans and the appropriate planning applications. This is their legal responsibility, which they should fulfill within the statutory time limits set out in the planning acts.

The Environment Agency, on the other hand, as a central government organization devolved through regional and area wide offices "wants to help achieve the best future, creating a better environment for everybody by encouraging sustainable development. The Agency is the Governments expert and professional advisor on many matters and plays a central role in putting the Governments environment policies into practice." Environment Agency Kent Area Planning Guidance (March 2001). In order to save time and streamline the work, the Environment Agency believes that this work can be streamlined and be carried out by a simple flow diagram approach.

In fact sustainable development in England and Wales is much more complex. There are no areas in Kent that can be considered wilderness areas. Areas of ancient woodland represent less that 3% of the County. The complex geology of the weald of Kent means that villages in Kent tend to be found every 2 to 3 miles rather that the expected 3 to 7 miles, which is the usual pattern, proposed in central place theory. Kent's proximity to London and now Europe with the channel tunnel and soon to be completed Channel Tunnel Rail Link means that it has twice the number of planning applications of any other county in the South East. It is also the largest County in England. The people of Kent are proud of these facts just as the people of Hereford are proud of the things that make Hereford unique. The Environment Agency need to acknowledge these differences and work with the differences instead of trying to shoe horn every County and Local plan to have the same Structure and Local Plan Policy across the country. KCC Structure Plan policy for groundwater protection is simple and straight forward. It needs to be 75% of our drinking water comes from groundwater sources.

Similarly, planners want to get the best advice possible from the Environment Agency when they are considering a planning application. They cannot wait until the IPPC application is submitted because the planning department has no responsibility for that permit. They can however point out to the applicant that an IPPC application is no use without a planning consent. Planning Consent establishes the principle of the application – that the application is in the correct location in land use terms. The IPPC consent ensures that the best available technology will be used and that pollution from the operation of the plant will be minimized.

RECOMMENDATIONS

These recommendations go beyond the scope of considering just Groundwater, considering the role of the Environment Agency in general Town and Country Planning matters:

- The role of the Environment Agency as statutory consultee needs to be more clearly defined. When the planning authority writes to the Environment Agency requesting views on the application, it would perhaps be better to spell out precisely what they would like the Environment Agency to consider (e.g. BPEO, groundwater protection, and flood protection or waste disposal).

- The importance of giving a balanced and consistent view on a planning application by the Environment Agency needs to be emphasised.

- If Planning and IPPC are processed at the same time it must be made completely clear which documents relate to the planning application and which relate to the IPPC authorization. Otherwise legislation may be needed combining the two systems.

- Local liaison between planning authorities and the Environment Agency needs to be strengthened by regular meetings so that Environment Agency advice particularly on strategic issues like future water demand and supply can inform the planning process at the Structure Plan and Local Plan preparation stage. This is now happening in Kent and expectations of the role of the Environment Agency and the planning authority are being revised in line with workload and manpower limitations.

Note

This paper is written from my personal experience of working for Kent County Council for the past 11 years, and being a member of the Kent Flood Defence Committee for the past three years. It does not represent the views of the county council or the Environment Agency.

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4. THE LAND-USE PLANNING PERSPECTIVE : AN ENVIRONMENT AGENCY VIEWPOINT

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OVERVIEW

There is a need to look at groundwater in the wider context of delivering and maintaining a sustainable water environment. Groundwater resources are susceptible to a wide range of threats (e.g. restriction of recharge, flow obstruction or diversion and pollution) arising from land use policies, the consequences of which may take years to manifest themselves. Overabstraction can lower the water table, detrimentally affecting aquatic environments and other water sources. Once polluted, groundwater is difficult and expensive to remediate.

In areas where the stress on water resources is already severe, the development costs and environmental costs will be high if further development takes place in these areas.

The Environment Agency (the Agency) sees the planning system as a primary means to protect groundwater resources and aims to influence planning policies and development control decisions accordingly, focussing on zones of highest risk. Its draft policy on location of Landfill sites in relation to sensitive aquifers is a key example. From the environmental protection viewpoint, it is far more cost-effective to prevent development happening in the wrong locations than to try to prevent or mitigate the impacts.

The Agency has produced a good basic technical framework and national mapping to identify priority groundwater protection zones. There are continuing efforts to develop/refine this approach, looking for ways to ensure it is properly exploited by planners. *Note the Agency's "Policy and Practice for the Protection of Groundwater" and their groundwater maps.*

PLANNING POLICY FRAMEWORK

There is little in primary legislation governing the planning system that directly acknowledges water as a material consideration in planning decisions or policies. But water is no different from many other key issues, e.g. housing, transport, in that most of these issues are dependent on policy rather than statute for their status within the planning system.

Policies towards water management issues have moved forward a long way during the last few years, encouraged by the 1999 revision of PPG12, (Secretary of State guidance to Local Planning Authorities (LPAs) as to what topics should be covered in Structure and Local Plans). However, there is still a very marked inconsistency between individual LPAs in terms of the detail and breadth of coverage in their plans. This cannot be fully explained by variations in regional policies or other planning circumstances.

There is no single national planning policy guidance for sustainable water management. Research suggests that water management issues do not usually feature significantly in decisions on where or how new developments should be constructed. There is a need for good practice guidance on the incorporation of water management issues as part of the planning process for new developments. *[The Agency is collaborating in a CIRIA research project on this].*

The Agency, (as with other stakeholders), must involve itself in the review of Planning Policy Guidance (PPG) notes etc. to ensure that its legitimate concerns are considered. For UK legislation to implement the EC Water Framework Directive, it will need to determine an appropriate role for planning in pursuit of the sustainable development duty in that Directive.

Regional Planning

Under the new PPG11 guidelines, a 'Sustainable Development Appraisal' must be carried out, to confirm that sustainability objectives have been taken into account in new regional plans. Matters to be considered must include the Government's stated 'objectives for sustainable development', which include:

- maintenance of high and stable levels of economic growth and employment
- social progress, recognising the needs of all sections of society
- effective protection of the environment
- prudent use of natural resources.

The Agency and Water Companies must address the issues raised at Regional Planning Level. It is at this point where major issues of water resource availability/cost should be addressed. It is also possible that water demand management issues could be incorporated into Regional Planning Guidance.

The Agency is aiming to work closely with Regional Planning Bodies by contributing to regional planning guidance and regional sustainability frameworks. There is variable content concerning water issues. Future developments in elected regional government are also key.

- Continue to support the environmental and sustainability aspects of the work of the Regional Development Agencies.

- How can we improve the regional dialogue on this?

Development Plans

There are various broad environmental topics identified in PPG12 to which LPAs should give consideration, including:

- Protection of groundwater resources from contamination or over-exploitation.

- Conservation of natural resources including water resources, and consideration of their availability in determining the location of new development.

At the county Structure Plan level, the Agency, Water Companies and other relevant agencies need to be involved to ensure concerns are recognised. This is best achieved through ongoing dialogue with planners, rather than simply responding to published draft plans. Planning timescales need to be "in sync" with Water Companies' 5 year investment plans which control their investment on wastewater and water supply facilities, to avoid problems of mismatched population estimates, etc.

The Agency needs more information on whether development plan water-related policies are being implemented successfully.

- The Agency has a large amount of information which should be made available to LPAs for inclusion into their development plans. Is this happening satisfactorily? How could the process be improved?
- Is there an adequate link between Local Environment Agency Action Plans (LEAPs) and development plans?
- How are Catchment Abstraction Management Strategies (CAMS) to be absorbed into the process?

DEVELOPMENT CONTROL

The main issue at the Development Control level is to ensure that the policies further up the planning process have not been compromised. Given the large number of planning applications, the stakeholders need to target and review only those major development applications which are likely to have major impacts on water sustainability.

Development control decisions are not always in accordance with development plans. How can we improve performance?

Is sufficient attention being paid to water management and related issues in the handling of individual planning applications? For example, are water issues taken sufficiently into account in determining which planning applications should be subject to Environmental Impact Assessment (EIA) and within the EIA process itself?

There is a Co-ordinated Permitting Project being promoted by the Agency, Local Government Association, Environmental Services Association and CBI intended to reduce misunderstandings and reduce overall timescales for planning and environmental licence decisions.

5. GROUNDWATER ISSUES IN THE CELTIC COUNTRIES

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INTRODUCTION

The extent of groundwater exploitation and hydrogeological research in the Celtic countries, defined here as Scotland, Northern Ireland and Wales, is limited in comparison with England. The nature of regional geology results in Celtic aquifers tending to be small, and with ample alternative surface water resources they provide only a small percentage of total water supply. Consequently, groundwater resources have tended to be largely neglected in comparison with the major English chalk and sandstone aquifers. Nevertheless, groundwater resources have a genuine strategic importance in the Celtic countries.

Large numbers of rural and island communities rely on groundwater supplies, a reliance that may rise with any future increase in the seasonality of rainfall due to climate change. The inability of many surface water sources to meet the EC Drinking Water Directive (80/778/EEC) standards, particularly with regard to colour, without substantial investment in pre treatment has resulted in the development of several groundwater resources in recent years such as Fort William and the lower Spey Valley. This paper outlines the hydrogeological context of the Celtic countries, some of the issues pertinent to groundwater protection in these countries and the implications of future legislation.

HYDROGEOLOGICAL CONTEXT

The geology of the Celtic countries is highly diverse and groundwater is present, to some extent, in many of the solid rock strata. This geological diversity produces a range of hydrogeological characteristics with varying transmissivities, permeabilities and safe yields, although the majority of the groundwater flow is fissure flow. The characteristics of Celtic aquifers are not generally as well understood as the major English aquifers and relatively little research has been devoted to improving the knowledge base. The most comprehensive publication setting out data on Scottish hydrogeology was Robins (1990). There is no comparable document available for Wales.

Although major aquifers are comparatively limited in extent, small aquifers abound in a wide variety of geological settings. Many of these small aquifers are in located in drift deposits such as river gravels, raised beaches and the extensive glacial sands and gravels which cover large parts of the Celtic countries. The hydrogeological nature of the deposits varies considerably, depending upon the depth, permeabilities and extent of the deposit and its hydraulic conductivity within the underlying strata.

CURRENT GROUNDWATER USAGE

In contrast to parts of southeast England where over 70% of public potable supply comes from groundwater, the Celtic countries are comparatively low exploiters of groundwater for drinking water. In Scotland only 5% of total public potable supply comes from groundwater, in Northern Ireland 10% and in Wales 8%. In addition, it is estimated that there are over 25 000 private sources in the Celtic countries (Robins and Misstear, 2000).

MAIN GROUNDWATER ISSUES IN THE CELTIC COUNTRIES

A fundamental issue in respect of groundwater in the Celtic countries has been the lack of recognition of the importance of groundwater resources. Groundwater is not a resource recognised by the general public and the concept of obtaining water from aquifers as opposed to surface waters is by and large novel. Other long term issues affecting groundwaters are disposal of spent sheep dip, nitrate pollution, pollution from septic tanks and abstraction control.

The majority of the disposal authorisations in the Celtic countries which are issued under the Groundwater Regulations 1998 are for spent sheep dip. The use of traditional organophosphate based dip is declining and being replaced by synthetic pyrethroids. In order to establish a baseline for the levels of both groups of compounds in Scottish groundwaters, the Scottish Environment Protection Agency (SEPA) recently undertook a survey of 302 sites. This survey revealed that 11 sites displayed positive results. All but one of these positive results were within the limits stated in the 1989 Drinking Water Regulations[3]. The source of these positive results are the subject of further investigation.

Another key area of concern is the potential for nitrate pollution. In May 2000, SEPA established a representative network to monitor groundwater quality across Scotland. The network was designed to represent the wide variation in groundwater vulnerability to pollution in Scotland. This network was designed on the basis of three key parameters, aquifer permeability, land-use and soil leaching potential. To date, this network has demonstrated that 89% of the samples taken have nitrate concentrations of less than 40 mg/l (adopted as the threshold at which groundwaters are considered to be vulnerable to nitrate pollution). Further work is required to identify those areas which would be at most risk of nitrate pollution to assist the Scottish Executive to thereby identify Nitrate Vulnerable Zones as specified in the Nitrates Directive (91/676/EEC). In Wales, a number of Nitrate Vulnerable Zones have already been designated and there is a possibility of further areas being designated.

The importance of protecting groundwater resources rose rapidly up the political and media agenda during the recent foot and mouth disease outbreak as authorities in both Scotland and Wales considered the use of burial as a means of carcass disposal. Appropriate siting of burials was essential to minimise the risk of groundwater contamination from the breakdown products from hundreds of thousands of animal carcasses.

In Scotland, SEPA assessed each site for its suitability for burial and insisted that adherence to the Prevention of Environmental Pollution from Agricultural Activity (PEPFAA) code[4] was achieved. SEPA was prepared to issue absolute prohibition notices under the Groundwater Regulations 1998 in order to prevent inappropriate burial sites being used. No exhumations have been necessary and there has been no evidence of pollution from the monitoring being undertaken so far. During the course of the outbreak, a carcass burial site at Sennybridge in mid-Wales was closed when it became apparent that breakdown products from buried carcasses were threatening groundwater resources.

[3] Water Supply (Water Quality) Regulations 1989.

[4] The Water (Prevention of Pollution) (Code of Practice) (Scotland) Order 1992.

WATER FRAMEWORK DIRECTIVE

The Water Framework Directive (2000/60/EC), which was adopted by the European Parliament on 23 October 2000, recognises the importance of groundwater resources and will serve to markedly increase the level of protection afforded to groundwater resources, not just the supply of water from groundwater. The Directive combines groundwater protection with that of surface waters, in terms of both quality and quantity. This integration between surface and groundwaters is profoundly important to ensure that, for example, any groundwater abstraction is ecologically sustainable and wetland habitats are not damaged. The Water Framework Directive also demands that groundwater management strategies are developed.

Given that many aquifers in Celtic countries are comparatively small, the development of aquifer catchment management schemes will be particularly challenging. In order for such schemes to be effective, it will be essential that groundwater abstractions are registered and, where appropriate, licensed in the future. There is already a licensing system for groundwater abstractions in large parts of Wales. In Scotland, arrangements for such licensing have yet to be developed but they will have to take account of the social and economic context, as demanded by genuinely sustainable development. It is possible that licensing will only be required in situations where environmental degradation due to abstraction is a risk.

SUMMARY

The diverse geology of the Celtic regions produces a wide range of hydrogeological situations. Historically, the groundwater resources of these regions have tended to suffer from a lack of attention and public recognition of their importance. The recent foot and mouth disease outbreak has serve to raise the profile of the need for effective groundwater protection and the implementation of the Water Framework Directive will act to increase levels of groundwater protection.

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6. U.S. ENVIRONMENTAL PROTECTION AGENCY SOURCE WATER PROTECTION PROGRAM

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ABSTRACT

In 1996, the Safe Drinking Water Act was amended to require each State assess their sources of drinking water. Each State was given flexibility in their approach, but there were four major steps required by each. EPA is assisting States by providing guidance on how to conduct source water settings in different hydrogeological settings, and on Best Management Practices for preventing source water contamination by many different sources. EPA is also developing a Strategic Plan that will provide for maximum involvement of interested parties throughout the United States.

INTRODUCTION

In 1996, the United States Congress amended the Safe Drinking Water Act (SDWA), and required States to develop **Source Water Assessment Plans** (SWAPs) to assess the areas serving as public sources of drinking water in order to identify potential threats and initiate protection efforts. While protection measures are not required by SDWA, EPA is developing guidance for States to use to prevent contamination of drinking water supplies, assessments are completed.

EPA prepared a Guidance Document for States to use on developing their assessment Plans. The Guidance stressed the importance of public involvement, basing assessments on a watershed approach, and provided options for how the steps of the Plans should be developed and implemented.

SOURCE WATER ASSESSMENTS

The source water assessments created by States differ since they are tailored to each State's water resources and drinking water priorities. However, each assessment must include four major elements:

1. Delineating (or mapping) the source water assessment area;

2. Conducting an inventory or potential sources of contamination in the delineation area;

3. Determining the susceptibility of the water supply to those contamination sources, and

4. Releasing the results of the determinations to the public.

While Tribes are not required to develop SWAPs, many Tribal systems have submitted plans, which have been approved.

What it takes to get there

Now that many states are well into their first year of implementing their assessment plans, we are finding that approaches vary by state, but that there is a lot of preliminary activity that goes on before the steps described above are being completed. We have found that these activities can be grouped into the following descriptions:

- Inventorying and assessing previous ground water, surface water/watershed efforts that contribute to progress on source water assessments.
- Building public involvement capacity up front, or into an ongoing process. This includes mass mailings or holding community meetings where input regarding the location of drinking water resources and potential sources of contamination may be found.
- Setting up contracts and hiring staff to conduct the assessments. Many State agencies do not have their personnel to assess all water supply systems themselves.
- Running pilot projects to test approaches/methods etc. Many States are beginning with a few pilots, then the results will be fed back to enhance the results of remaining assessments.
- Investing time and resources into the development of automated processes, databases, and/or models designed to standardize and improve the quality of assessments. Almost all States have some level of activity up front regarding the establishment of models, databases etc. Many believe that the use of technology will greatly enhance their ability to complete the 170,000 national assessments.

Source Water Protection Strategic Plan

EPA is drafting a Source Water Contamination Prevention Strategic Plan that will outline a coordinated approach to protect sources of drinking water and the health of those who rely upon these sources. To develop the plan, the Office of Water is encouraging cross-program support and support of source water contamination prevention, and is working with a wide array of national partners to develop the measures that drive program priorities and that are used to measure program success.

The Strategic Plan is based upon the following draft goal, and vision:

Goal: Increased public health protection by keeping contaminants out of the source of drinking water.

Vision: All interested Stakeholders, utilizing a variety of tools in a co-ordinated fashion, establish management actions that significantly lower the risks of contaminants entering drinking water resources.

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Actions to move toward achieving the Vision:

1. Ensure comprehensive and useful source water assessments for all public water supplies (E.g., provide for wide public availability of local assessments.).

2. Target relevant state and federal programs to address source water contamination prevention priorities (e.g., develop national UIC Program management actions to implementing a Class V program, initially targeting prevention to higher priority areas to protect current and potential water supplies.)

3. Increase awareness, education, and involvement by private industry, government, and the public (e.g., promote initiatives to reach out to businesses).

4. Foster local control and capacity (e.g., increase in the field support).

5. Increase Private Industry Awareness and Involvement.

The Strategic Plan has been through a series of drafts incorporating information on the vision, objectives, and measures received from various partners and stakeholders. Strategy is limited to EPA's role and commitments, but vision, and actions are intended to be commonly accepted among all stakeholders.

MEASURING PROGRESS

The current measure of source water protection as established by the Government Performance and Results Act (GPRA) is that by 2005, 50 % of the population would be served by a water system with a source water protection plan in place. The GPRA measure for the Underground Injection Control Program (UIC) is that by 2005, protection of ground water resources would increase due to better management of all class I, II. And III injection wells and by managing high risk class V wells in 100% of high priority protection areas.

National Information is needed to Answer These Core Business Questions

- Are the source water assessments being completed and are the UIC inventories being done?
- What are they finding?
- What's being done about the problems found?
- Are the preventative mechanisms working/are the actions making a difference to public health?

Information Strategy

Effectively tracking national measures for prevention programs and other information elements that will answer the key business questions requires a coordinated nationwide effort.

The Office of Ground Water and Drinking Water (OGWDW), in cooperation with the Office of Water and the Office of Environmental Information, is developing an Information Strategy as a first step to focus on essential data, reporting, and analyses supporting decisions of national programs to protect public health. The objective of the OGWDW Information Strategy is to identify a range of options for modernizing information systems given evolving information needs and technology and to ensure effective and efficient information management to support public health protection.

Issues/Challenges for the Future

- Water Quantity/Water Quality including conservation and future use;
- Private water wells - what role should EPA play?
- Emerging contaminants (i.e., new pathogens, pharmaceuticals)
- Tribal prevention programs

Stakeholder Process to Develop Strategy

- Key national meetings with EPA/State Workgroup
- National Stakeholder Meeting September 11, 2000 (over 100 attendees from many states, federal agencies, local governments, interest groups, trade organizations, and citizen and environmental organization.
- Discussions at national meetings of state ground water and drinking water and clean water managers.
- Over 100 comments on different drafts over 1 year

SUMMARY

The Safe Drinking Water Act provides the statutory basis for required source water assessments. It is EPA's intention to build on these requirements, and provide technical guidance as well as community outreach assistance to States and communities to implement prevention and protection programs as well. Developing consensus on a national strategic plan has been taken more time and effort than was initially thought. States are finding that completing assessments is taking more time than many initially thought as well. Both the activities described under the section "What it takes to get there", as well as the brief description of the number of drafts developed for the strategic plan, underscore the necessity of up front planning and lots of communication with stakeholders.

7. CO-OPERATIVE AGREEMENTS BETWEEN WATER SUPPLY AND AGRICULTURE IN GERMANY

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ABSTRACT

More than 70% of the raw water for public supply in Germany is groundwater taken from aquifers. In principle the groundwater in catchment areas is protected from agricultural pollutants by the demarcation of water protection areas and the provision of adequate legal measures. In fact these political instruments have not prevented an increase of nitrate and pesticide concentration in groundwater. Therefore co-operative agreements between agriculture and water supply are being introduced.

In the federal state of Hesse there are 24 local and 6 regional such co-operatives. Interviews (with water supply companies, farmers and water authorities) as well as positive results from studies of mineral nitrogen in soils show that such co-operation seems to be productive. The costs of local co-operatives are split into three nearly equal parts: agricultural expert advice, compensation for farmers and supplementary costs. Costs for regional co-operatives consist mainly of expenditure for expert advice. The estimated specific costs of local co-operatives are roughly similar to the cost of water treatment in relation either to the amount of groundwater withdrawal (0.1-0.3 €/m³) or to the reduction of nitrate (2-6 €/kg NO_3-N_{elim}). However, it has to be remembered that water treatment only reduces nitrate in drinking water whereas co-operative agreements contribute to the protection of groundwater over the longer term.

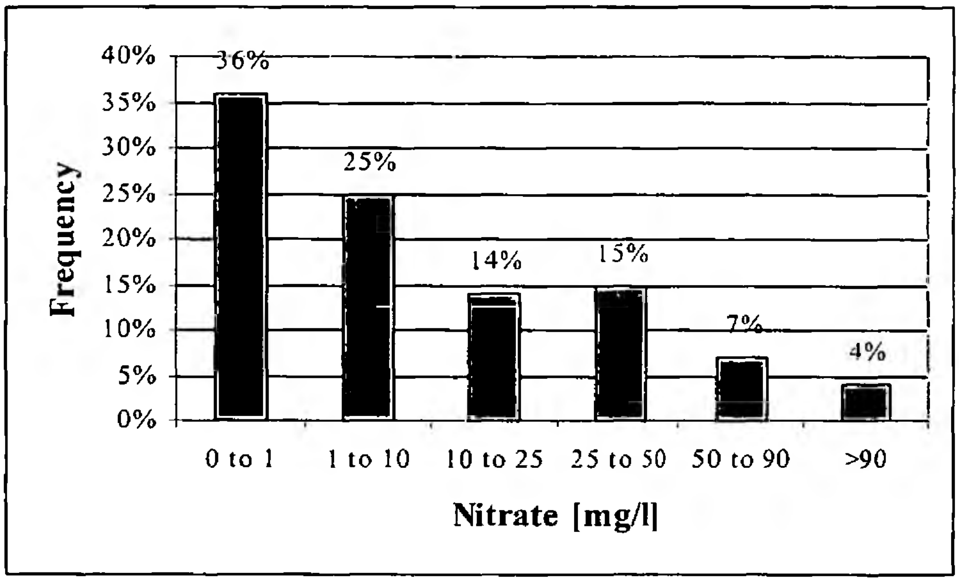
SITUATION AND DEVELOPMENT OF DIFFUSE GROUNDWATER POLLUTION IN GERMANY

Groundwater situation

More than 70% of the raw water used for the public drinking water supply in Germany is taken from aquifers. This proportion continues to increase (LAWA 1995). In principle groundwater is seen as the cleanest and safest water resource – particularly when compared to surface waters. During the eighties groundwater resources were overexploited in some German regions (e.g. in the region of Frankfurt/Main) which lead to considerable lowering in the groundwater levels with negative consequences for ecology and buildings. Today the quantitative problems are less important in Germany largely because of a decrease in the water demand. The level of demand for water in households and small sized enterprises in Germany has decreased from 4 234 million m³ in 1990 to 3 894 million m³ in 1998. The water demand for industry (supplied by public water supply) decreased from 1 132 million m³ in 1990 to 678 million m³ in 1998 (BGW 2000).

In contrast, the quality of groundwater in some German regions has become a crucial issue. Important pollutants are drawn from diffuse sources, especially nitrogen based fertilizers and pesticides (e.g. SRU 1998). As shown in Figure 1 about 11% of the observation points have nitrate concentrations above the limit value of 50 mg/l and about a quarter have levels close to or above the limit value (>25 mg/l[5]).

Figure 1 Frequency of nitrate concentration in groundwater
(LAWA 1995)

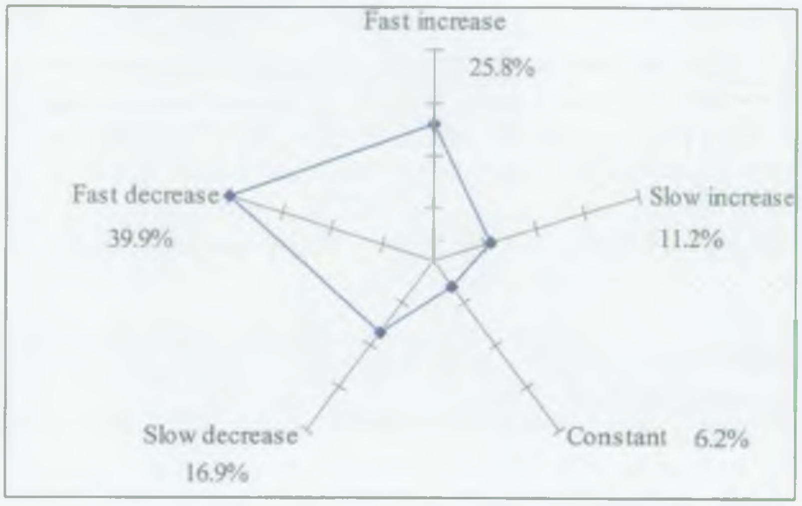


Unequivocal statements about the development of nitrate concentrations in groundwater are very difficult to make. For example, the German government commissioned a report in response to the EU Nitrate Directive, which looked at nitrate concentrations at 116 observation points (Figure 2, Regierung der Bundesrepublik Deutschland 2000). At first sight the results seem clear: 39.9% of samples have rapidly *de*creasing nitrate levels[6] whereas only 25.8% have rapidly *in*creasing levels. In fact these values could be coincidental or could result primarily from hydrological effects and are not the effects of lower emissions.

[5] 25 mg/l NO_3 = 5.6 mg/l NO_3-N which represents the European reference value

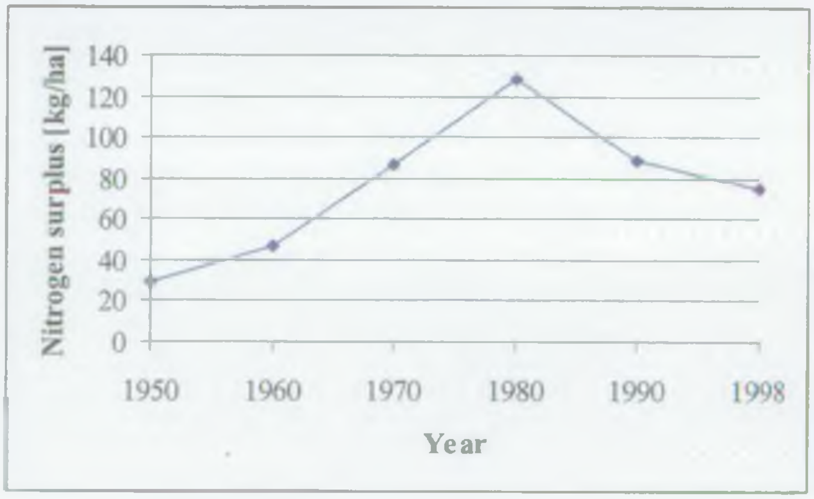
[6] 'Fast decrease' means the reduction of the nitrate concentration of more than 6 mg/(l·a) analyzed by the method of linear regression, 'slow decrease' means the reduction of 1.5 mg/(l·a) to 6 mg/(l·a). The increase of the concentration is defined with the same values.

Figure 2 Development of nitrate concentration from 1994/95 to 1998/99 (Regierung der Bundesrepublik Deutschland 2000)



The most important source for nitrogen emissions is agriculture. Since the discussion about high nitrate concentrations in groundwater and 'good agricultural practice' began in the eighties, the nitrogen surplus has decreased considerably (Figure 3). It is estimated that the level of the nitrogen surplus will be roughly constant in the future (Regierung der Bundesrepublik Deutschland 2000).

Figure 3 Development of nitrogen surplus of agricultural used areas[7]



[7] Nitrogen Surplus = mineral fertilizer + farm manure + nitrogen fixation through leguminosae + atmospheric deposition - diminution through harvesting

Traditional political instrument: definition of groundwater protection areas

The traditional political instrument to protect groundwater resources against pollutants was the demarcation of protected areas (Section 19 of the German Water Act *Wasserhaushaltsgesetz*). Every protected area has its own ordinance, which defines the specific prohibitions and regulations that must be adhered to within its limits. These ordinances reflect the technical rules of the German Technical Scientific Association on Gas and Water (DVGW 1995) and in some federal states (*Bundesländer*) are based on model ordinances (e.g. in the federal state of Hesse the *Muster Wasserschutzgebietsverordnung*). As in the UK, these protected areas are split into three zones:

- Zone I (inner source protection)
- Zone II (outer source protection)
- Zone III (source catchment)

However, in Germany the boundaries of these zones are defined in a different way from the UK.

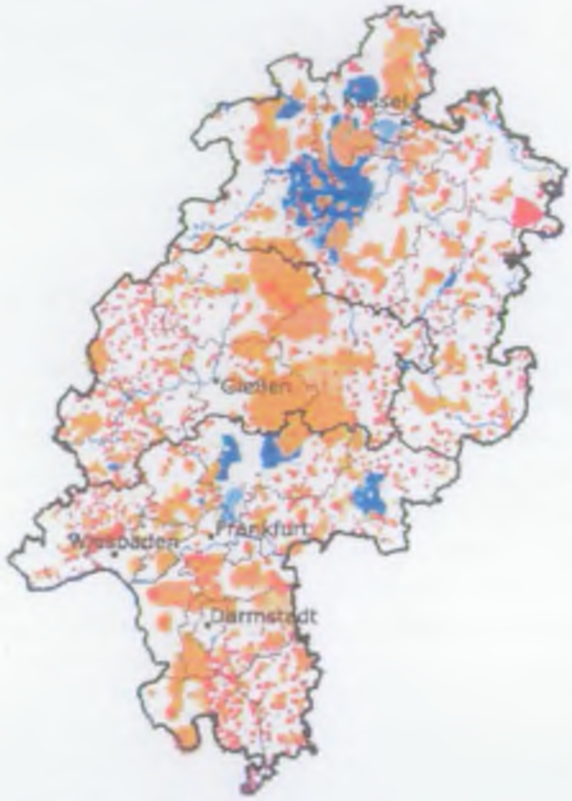
Zone I is the area directly around the water source. Generally it covers a surface area of at least 10 m around the water catchment. This land is owned by the water supply company. In zone I any other form of land use is forbidden.

Zone II is defined by the 50-day travel line. Typical prohibitions in zone II are the construction of sewer pipes, the infiltration of collected precipitation, the construction or extension of industrial and agricultural buildings, (in principle) roads and tracks, the use of manure as fertilizer, grazing, storage of manure, mineral fertilizer, pesticides or oil. Also the use of mineral fertilizer is limited.

Zone III contains (in principle) the whole groundwater catchment area. It is often split into zone III A (less than 2 km from the catchment) and III B (the rest of zone III). In zone III the regulations mainly concern industrial plants, sewer pipes, waste sites and building.

In some federal states of Germany such protected areas cover a large part of the surface land area (Figure 4).

Figure 4 Water protection areas in the German federal state of Hesse
(http://www.umwelt.hessen.de/atlas/)



As the analysis of data of soil and groundwater shows, the juridical framework and especially the definition of protected areas is not adequate to prevent the diffuse emissions of the agriculture industry (e.g. SRU 1996, Bach and Frede 1995). One crucial point is that the ordinances of the protected areas define only regulations for the catchment areas. A protection of water over the whole surface area is not possible through this political instrument. For example the German Council of Environmental Advisors demands the introduction of a concept of countrywide groundwater protection with regional focal points (SRU 1998). Furthermore, inside the protected areas the groundwater is only partly protected. Effective control of diffuse emissions does not exist. In addition the ordinances are often outdated and there is no mechanism to implement amendments in the water administration. This situation lead to the creation of co-operative agreements between agricultural producers and water suppliers.

'Good agricultural practice' and Section 19.4 WHG: Basis for co-operative agreements between water supply and agriculture

Section 19.4 of the German Water Act (*Wasserhaushaltsgesetz WHG)* states that farmers have to be compensated if they are obliged to accept regulations which are stricter than 'good agricultural practice' in order to protect water resources.

The federal states have incorporated this article into their own legislative frameworks in a variety of ways. Two different models predominate: the centralized model (especially in Baden-Wuerttemberg) and the decentralized model (most other federal states e.g. Hesse) (LAWA 2000). The centralized model means that measures for the protection and the control of water are centrally defined by the administration of the federal state and the compensation is paid by the federal state. In the decentralized model the compensation has to be paid by the water supply company and the measures are also defined on a local level. Most federal states define the possibility of co-operative agreements between water supply companies and farmers in protection areas. As the regulations about co-operative agreements vary between the federal states the case of the federal state Hesse is described as an example.

CO-OPERATIVE AGREEMENTS IN HESSE: JURIDICAL BASIS AND GOALS

An Hessian ordinance (*Hessische Musterwasserschutzgebietsverordnung Muster-WSGVO*) introduced the possibility of co-operative agreements between farmers in water protection areas and the municipal governments, who are responsible for water supply in Germany (Section 13 *Muster-WSGVO*)[8]. The basic goal of such co-operation is the reduction of nitrate and pesticide emissions and efficient farming in the water protection areas (HMUEJFG 1997). The contract between an individual farmer and the municipality is drawn up under private law. New regulations are defined that replace the regulations of the existing ordinance of the relevant water protection area. This contract also has to be accepted by the higher water authority (*Obere Wasserbehörde: Staatliches Umweltamt*). Expert advice plays an important role in the context of the co-operative agreements:

- To find a balance of the interests between agriculture and water supply.
- To give scientific advice.
- To implement regular contact between the actors.
- To be "on the spot".
- To have the function of indirect control.

The co-operative agreements include - among other things - regulations about farming practices, e.g. N_{min}-measurements[9], catch-crop growing, top fertilization of stable manure, bonus systems for reduced nitrate in the soil (at the end of the vegetation period) and N-balances on the level of plots. They also set compensation payments corresponding to Section 19.4 WHG (and Section 92 of the Hessian Water Act *Hessisches Wassergesetz HWG*). When farmers do not enter into co-operative agreements it is their responsibility to prove that compensation payments are required (Section 92 HWG). As a result of the high cost of such a procedure farmers who are not integrated into co-operation agreements do not often demand compensation.

Survey of co-operative agreements in Hesse

All together in Hesse there are 24 local co-operative agreements in water protection areas (Figure 5). Five of the 21 Hessian districts (*Landkreise*) have regional co-operative agreements. This represents more than a quarter of the surface of this federal state. Compared to the local co-operative agreements the regional contracts involve a lower level of agricultural expert advice. They also provide no compensation payments or payments for special agricultural measures (Richter *et al.* 1998).

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[8] Concerning Section 28 of the German constitution *Grundgesetz* the municipalities are responsible for elements of the provision of vital public services (*Daseinsvorsorge*), e.g. the water supply. Usually the realization of the water supply is in the hands of water supply companies which are mostly owned by the municipalities. However the co-operative agreement with the farmers is in Hesse are signed by the municipality.

[9] Measurements of the mineral nitrogen in the soil (usually 0-90 cm)

In local co-operative agreements the corresponding raw water tends to have nitrate concentrations over 25 mg/l NO_3 or have a rapidly increasing nitrate concentration. On the other hand almost no co-operative agreements exist in the regions where the nitrate problem is very intensive[10].

Figure 5 Local and regional co-operations in the German federal state Hesse

Impacts of co-operative agreements in Hesse

The analysis of interviews[11] with agricultural advisors, farmers and representatives of water supply companies showed that, in general, co-operative agreements are seen as useful for groundwater protection. But the various participants have different reasons for supporting this policy. All the participants also identified crucial obstacles and negative aspects of co-operative agreements.

- Most farmers are unwilling to sign contracts which reduce their freedom to choose the way they farm. Often the proof that they are not groundwater polluters is an important motivation for farmers to enter into co-operative agreements. Compensation payments are a central aspect but do not dominate all other issues.

- Water suppliers have a number of reasons for signing co-operative agreements, in particular the cost of treating water with high nitrate concentrations and an orientation to long-term impacts of the agriculture on the raw water. In any case the water supplier investigates the cost-effect of co-operative agreements[12] in the context of the water price.

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[10] concerning the Hessian Environment Agency *HLFU Hessische Landesanstalt für Umwelt*, 1999.
[11] carried out during the time from 1998 to 2000.
[12] especially compensation payments basing on Section19.4 WHG – the German Water Act.

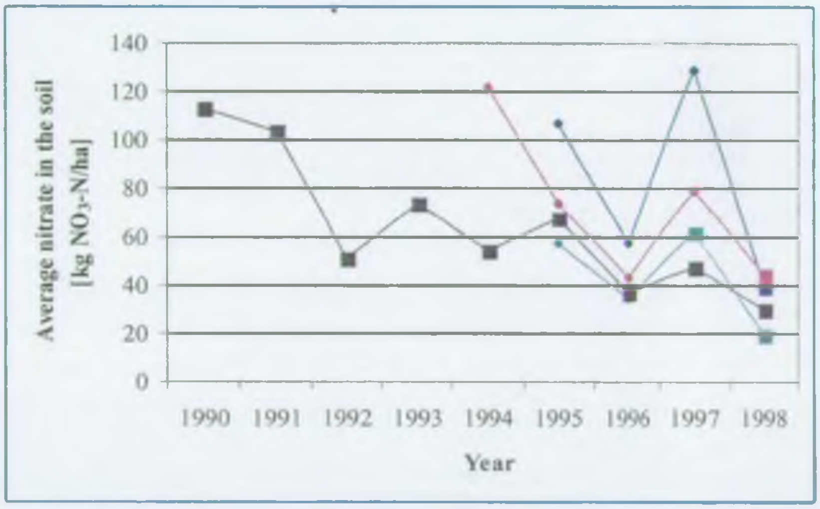
- An important element for the successful initiation of co-operation is the strong link with the political instruments of the regulatory law (especially the definition of water protection areas and adequate regulations). The analysis showed that with the amendment of a water protection area ordinance the willingness to create co-operative agreements (especially on the side of the farmers) often increases.

The focal point of this co-operation is the reduction of nitrate concentrations. Beyond that co-operative agreements can have an effect on the emission of other substances from fertilizers (e.g. phosphates). The resulting reduction of nitrate concentrations in wells/sources can only be shown in two Hessian cases. This result is not astonishing as the nitrate reduction in groundwater is very slow because of the long time the water needs for seepage through the unsaturated zone and the time for the mixing process in the aquifer (e.g. Rohmann 1993).

The reduction of NO_3-N in the soil at the end of the vegetation period cannot be identified unequivocally (**Error! Reference source not found.**). Also meteorological variations have a dramatic influence on NO_3-N in the soil. For example the high NO_3-N values in 1997 were caused by a low level of precipitation, which lead to a low level of vegetation and nutrient absorption.

Figure 6 Average values of NO_3-N at the end of the vegetation period in five co-operative agreements in the federal state Hesse

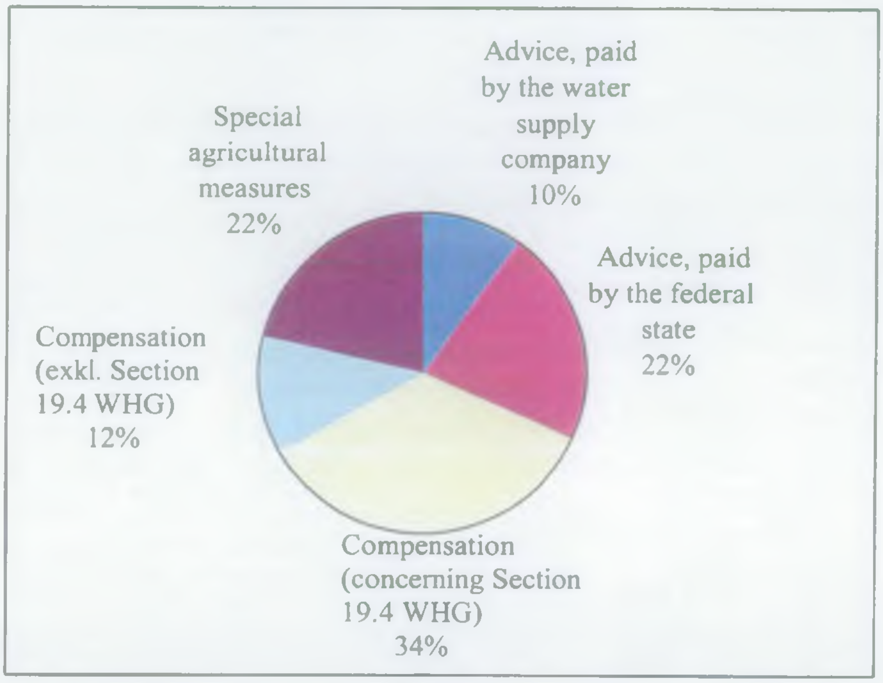
(Key: ♦ co-operations do not exist, ■ co-operation exists)



Costs and efficiency

The costs of co-operative agreements are split into three roughly equal parts: agricultural expert advice, compensation payments (Section 19.4 WHG) and other payments (Figure 7). In the context of local co-operation roughly a fifth of the costs were paid by subsidies from the federal state (through the Hessian Groundwater Tax). The subsidies were mainly used to cover the costs of expert advice but also for field experiments, information and training meetings and other costs. The subsidized share of regional co-operative agreements was about 80% (data base: 4 out of 6 of the regional co-operative agreements). Costs for regional co-operation consist mainly of expenditure on expert advice, which was also subsidized through the Hessian Groundwater Tax. Recently the new conservative-liberal Hessian government has resolved to abolish the Hessian Groundwater Tax, and as a first step the tax has been halved (years 2001 and 2002). By way of contrast the co-operation between agricultural producers and water suppliers will be subsidized later on (following a decision of April 2001).

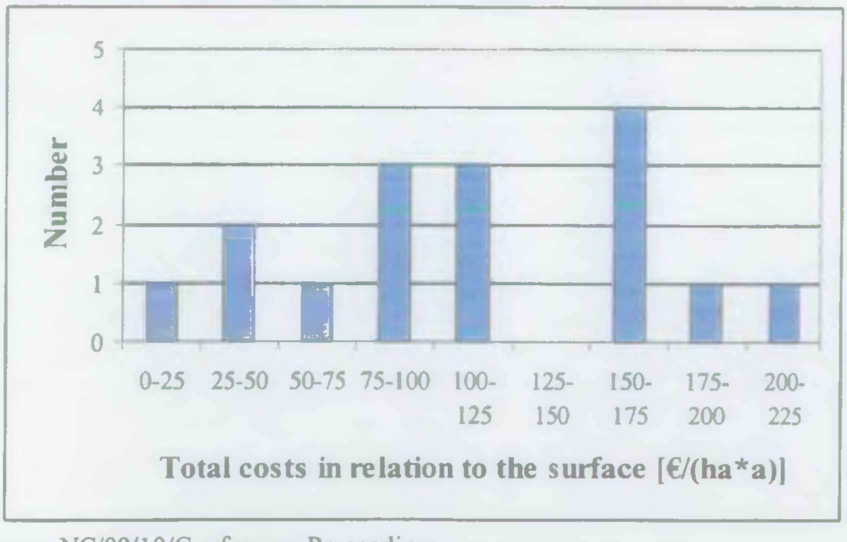
Figure 7: Costs of local co-operative agreements (data drawn from 12 out of all 24 local contracts)



Costs in relation to the surface of the co-operation

The total costs of the regional co-operative agreements in relation to the surface area protected (1.5 to 40 €/(ha·a)) are much lower than the total costs of the local co-operative agreements (Figure 8). This difference can be explained by the low intensity of expert advice and the elimination of other costs (e.g. costs for compensation or special measurements).

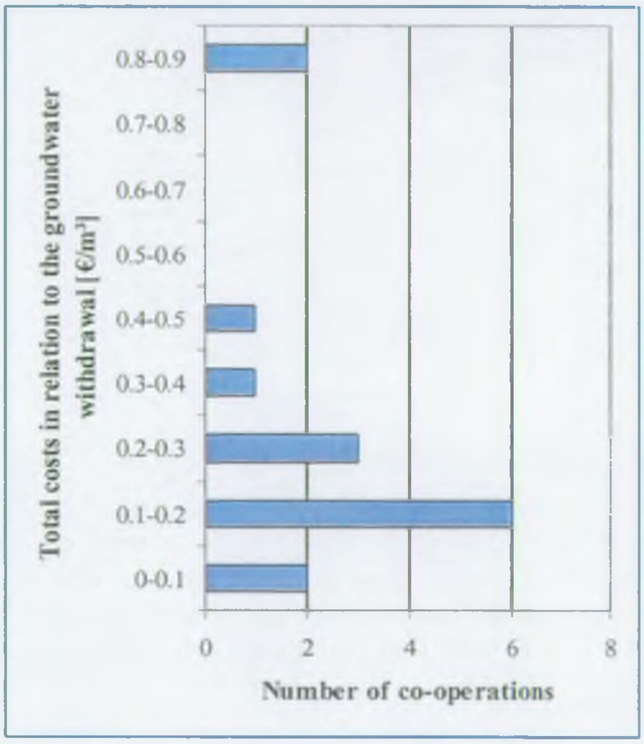
Figure 8 Frequency of the total costs of local co-operation in relation to the surface (data drawn from 16 of the 24 co-operative agreements, Average ± standard deviation: 114 €/(ha·a) ± 58 €/(ha·a))



Costs in relation to groundwater withdrawal

The focal point of the costs in relation to groundwater withdrawal is between 0.1 and 0.3 €/m³ (Figure 9). In two specific co-operative agreements, where the value of groundwater withdrawal is relatively low, the specific costs are the highest (between 0.8 and 0.9 €/m³). If the total costs are calculated in relation to the whole groundwater withdrawal by the water supply companies the values are much lower (18 of 24 contracts 0.09 €/m³± 0.08 €/m³).

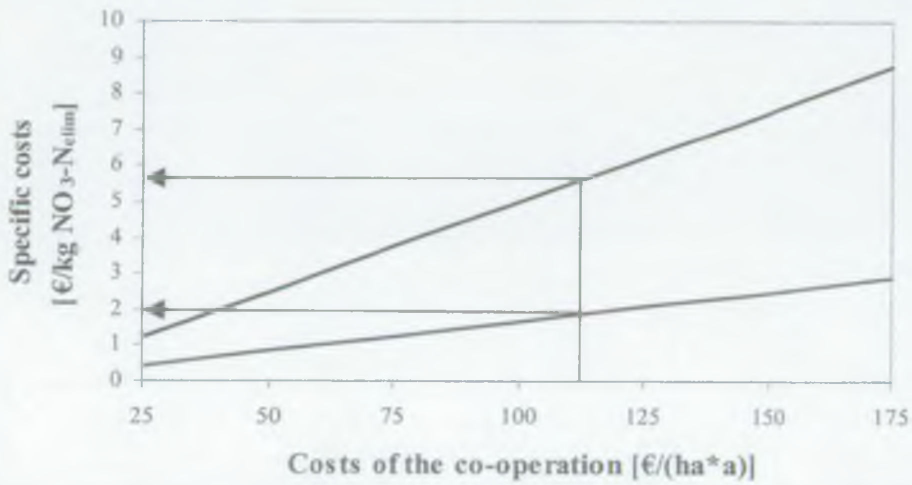
Figure 9 Frequency of the total costs of local co-operations in relation to the groundwater withdrawal of the adequate catchment area (data drawn from 16 of the 24 local co-operative agreements, 0.29 €/m³ ± 0.26 €/m³).



COMPARISON OF THE SPECIFIC COSTS OF LOCAL CO-OPERATION AND NITRATE REDUCTION THROUGH TECHNICAL WATER TREATMENT

The costs of nitrate reduction through water treatment are about 0.25 €/m³ to 0.75 €/m³ (authors' calculation based on Köbler 1997). This value has to be compared with the average specific cost of local co-operative agreements (0.29 €/m³, range of cost values: 0.05 to 1.05 €/m³). The costs of the nitrate reduction through water treatment in relation to the eliminated nitrate are roughly between 3 and 11 €/kg NO_3-N_{elim} (authors' calculation based on Köbler 1997). The results of various co-operative agreements and research-projects (among others Homm-Belzer 1995, Frede *et al.* 1998, KTBL 1995, KTBL 1994) as well as the investigations of the authors show a reduction of nitrate in the soil (at the end of the vegetation period) through local co-operation of 20 to 60 kg NO_3-N_{elim} / (ha a). Together with the values of the costs in relation to the surface area, the efficiency can be calculated (Figure 10). If the costs in relation to the surface are 114 €/(ha·a) - the average of the costs of local co-operations - the specific costs are 2 to 6 €/kg NO_3-N_{elim}.

Figure 10 Costs of co-operative agreements concerning the reduction of nitrate (at the end of the vegetation period) in the soil (upper graph: 60 kg NO_3-N_{elim} / (ha a); lower graph: 20 kg NO_3-N_{elim} / (ha a)).



These comparisons have been worked out with the assumption that the costs for water treatment and co-operation remain the same over time. In fact one can assume that the intensity of the expert advice in the context of co-operation will decrease over the time. Considering these co-operative agreements could become more economic in the long run. On the other hand it is clear that changes in agricultural practice normally need years or even decades to have any effect on groundwater. The implication of this is that co-operative agreements have to be started much earlier than water treatment - which is an 'end-of-the-pipe' technology - to secure a safe water supply. It should also be stressed that the sampling points of this comparison are different. In the case of water treatment it is the nitrate concentration in the raw water whereas in the case of the co-operative agreements the nitrate reduction in the soil is taken as the spatial reference point. Additionally it has to be considered that the water treatment is only related to drinking water quality whereas co-operative agreements contribute to sustainable water management.

CONCLUSIONS

Diffuse pollution from agricultural inputs (nitrate, pesticides) is a crucial problem for groundwater management and the public water supply. In the past the definition of water protection areas has failed to prevent high concentrations of nitrate and pesticides reaching groundwater. The first research results show that co-operative agreements between agricultural producers and water suppliers successfully complete the work begun by the ordinances of water supply areas – even if a lot of obstacles exist. An initial result could be the reduction of mineral nitrogen in the soil. In the federal state of Hesse most of the co-operative agreements are not well enough established to state clearly whether such a reduction has occurred, but clear trends exist. Taking typical values of nitrogen reduction achieved through co-operation the same range of efficiency as water treatment can be achieved (in relation to the water quantity and the reduced nitrogen).

But it has to be stressed that co-operation need years or even decades to have any considerable effect on the quality of the groundwater. In contrast to technical measures (such as mixing different raw waters, water treatment or water transmission from another catchment) co-operative agreements contribute to a qualitative improvement in water management in general (also regarding surface waters) and support sustainability targeted water management.

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8. GROUNDWATER PROTECTION IN DENMARK, 2001

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ABSTRACT

The water supply in Denmark is based on high quality ground water and complex and expensive treatment is not required. The county councils in Denmark are responsible for the planning and administration of the water resources. Increasing problems with water quality have made groundwaters a very important issue in Denmark. In December 1998 the Danish parliament decided, that the county councils should be responsible for a detailed mapping of the water resources within an area of 33% of Denmark. The detailed mapping will be used in the classification of ground water protection zones and to set restricted guidelines to prevent ground water pollution from city development, leaching of nitrate etc. The protection zones will have great influence on future area planning. In 2001 the county councils shall decide a plan of action with timetable for implementing the necessary measures. The total cost price is estimated to 115 million Euro. During a 10-year period the consumers pay extra 0,02 Euro per m3 of water.

INTRODUCTION

Denmark occupies an area of some 43,000 km2. The country is fragmented. The peninsula of Jut land has an area of 30,000 km2. Denmark is low-lying, with its highest point just 172 m above sea level. Most of the country consists of Quaternary deposits overlying chalk, limestone and tertiary clay. The combination of low topography and widespread consolidated and unconsolidated aquifers ensures a plentiful and easily accessible water supply. The total water abstraction in Denmark is approx. 800 million m3 per year. The household consumption of the 5.25 million inhabitants in Denmark amounts to approx. 250 million m3 per year. Groundwater provides 99 per cent of water need in Denmark. The only surface water used for public supply is in Zealand. Since the water quality generally is good, complex and expensive treatment is not required. Expensive lengthy pipelines, served by large central water plants, are also unnecessary. Thus, water supplies in Denmark are mainly decentralised. Altogether there are about 3.300 public supplies and some 130,000 private water sources (boreholes and dug wells). Two-thirds of the national supply is provided by about 200 municipal waterworks and the remainder by private cooperative plants. Planning and public administration in Denmark is carried out at three governmental levels: Central government, County councils (14) and Municipal councils (275). Laws and legal notices are prepared by the State. The county councils are responsible for the major administration of water abstraction licences and for the protection of water resources against contamination. The Water Supply Act and Environmental Protection Act set rules, according to which the use of groundwater and surface water must be regulated on the basis of integrated planning and through comprehensive evaluation of the size and protection of the water resource, the needs for a water supply and the protection of the environment and nature. The administration of water licences is regulated by water resource plans, drawn up by the county councils in accordance with the Water Supply Act. The water resource plan is the frame for the water supply plan drawn up by the municipal councils. The water supply plan contains the guidelines for the organisation of the water supply, i.e. the co-ordination of present water supply and extension and operation of water supply. The water supply plans have to be approved by the county councils.

Water planning in Denmark is part of a larger system of physical and environmental planning called Public Sector Planning. The county councils carry out the public sector planning at regional level. The general rules for this planning are issued by the Minister of the Environment The object of this planning is to ensure that the use of land and natural resources is based on an overall assessment, which aims to provide the foundation for a sound environment and to contribute to the prevention of pollution: the principles of sustainable development.

The planning scheme consists of a number of mutually balanced plans for public administration and services. The water resource plans play a vital role in the balancing of plans for use and protection of natural resources in the open landscape. Public planning in Denmark is first and foremost the physical planning of the counties and municipalities. The planning scheme is based on three main principles: framework management, decentralization and public hearing. The framework management implies that central government or county authorities determine the framework for the actions of the subordinate authorities, but do not subsequently interfere in these actions. Decentralization implies that county and municipal democratically elected authorities decide for example the utilization of water resources and ground water protection within the given framework. Public hearing implies that citizens may participate in the planning prior of the decision-making.

Figure 1 Increasing problems with water quality have made ground waters a very important issue in Denmark.

In 1995 the Minister of Environment decided a 10-subject scheme to improve ground water protection. One of the major issues is that all pesticides that can pollute the ground water should be forbidden. Another major issue was that counties in Denmark by the end of 1997 should make new water resource plans and classify the counties into 3 types of recharge areas. The classification includes 1. Recharge area of particular value for the drinking water supply, 2. Recharge area of value for the drinking water supply and 3. Recharge area of limited value for the drinking water supply. The classification is based on a comprehensive evaluation of the size and quality of the water resource.

In July 1998 the Danish Parliament (Folketinget) decided to launch an ambitious plan to significantly intensify the hydrogeological investigation of the Danish ground water resources in order to be well prepared to meet the future water supply challenges in protecting the ground water resources. The Danish parliament have decided, that the 14 county councils in Denmark on top of their water resource planning duties should also be responsible for a much more detailed mapping of the water resources and a public planning scheme for ground water protection.

This mapping and planning is supposed to take place over the next 10 years and includes all areas characterized a recharge area of particular value for the drinking water supply interests amounting to almost 16.000 km2 or 1/3 of the total area of Denmark. The financial aspects of this detailed mapping and planning project has also been decided upon. The total cost price is estimated to be around 115 million Euro. The cost price for detail mapping of one square kilometre is estimated to be 7.500 Euro including geophysical mapping, drilling, water samples and hydrological modelling.

During the 10 year mapping and planning period the consumers pay extra 0,02 Euro per m3 of water to the county councils amounting to about 4 Euro per family per year.
The next step in the ground water protection scheme will be classification in ground water protection zones based on this detailed geological mapping and calculations made by hydrological models within the areas classified as recharge areas of great drinking water interest. The classification in protection zones and guide-lines will be used to prevent ground water pollution from city development, leaching of nitrate and to decide on possible clearing of old waste disposals etc.

The hydrological conditions in Denmark imply that for every million cubic metre of ground water you whish to abstract, you have to take the necessary steps to evaluate the protection of 10 to 15 square kilometres.

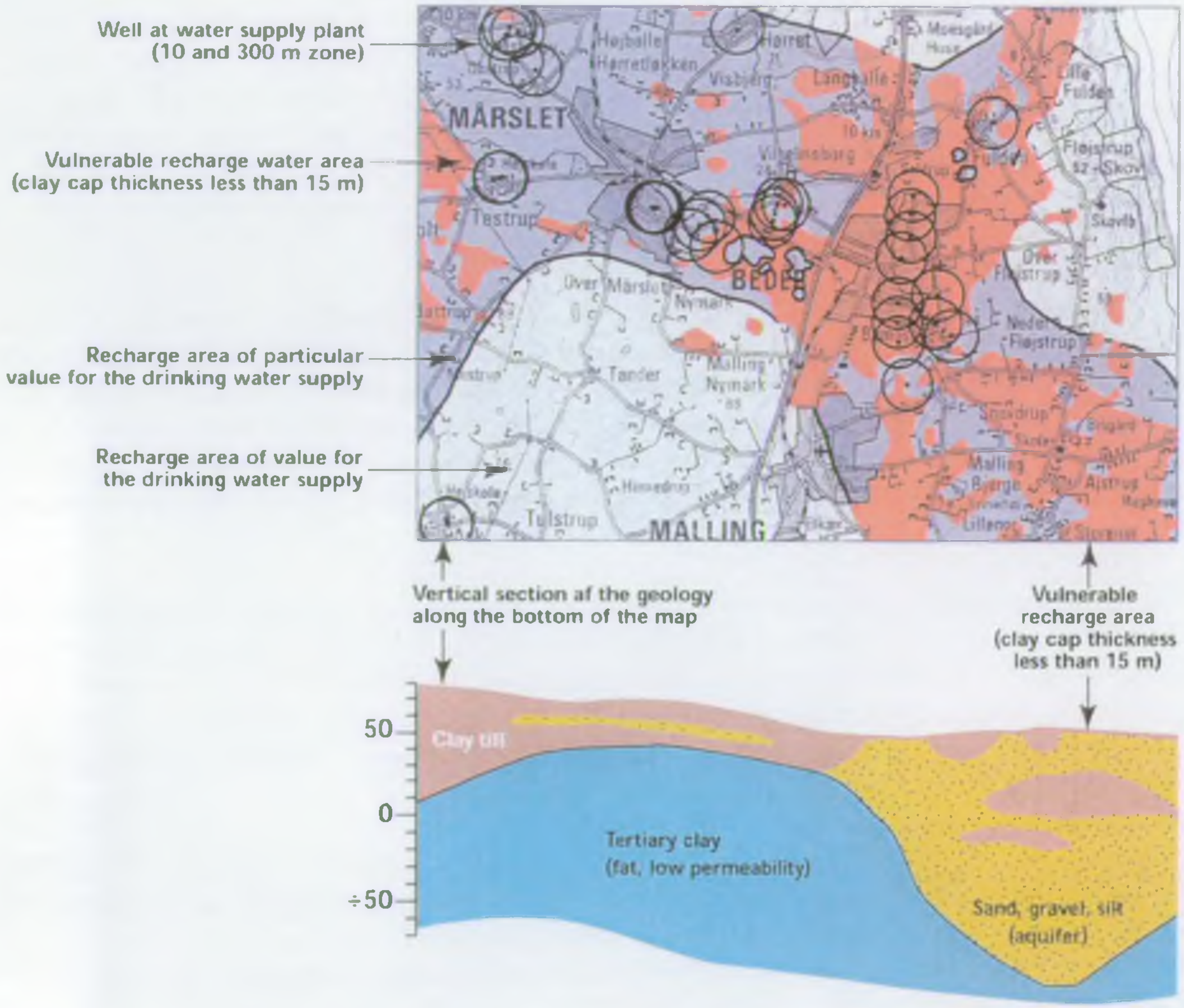


Figure 2 Ground water protection by way of zones at Beder in Jutland (well field)

The most important source of countrywide information on ground water conditions and aquifers is drilling information. The national file of drills in Denmark containing information about water supply drills back to 1926 has up until now been the primary source of geological and hydro geological knowledge about the aquifers. There have been more than 120,000 such drillings in Denmark. It amounts to an average no more than approx. 3 drillings per km2, including the poorly documented drillings. This drilling density allows only a very general description of the complex geological composition of the Danish aquifers.

Detailed mapping in Århus County during 1994-97 has shown that the traditional mapping based only on drilling data is too inaccurate to set restricted guide-lines for land use. According to the guide lines in guidance from the Danish Environmental Protection Agency the usage of geophysical methods are expected to play an important role in this very massive mapping campaign. The experience from the usage of geophysical methods in the mapping of large-scale geological structures around the city of Århus, which will be referred to on the following pages, has been of great value for this guidance. In recent years, new methods of geophysical mapping have been developed through a joint venture involving Århus County, the Public Utilities of Århus and the University of Århus, designed to upgrade and rationalise fieldwork, as well as regionalise the use of the mapping methods. These new methods allow precise the detailed mapping, which is needed today. In the municipality of Århus with an area of 500 km2 there has been made more than 7,000 Transient Electromagnetic Soundings and run more than 2,000 km using the Pulled Array Continuous Electrical Profiling Method. The kind of mapping necessary involves so many aspects that one method of investigation alone will not suffice. There has therefore been developed different mapping methods, which are used to investigate different facets of aquifers: Their extension, vulnerability and water quality.

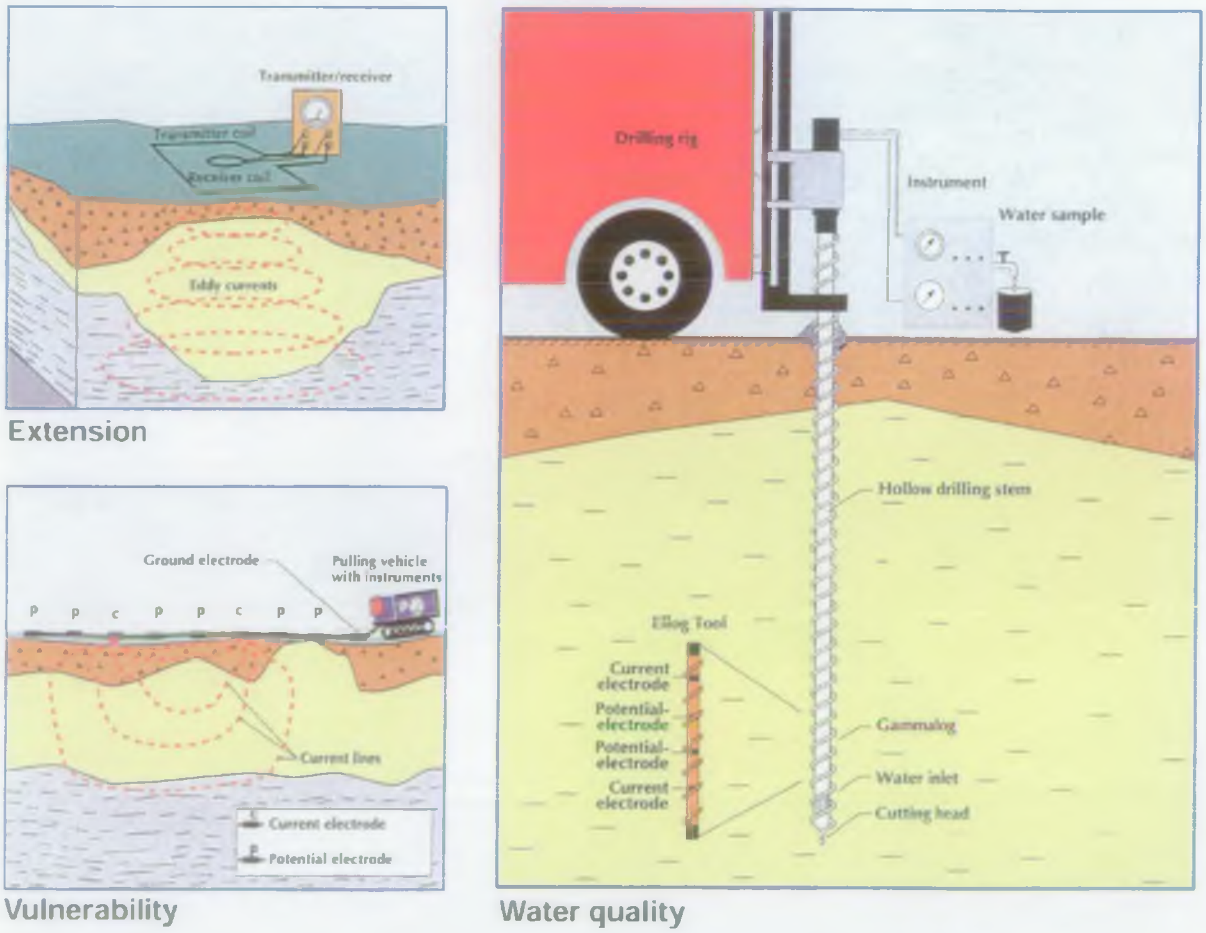


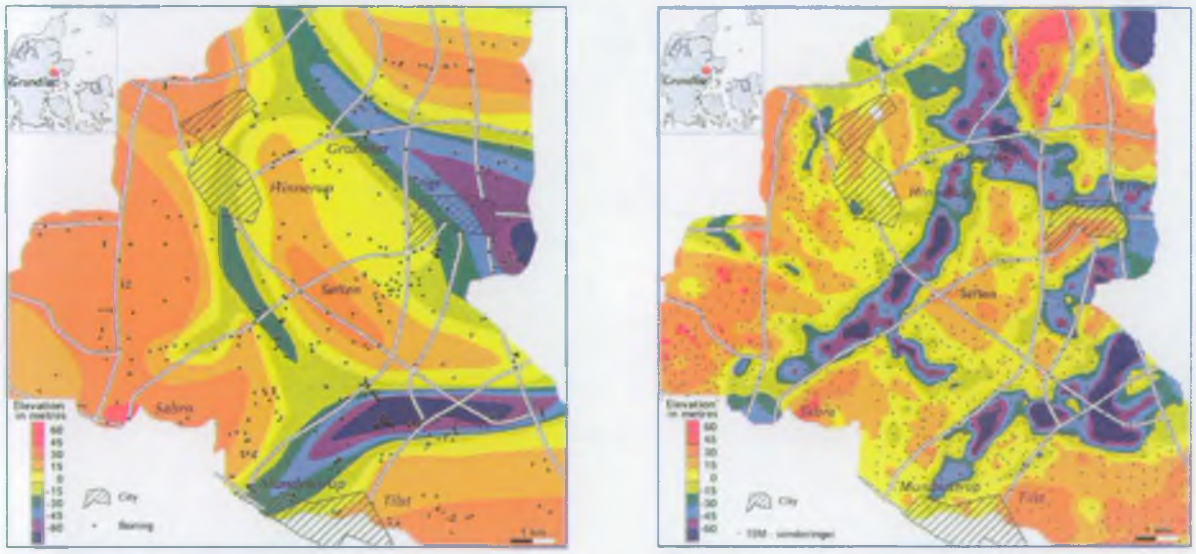
Figure 3 Different mapping methods to investigate different facets of aquifers

THE EXTENSION OF AQUIFERS

Aquifers are often to be found in the tertiary clay substratum of bounded, eroded valleys. They can, to a greater or lesser degree, be interconnected. However it is important to know the regional structures and their interconnections in order to be able to assess potential possibilities for abstraction, to account regional resources and to point out key vulnerable land areas above aquifers. The Transient Electromagnetic Sounding Method (TEM) has in recent years been introduced in connection with the mapping of larger structural geological pictures, and has provided extremely good results. The method maps out primarily those layers of clay, which demarcate the boundaries of the aquifers. Despite TEM only having been practised in Denmark for a limited amount of years, a substantial number of investigations have been carried out. The results have corresponded fully with drilling information which were available from the areas concerned. For the sake of the quality and interpretation of the data, the method requires somewhat dense measuring. It thereby also reveals the relatively heterogeneous composition of most aquifers. Insight into this is a precondition for building up monitoring programmes and interpreting the results of these. Heterogeneity is of great importance to the flow pattern of the ground water within an aquifer and thereby also to the interpretation of the quality of water which is observed at any given place.

Today the TEM has been developed to a continuous profiling method. The receiver antennae have been reduced to 3x5 meters from 40x40 meters and transmitter effect has been upgraded. The new system makes continuous measurements when pulled by a small caterpillar. The position of the measurements is based on GPS. All data are stored and interpret for quality test in the field. The measurements are made in profiles with an average in distance of 250 meters.

The prequartenary clay surface



Map based on 518 borings

Map based on 1400 TEM soundings

Figure 4 The prequartenary clay surface

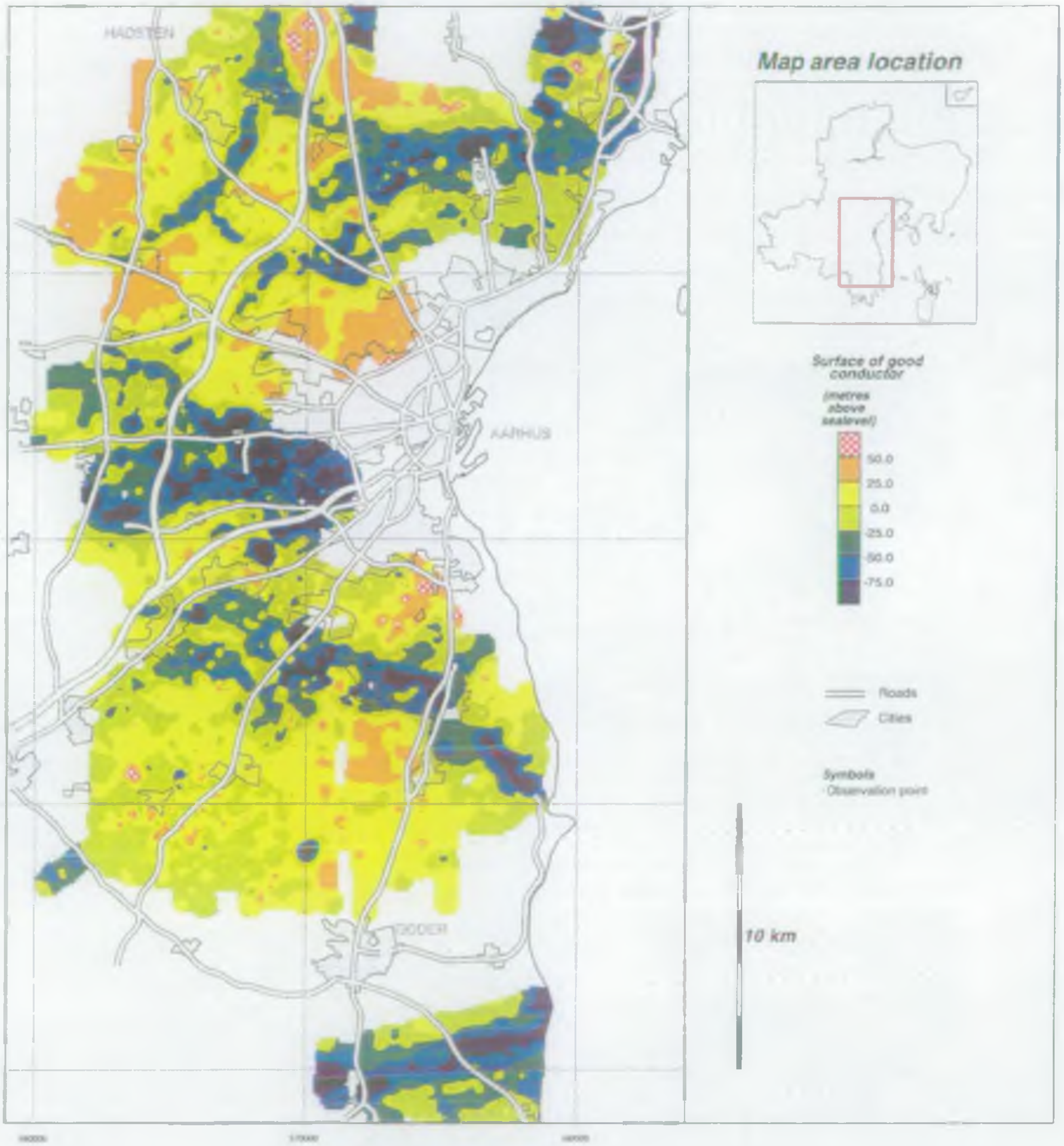
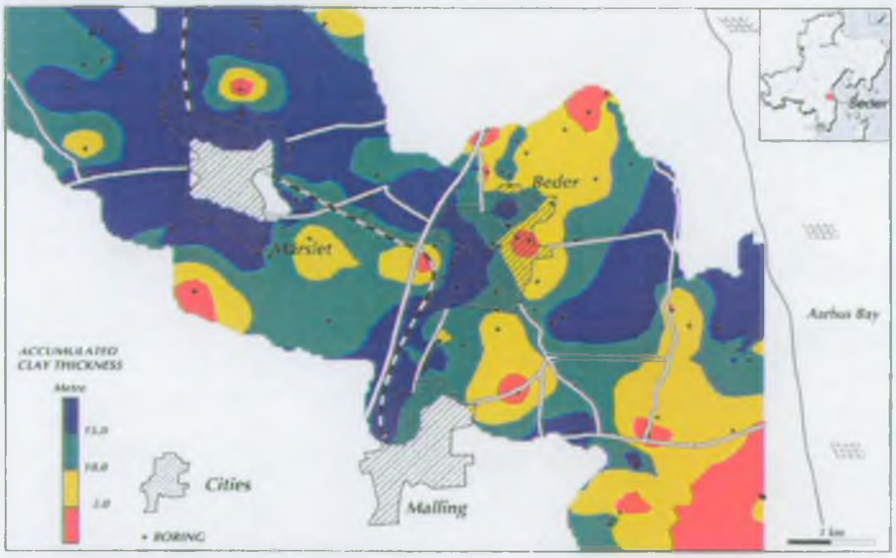


Figure 5 TEM-surface of good conductor 7000 soundings

THE VULNERABILITY OF AQUIFERS

Aquifers are recharged with water, which seeps down through above-lying covering layers. How fast the water seeps down through the earth and how the quality of the water changes, depends very much on the nature of the layers through which it passes. Water moves quickly in sandy layers and slowly in clay. Very generally speaking, it can be said that the biological/chemical/physical processes, which take place when water passes through the clay, purify it better than when it passes through sand. It is therefore important that detailed mapping of the distribution and variation of sandy areas (window) in the covering layers above the aquifers can be carried out. Such mapping can be done by means of a newly developed Pulled Array Continuous Electrical Profiling Method.



Mapping of the upper 20 metres based on 100 km of continuous electrical profiling

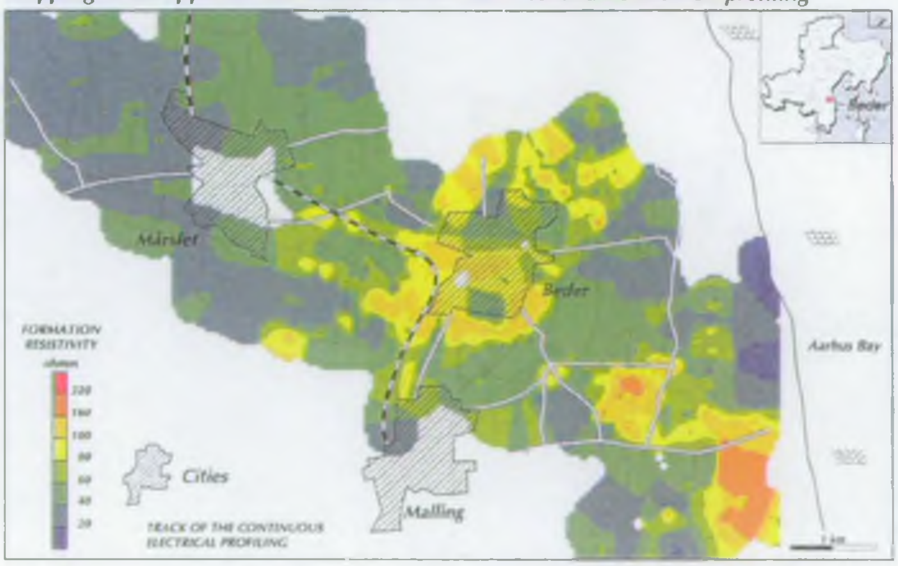


Figure 6 Mapping of the accumulated clay thickness within the upper 20 metres based on information from 165 borings

AQUIFER WATER QUALITY

In Denmark the aim is to avoid complex water treatment at water works. It is therefore necessary to have detailed knowledge of the quality and the variation in the quality of water in aquifers. Otherwise, the location of abstraction wells and the distribution of abstractions will not be optimised. Likewise, this detailed knowledge is a precondition for the estimation and monitoring of water quality. It is economically and practically impossible to gather knowledge of this detail by means of traditional drilling methods.

A new Ellog Auger Drilling method has therefore been developed, whereby different log-measurements are made and level-specific water samples are taken. A major advantage of using the new Ellog Auger Drilling method is, that the interplay between the variation in water quality and litho logical conditions can be observed - interplay, which is important but seldom recognised in connection with traditional drilling techniques. The method can be used to build up a picture of water quality in an aquifer.

Figure 7 below shows the mapping of the upper approximate 30 meters based on continuous electrical profiling. The vulnerable, sandy "window" down to the aquifer appears as the dark high resistive area in contrast to the light colour low resistive clay cap. Note the trace from well 79.920. (The Grundfør trace).

The vulnerable, sandy "windows"

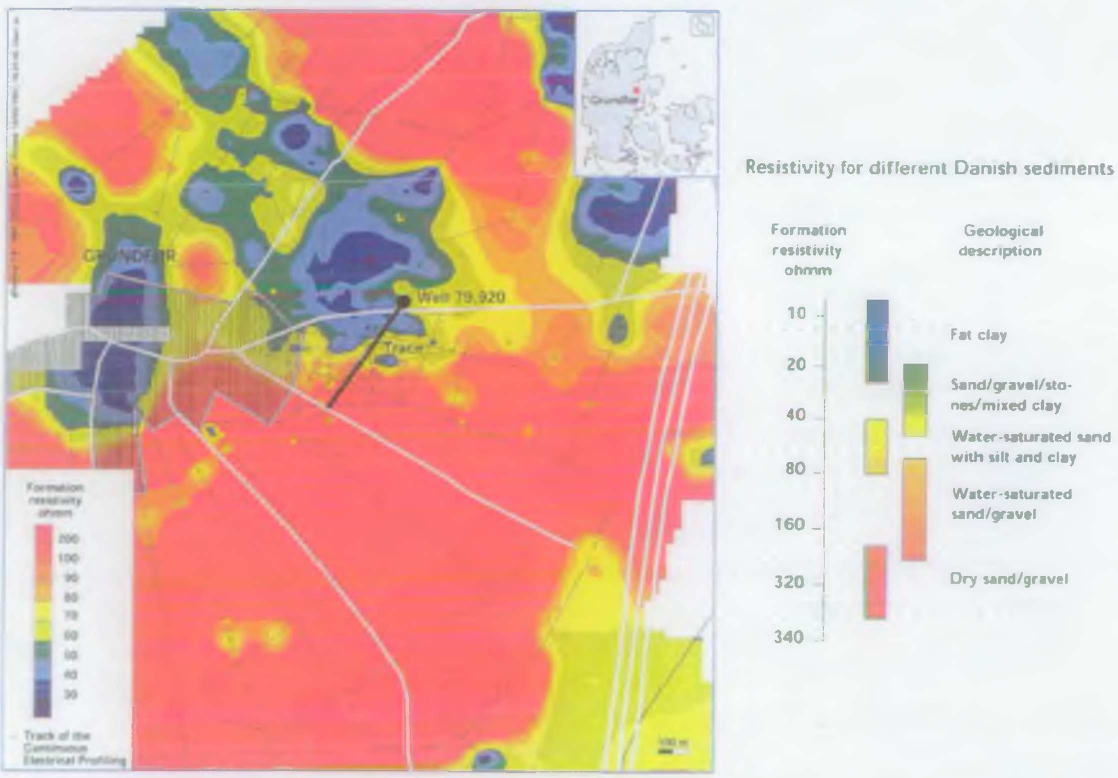


Figure 7 The mapping of the upper approximate 30 meters based on continuous electrical profiling.

Nitrate profile at the Grundfør trace. With the Ellog Auger Drilling Method water samples has been taken during the drilling in the saturated zone. The nitrate has easy access to the aquifer through the sandy "window". As is shown below nitrate and other pollutants affect the ground water quality to considerable depths in areas with sandy windows.

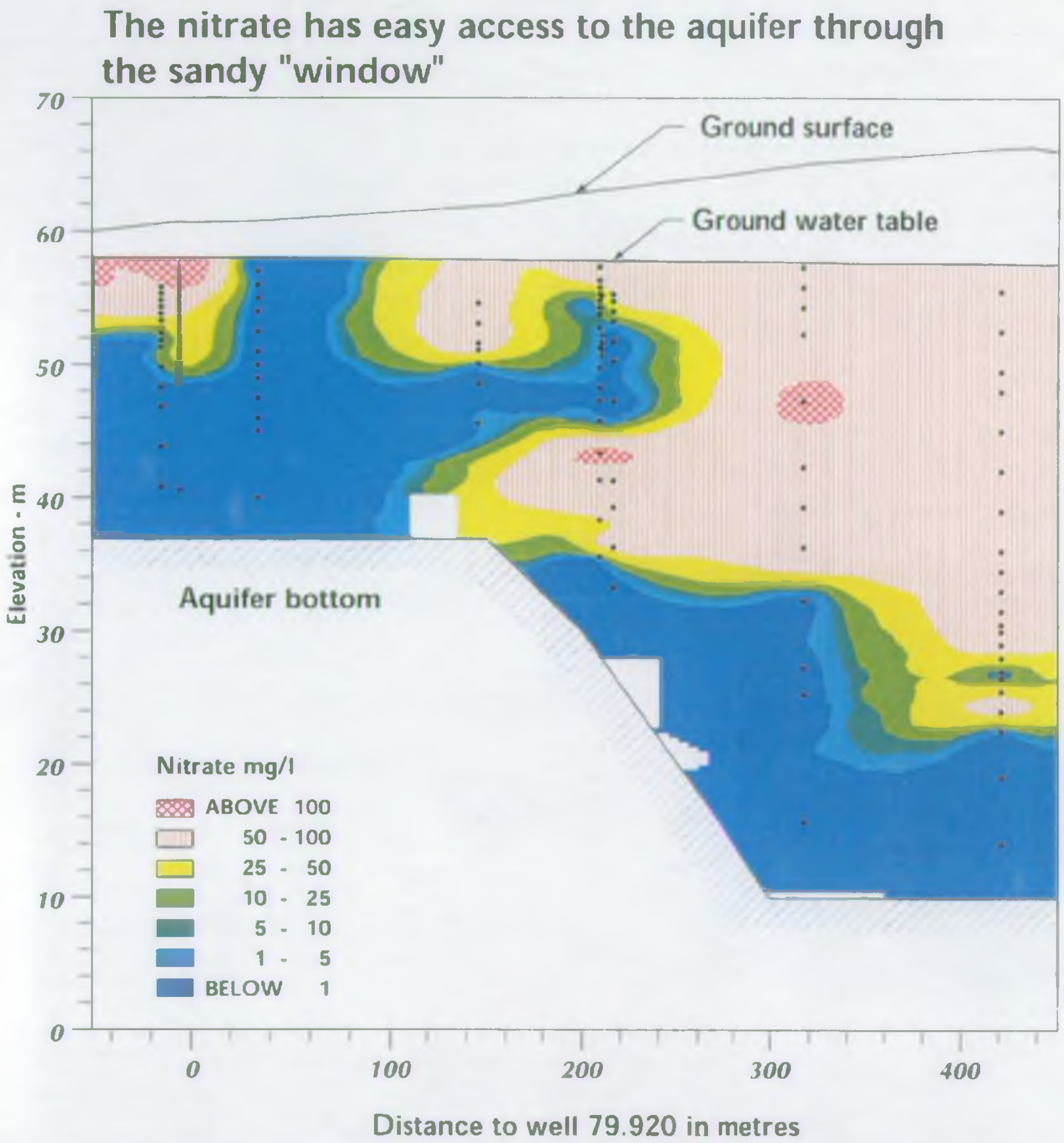


Figure 8 The affect that nitrate and other pollutants have on ground water quality in areas with sandy windows

NATURAL PROTECTION OF GROUND WATER

A combined interpretation of geophysical and geological information revealing total thickness of clay layers above the aquifers in the Århus area has been carried out. See figure below. It is estimated that ground water protection from clay layers is important in 50% of Denmark. The impact of the detailed mapping of the degree of natural protection against pollution provided by clay layers above the aquifers is great.

After negotiation with The County Council of Århus The Municipality of Århus has accepted the importance of an active protection of the ground water resources as a basis for a good quality drinking water supply in the future. The location of all new urban areas around Århus City must be held up against ground water interests and generally there will be no new urban areas where the natural ground water protection is poor. Most important is the fact the County Council in 1997 decided, that no new location of urban areas in Århus County after 1997 can be evaluated and decided unless a detailed mapping has been carried out in the area!!

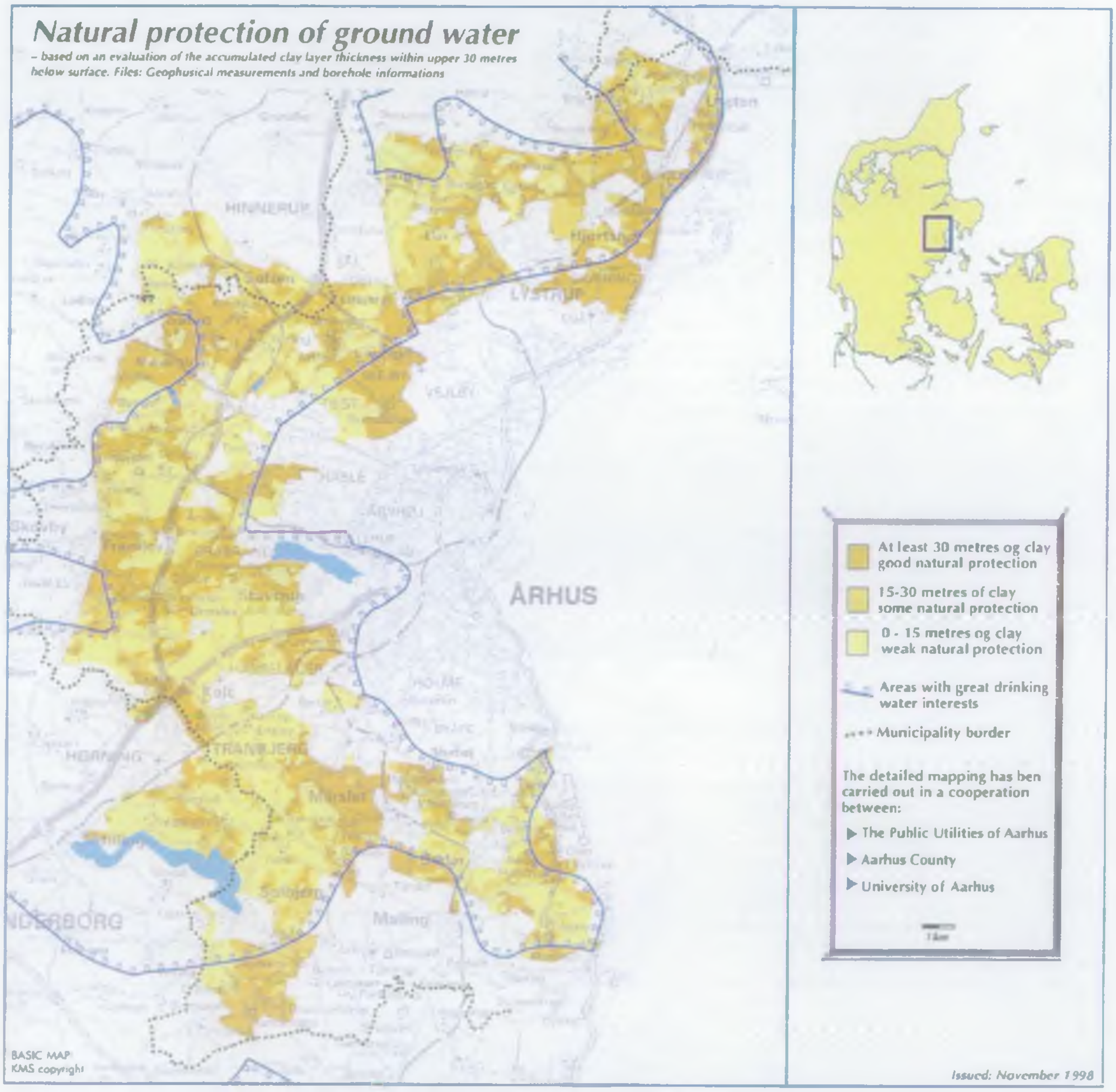


Figure 9 The natural protection of ground water

HYDROLOGICAL MODELLING

The detailed mapping includes setting up conceptual geological models and hydrological models. The models will be used to analyze the geological information and to calculate the water balance, effect of climatic change, extension of catchments area, pollution risk.

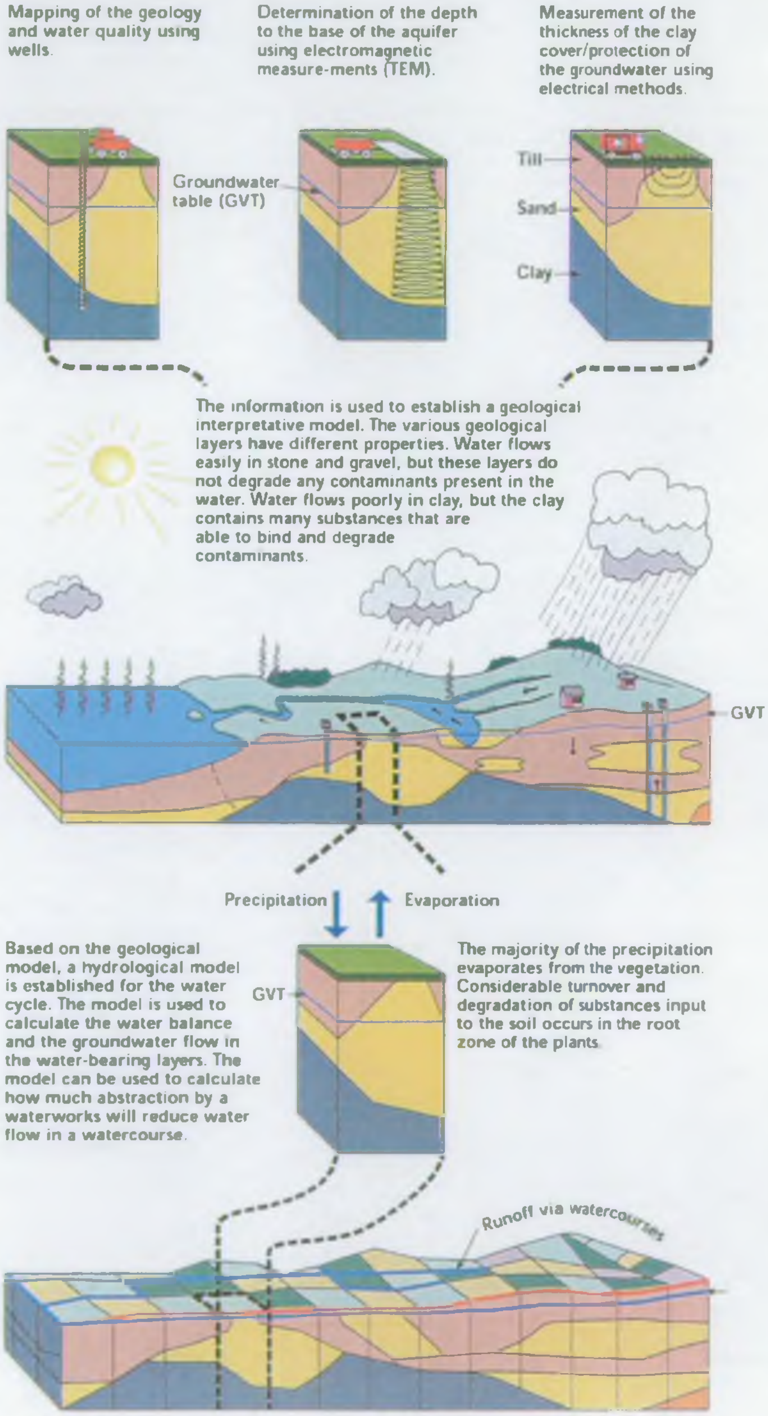


Figure 10 Detailed mapping of the groundwater resources and the establishment of groundwater models

STATUS FOR DETAILED MAPPING AND PLAN OF ACTION

In December 1998 the Danish parliament decided, that the county councils should be responsible for a detailed mapping of the water resources within an area of 33% of Denmark

In august 1999 the county councils established a technical adviser group who is responsible for the coordination of the ground water protection scheme. To solve the practical problems there are establish subgroups: one is working with geophysical mapping, one is working with hydrological modelling and one is working with geochemistry.

In august 1999 the county councils made a five-year contract (3 million $) with the University of Aarhus, Department of Geophysics. The object of the contract is to get a better use of geophysical data through lectures and through development of new and better computer programs to interpret geophysical data. Perhaps it will be possible use geophysical measurements directly in the hydrological models.

In marts 2000 the county councils made a contract with The Geological Survey of Denmark and Greenland for running a database with geophysical data. All geophysical data from the detailed mapping can be send to and withdraw from the database through the Internet. The database system GERDA has been developed by County Council of Aarhus, University of Århus, The Geological Survey of Denmark and Greenland, The Danish Ministry of Landscape together with a software company.

In May 2000 the county councils made a contract with The Geological Survey of Denmark and Greenland for making lectures in the use of hydrological models.

In June 2000 The Minister of Environment has decided a departmental order about how the county councils shall do the job with implementing the protection scheme.

In August 2000 the Danish Environment Protection Agency has published guidance for detailed mapping and setting up protection zones. (Only in Danish)

In 2001 the county councils shall decide a plan of action with timetable for implementing the necessary measures for ground water protection.

Through the last 2 years all major companies in Denmark working with water supply in Denmark have developed experience in all the aspects of detailed mapping. Through there are still a lot of problems to solve in the process of mapping and modelling.

THE PUBLIC OPINION ABOUT THE PROTECTION SCHEME AND THE DETAILED MAPPING

The public opinion is that the protection of ground water is very important.
The parliament has decided the scheme with the support of all the major political parties.
The County councils support the parliaments decision and will do the job conscientious.
The water supply organisations are happy.
The farmer's organisations demand the detailed mapping as a major condition for accepting protection zones and possible regulation. This is very important as the mapping imply a lot of traffic on farmland. Note that during the next 10 years 16.000 square kilometres will be mapped with ground based geophysics in profiles with an average distance of 250 metres.

The municipalities think that mapping is a god idea as basis for ground water protection but is some times annoyed when the protection affects city planning. When the protection is based on the detailed mapping it is almost impossible to bypass.

The public wish to take part in the planning process and implementation of the scheme of ground water protection. Information is very important through the whole process.

CONCLUSION

The water supply in Denmark is based on high quality ground water and complex and expensive treatment is not required. The Danish parliament has decided that it is important to keep the ground water clean and to keep the water supply decentralised. Increasing problems with water quality have made ground water a very important issue in Denmark. In December 1998 the Danish parliament decided, that the county councils in Denmark should be responsible for a ground water protection scheme including public planning and classification in ground water protection zones based on the detailed geological mapping and hydrological modelling within the areas classified as recharge area of particular value for the drinking water supply. (An area of 33% of Denmark.) The detailed mapping and modelling is necessary because, when you whish to use restricted guide-lines, it is important to have a precise knowledge of where the ground water resources are situated and how well it is protected. The classification in protection zones and guide-lines will be used to prevent ground water pollution from city development, leaching of nitrate and to decide on possible clearing of old waste disposals etc. The final step in the scheme to improve ground water protection is that all county councils before 2001 shall decide a plan of action with timetable for implementing the necessary measures against all sources of threats to ground water through a public planning process. This mapping and planning is supposed to take place over the next 10 years. The total cost price is estimated to be around 115 million Euro. During the 10 year period the consumers pay extra 0,02 Euro per m3 of water to the county council amounting to about 4 Euro per family per year.

9. A VIEW FROM AGRICULTURE

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INTRODUCTION

Groundwater is important to farmers, and farmers are important to protecting groundwater. The aim of this paper is to examine the relationship between farmers and groundwater, to consider some examples of issues which have arisen in the past and which may do so in future, and comment on the policy and legislative position, both as it exists now and may do in the future.

Water is essential for life, and the business of farming is to harness the potential of living organisms to produce food and other commodities. Farming therefore depends on adequate and dependable supplies of water of suitable quality, and cannot exist without it. The agricultural industry is as dependent on water as any economic sector, and much more than most.

Groundwater is important for farmers, and particularly so for the general reliability of supplies from this source. Wells and springs have long been used for stock watering, dairy hygiene and domestic use on farms. In more recent times deeper boreholes have taken over some of these functions, giving improved reliability and protection from contamination, and have also provided larger quantities for crop irrigation. The ability of groundwater to smooth variations in rainfall between seasons and from year to year, provided it is not over-abstracted in the long term, makes it a particularly valuable source and its reliability generally and availability during dry periods are important to farmers.

Most farmers will have a very limited grasp of the complexities of groundwater hydrogeology, the characteristics of the drift overlying the solid geology being of much greater direct relevance. They will readily appreciate whether their land is "free-draining" (ie precipitation infiltrating into the soil, and thence to groundwater, freely and without impediment) and "heavy" soils where drainage is impeded and often artificially improved with piped underdrainage systems which normally discharge to surfacewaters. In principle, therefore, farmers have an indirect appreciation of whether their land drains to groundwater.

Whilst many groundwaters are naturally well protected from contamination by substances which are degraded or retained by soils, the increasing abundance of potential pollutants against which the soil offers insufficient protection demands positive protection. Agriculture accepts that groundwaters forming important resources need to be afforded good protection since, once polluted, they are difficult to rehabilitate.

Agriculture occupies a unique position in forming the predominant catchment for water resources, covering almost 80% of the surface area of the UK. Most of the nation's water supplies drain through soils, which are under active management for food production. The role of land as a water catchment to supply human requirements, although of vital importance to society, is secondary to the purposes for which it is managed, at least in most areas. In the past large upland catchments were acquired by water undertakings, and managed primarily for water supply, with agriculture playing a secondary role. Now agriculture is the primary use of much catchment land. The water catchment function is generally expected to be provided by agriculture at no cost to water undertakers. This position is discussed further below.

The farming of land involves management of the soil by, for example:

- cultivation
- planting a range of agricultural crop species and varieties,
- enhancing the growth of crops by the use of organic and inorganic fertilisers,
- protection of crops from pests and diseases with a variety of commercial products approved for these purposes by regulatory authorities
- harvesting crops and
- grazing grass and other forage crops.

These agricultural activities have the potential to alter the chemical characteristics of water draining through it to varying degrees, and these changes may affect the suitability of the water for some of the uses to which it may ultimately be put. Changes of this sort or degree tend to be regarded as pollution, although other changes, which do not have significant unwanted effects, are not generally treated as pollution. The threshold beyond which quality changes are termed pollution is to some extent arbitrary, and may be politically rather than scientifically determined. When this happens such thresholds may become controversial.

As well as influencing groundwater quality, farmers' decisions may also affect the quantity of water draining from agricultural land, and this might in future be significant in areas of the UK where the recharge is in any event only a small percentage of typical evapo-transpiration. One example is eastern counties where annual recharge is 100 – 150 mm, as compared to evapo-transpiration around 400 mm. In such areas some crops may significantly reduce the recharge. One of the most extreme examples is evergreen trees, which in some areas may reduce recharge to low levels. Farmers are being encouraged to plant both deciduous and evergreen trees under the Farm Woodlands Grant Scheme.

Whereas the run-off from most business premises and from housing is directed to surfacewaters, agriculture forms the catchments of most groundwaters. These are normally of higher quality than surfacewaters, and farmers whose land drains to groundwaters may therefore have a particular responsibility – and face restrictions to conform to higher standards - than businesses draining to surfacewater

Climate change adds an extra dimension to the relationship between agriculture and groundwater. Not only will altered rainfall patterns have direct effects on recharge, but climatic changes will encourage farmers to grow new crops and rebalance the mix of crop types. This will inevitably lead to changes in the quality of water draining from agricultural land, and may alter total recharge.

AGRICULTURAL IMPACTS ON GROUNDWATER QUALITY

There are several current concerns about the impact of agriculture on the quality of groundwater. The principal ones are discussed below.

Nitrate

One of the main concerns amongst water managers about the impact of farming on groundwater quality relates to nitrate. The limit for nitrate in the EU Drinking Water Directive is 50 mg/l, and this is exceeded in a significant number of sources, necessitating nitrate removal or blending to enable supplies to meet this standard. Agriculture is one of the main sources of nitrate, although by no means the only one, and the EU Nitrates Directive has been introduced in an attempt to limit nitrate losses from farmland. However, the agricultural community is generally sceptical about the merits of this legislation for several reasons:

- nitrate is not thought to be a very significant problem under UK conditions, whereas phosphate poses more genuine environmental problems. Priorities appear to have been distorted.

- the standard of 50 mg/l both under the Drinking Water Directive and the Nitrate Directive is perceived as being based on poor science, and therefore not deserving respect.

- the health evidence on which the standard was based is now largely discredited, with blue baby disease attributed to nitrates having been considered by the World Health Organisation to be extinct in Western Europe for more than a decade, and the postulated linkage with gastric cancer becoming weaker as further research has been published.

- the use of a concentration figure as a standard means that variations in rainfall from place to place and from year to year are crucial in determining compliance. Linking controls to an external variable in this way is seen as unfair.

- the controls on agriculture are applied without taking account of the contribution made by non-agricultural sources, such as atmospheric deposition onto farmland originating from traffic emissions. This is also seen as unfair.

Most farmers would agree that some standard for nitrate is appropriate, but that the one previously used by the UK prior to the introduction of the Drinking Water Directive proved perfectly satisfactory. The only remaining justification for the current standard appears to be that it offers a good margin of safety, although this should to be balanced against the costs, and compared with competing needs for resources which may be able to deliver greater benefits than an increased margin of safety.

Pesticides

The other main concern amongst water suppliers in terms of the impacts of agriculture relates to pesticides. The standard imposed by the EU Drinking Water Directive is 0.1 μg/l for individual pesticides, and 0.5 μg/l for total pesticides. Whilst farmers readily accept that pesticides are undesirable in water and should never exceed safety limits, there is scepticism as to the merits of the same standards applying to all these substances and which bear no relationship to the risks posed by individual substances. Health related standards published by the World Health Organisation (WHO) are less stringent, some by two orders of magnitude.

Extensive use of pesticides has become an integral part of many modern farming systems. By controlling pests and diseases pesticides serve to increase yields, thereby reducing costs and prices per unit of production. They also have an important role in the achievement of the high quality standards now required by consumers and by legislation, such as for fruit and vegetables. The principal exception to this is the small but growing organic farming sector where only a limited range of pesticides largely of natural origin, such as pyrethrum, may be used. However, yields are lower and unit costs and prices are often higher under organic systems.

Pesticides are an integral part of modern farming, and many pesticides are mobile in water and therefore find their way into water supplies in small concentrations. However, pesticides may only be lawfully used if they have been subjected to the exhaustive evaluation required under the pesticides approval schemes, which includes human safety and environmental impact. The majority of current problems experienced with pesticides from agricultural sources detected in water relate to breaches of the uniform standards set for drinking water and not to any health risk or environmental hazard. However, it is also worth remembering that many pesticides in water originate partly or solely from non-agricultural sources, such as carpet treatment, or spraying of pavements and railway tracks.

Considerable efforts are being devoted to minimising losses from agricultural application systems, and there are grounds for believing that there is scope to make significant improvements. Studies have shown that a surprisingly high proportion of concentrations in water arises not from the application itself, but from filling spraying equipment, spillages etc. The majority of such losses should be avoidable if improved systems can be developed. However, some promising options, such as the use of 'biobeds' on which to carry out sprayer filling operations and to break down any materials spilled face bureaucratic difficulties in terms of the necessary approvals under the EU Groundwater Directive. Such difficulties, resulting from the framing of legislation, which impede the development of improved systems to reduce environmental impact, are very frustrating.

The question arises as to what view should be taken of breaches or potential breaches of the pesticide standard in the Drinking Water Directive. It is generally understood that the standard was set at the limit of detection at the time, and represented a surrogate for zero concentration. The philosophy behind this was perhaps something akin to that espoused by Friends of the Earth that 'pesticides have no place in water', but unfortunately this ignores the inevitability of any substances released into the environment becoming widely distributed in small concentrations which are increasingly measurable. Nonetheless, political and ideological obstacles have served to prevent the substitution of risk-based standards, such as those published by respected authorities such as the WHO and in consequence the position remains that many breaches of the drinking water standard are unrelated to any real risk or hazard. In consequence, breaches of the standard have tended to be of interest mainly to those involved with technical enforcement of the standard, and farmers regard them as of little real importance. In agricultural circles at least, the legislation has fallen into disrepute – a very disturbing situation.

The further question arises at to whether the substantial sums spent on removing or reducing very low levels of pesticides from drinking water represent a cost-effective use of resources, since there are good grounds to believe that concentrations could be substantially higher than those currently permitted without posing a risk to human health. This in turn leads to questions about priorities in the wise use of scarce resources, questions which institutions such as the

European Commission have appeared reluctant to address. Such questions are very pertinent to farmers since the understandable reaction of water suppliers faced with such rigorous standards is to seek remedies for such problems at source in order to avoid the need for water treatments, which may itself introduce new hazards for water consumers. Given the low level of risk posed by the pesticide contaminant, it appears entirely possible that the risk to human health arising from water treatment to reduce the pesticide level is greater than the risk from the pesticide in the first place. This would be a classic example of a perverse effect whereby legislation intended to reduce the risk to human health actually increased it. Unfortunately, there are an increasing number of examples where the stringency of legislation generates incentives or imperatives which operate contrary to the original purpose of the legislation.

Another example can be found in the Groundwater Regulations, which are so onerous in respect of sheep dip management and disposal that farmers are giving up the use of sheep dip and switching to alternative strategies for addressing the economic and animal welfare consequences of sheep ectoparasites. So far as I am aware, there is no life cycle analysis of the alternative strategies being adopted to provide information on their environmental and other benefits/disbenefits. It is very likely that the risks to groundwater will have been reduced, which may be all that is sought by scientists and policymakers concerned with groundwater. However, the delivery of a net benefit to society is by no means assured since the wider consequences of introducing the legislation may not be understood.

Newer legislation attempts to be more holistic and less prescriptive. The Integrated Pollution Prevention and Control Directive (IPPC) seeks to deliver regulatory integration, although this process lacks a risk assessment aspect.

POLICY AND LEGISLATION

The protection of groundwater is a prudent policy which few would question. Agricultural organisations have participated in the development of the Groundwater Protection Policy by the National Rivers Authority, the predecessors of the Environment Agency. The operation of the policy has not caused major problems for farmers to date.

Future UK policies appear rather more threatening, particularly in respect of proposals to time-limit all abstraction licenses. It is clear that some catchments are over licensed, and that some may actually be over-abstracted. Both situations are clearly undesirable and the latter is unsustainable and need to be addressed. However, the removal of the security that the current system provides – on which much investment is founded - could depress confidence and restrict investment and economic activity. Water companies may be reluctant to construct large new raw water reservoirs without an assurance that they will be permitted to abstract water to fill them for a period of at least several decades, and the position is the same for farmers in respect of winter storage reservoirs and structures such as watercress beds. Whilst the need to take action in some catchments is clear, the policy adopted appears in danger of throwing the baby out with the bathwater!

Catchment Abstraction Management Plan policy appears in many ways a positive development, although it remains to be seen how it will develop. However, it does suffer from the disadvantage of implying that abstraction licences will be permanently under review. This may further undermine the confidence that has previously existed in the security of abstraction licences, with consequent reluctance to invest to the same extent.

EU legislation as it relates to groundwater, including the Drinking Water Directive, Groundwater Directive and the Nitrates Directive, is largely viewed with disfavour by the agricultural community. The reason for this is not that all the legislation is seen as pointless or unnecessary. Farmers recognise that water in general and groundwater in particular should be protected. However, the legislation which is in place is over-prescriptive and heavy-handed, requiring procedures which neither regulators nor the regulated believe to be sensible, and is perceived as incorporating standards based on poor science unrelated to real risks or priorities.

New EU legislation in the shape of the Water Framework Directive (WFD) has recently been adopted, with the aim of bringing all water bodies up to "good quality status", the highest quality achievable consistent with human activity. This is an ambitious aspiration which few would question in principle, and is to be welcomed if it is treated as an aspiration, but posing threats if the objectives are pursued without regard to cost or proportionality. How good status is defined for individual water bodies remains to be seen. There may be opportunities to concentrate efforts towards parameters which genuinely impact on health or the environment, although indications are that these may be limited. Initial costings published by the Government, showing average figures for agriculture on affected land of £175/ha for arable and £117/ha for grassland, imply that major changes to farming practices are anticipated. This is because such costs are not sustainable within the industry as it stands today, and if the figures turn out to be reliable, alternative means of delivering water quality will need to be found. This could mean the industry changing to different forms of agriculture in some areas, new techniques for minimising losses of potentially polluting substances from farmland or alternatively adopting realistic objectives compatible with the current systems of farming.

It is common knowledge that UK agriculture is currently depressed, suffering from a range of pressures including BSE, the weak Euro (in which farm support prices are denominated), weak commodity prices and the aftermath of the severe outbreak of Foot and Mouth Disease. Combined with the projected expansion of the EU to include eastern European countries, pressures are rapidly mounting for a major re-appraisal of agricultural policy. It is essential that new policies for farmers, which emerge from this process, are not themselves rapidly reviewed to address the requirements of the WFD. Any major implications of the WFD for farming need to be identified rapidly so that they can be provided for in the forthcoming review of agricultural policy. This may require substantial efforts well ahead of the schedule laid down in the Directive, which requires programmes of measures to be in place in 2009. Whilst agriculture needs a consistent approach to policy, it does not need to be handicapped in competing with other EU countries, many of whom are enjoying better fortune, at least in terms of the value of support payments. It is therefore also important that, while the approach required from agriculture under the WFD needs to be identified early, the actual implementation of policies should be timed so as not to impact on UK farmers earlier than in other member states.

CONCLUSIONS

This short review of the main current and anticipated interactions between water policy and agriculture in the UK does not reveal a harmonious situation. The current deep depression in agriculture combined with the accumulating burden of environmental and other regulation, which bears particularly harshly on small businesses, provides an unhelpful backdrop. It is in this context that the UK's commitments to EU legislation still to impact on the industry are in danger of generating a backlash against environmental legislation and regulators, who all too frequently are in receipt of reactions which would be better directed at legislators. It is a feature of our system of government that those who really take key the legislative decisions are far removed in distance and often in time from the consequences of those decisions. This means that political expediency frequently takes precedence over good law. The EU Nitrates Directive is an example where mistakes have been made, but political considerations prevent their rectification, at least in the short to medium term.

The combination of inappropriate standards and unsuitable legislation, together with the imposition of "cost-recovery" charging by the Environment Agency, implemented up to the hilt under Treasury rules, is a potent mixture. Even the Groundwater Regulations, characterised by the Agency as well as by farmers as inappropriate, and which impact on only a modest proportion of farmers, generated a sufficient revolt for the Government's Action Plan for Farming to include a measure waiving charges for 4 years. It requires little imagination to foresee that the deepening of agriculture's problems since the introduction of those regulations, the desperate problems created for many farmers by Foot and Mouth Disease, and the application of further environmental legislation to farmers on a wide scale – whether it be Integrated Pollution Prevention and Control, Waste Management Licensing, wholesale extension of Nitrate Vulnerable Zones, revocation of abstraction licences or the threatened impact of the Water Framework Directive or a revised Groundwater Directive – will drive some farmers to despair and others to resist further regulation.

There is of course a difference between well-designed legislation, which targets an acknowledged problem accurately and effectively, and bureaucratic and controversial regulation which generates much unnecessary cost. It is an unfortunate fact that a considerable part of the current water legislation now existing or in the process of implementation is viewed by farmers as falling into the latter category. An opportunity exists to avoid the potentially flexible Water Framework Directive sharing this fate, although the projected costs for farmers published by the Government have already produced a strong negative reaction.

One way to target the opportunities for a constructive and productive approach to the water Framework Directive is to consider the difficulties generated by other legislation. The new agenda will focus principally on diffuse pollutants from agriculture, rather than point sources, and also on the availability of water resources. The current standards for diffuse pollutants such as nitrate and pesticides in drinking water mean that water suppliers must spend large sums on reducing concentrations, which exist in raw water. Much of this expenditure can be recovered by water companies from consumers under the cost pass-through provisions of water price regulation specifically provided by Parliament. However, as their charges come under increasing scrutiny, water companies would understandably prefer the concentrations of these substances in water to be reduced at source. Clearly farmers should take all reasonable good practice to minimise leaching of these substances from agricultural soils, but losses cannot be avoided entirely. In some areas and for some crop systems it may not be currently possible to avoid concentrations exceeding the standard required for water at the tap, and indeed it is optimistic to expect it to be so. Treatment will always be required for some parameters, for example microbiological quality in the case of surface water. The question then arises as to whether farming systems should be subject to major change to avoid the need for water companies to treat the small proportion of water which is put into public supply. There will be differences of opinion on this, and a tension between the agricultural and water industries stemming largely from the adoption of standards which are not well related to risks. This situation is unfortunate when farmers, who provide so much of the catchment for water supplies, should have close relations and understandings with the water industry.

The question could be posed as to whether farmers – as occupiers and often owners of water catchments – should have a stake in water supply and the water environment from which they are currently largely excluded. It would then be in their interest, rather than a burden, to safeguard water quality and to balance the competing demands of farming with the advantages of avoiding water treatment. This could transform at a stroke the conflict between farming and water supply and quality by internalising the costs and benefits.

The question could be posed the other way, as to whether to involve water supply companies and other direct beneficiaries of good water quality more in land occupation and ownership so that the costs of extensive changes to agricultural systems are internalised to those who reap the benefits. This implies a reversion to the days when greater areas of water catchments were owned by water undertakers, and farming in those catchments was a secondary activity restricted in order to give priority to the water catchment function.

At least one water company has already taken some small steps towards co-operating with farmers by providing incentives to give greater priority to the water catchment function. Indeed, in certain circumstances this may make financial sense for water companies compared to the costs of installing treatment plant, but what is needed is a coherent institutional framework whereby at least some of the costs and benefits fall within the same balance sheet and profit-and-loss account. The current position whereby costs fall to one group and benefits to another, and one group is enabled by Parliament to recover costs from customers and another has no mechanism at all to do this might have been designed to promote conflict! It appears that in Germany funds provided by consumers through water charges are passed back to farmers within specific catchments in exchange for steps to reduce undesirable substances in water supplies for the public. This contrasts with the UK situation where such funds are retained by water companies and used for water treatment. The German approach appears the more enlightened to me.

It is important to appreciate that farmers are not opposed to the principles of sustainable practices, and that the aim of achieving the best water quality practicable is not only supported by farmers, but is in their ultimate interests – as also is the sustainable use of water resources. The current opposition of many farmers to legislation intended to protect water quality and resources is just that – it is opposition to the specific legislation, in their view bad legislation, and not to the principles of water protection. This is exacerbated by the institutional structures which impose highly bureaucratic systems of regulation, the costs of which fall directly on affected businesses, and which award the costs and benefits of actions to different individuals or groups. Farmers recognise that they are in an era of great change, and that many must change to survive. These changes will be best made to the benefit of both society and farmers themselves if the right incentives are in place to steer both them and other businesses towards a more sustainable future The pressures should be directed towards coherent solutions arrived at by common understanding and interest, rather than driven by regulation and conflict.

10. GROUNDWATER PROTECTION AND PUBLIC WATER SUPPLY

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ABSTRACT

The need for a sustainable supply of high quality groundwater is crucial to the infrastructure of the UK in terms of its economy, health, community and environment, without sustainable groundwater resources all of these would suffer. Abstraction from groundwater is an essential part of the public water supply system in the UK, contributing around a third of supply. In the major supply aquifers groundwater abstractors are generally able to rely on a plentiful supply of water at a consistently high quality. Groundwater also interacts with surface water, providing the baseflow for many rivers and sustaining important wetlands. However there are an increasing number of threats to this precious resource, urbanisation, industrial growth, and widespread intensive agricultural activity all have a serious potential impact upon aquifer water levels and groundwater quality. Once an aquifer is contaminated, the very attributes that ensure high quality water, such as low flow rates and low temperatures, increase the difficulty of clean-up and once compromised it is difficult to recover the integrity of a source. Similarly there is a delicate balance regarding quantity, once long-term abstraction exceeds aquifer recharge, groundwater will be 'mined' and the aquifer will begin to dewater, this will threaten security of public water supplies and the ecology that depends on the groundwater-surfacewater interaction. Due to the complex nature of both the aquifer systems and the actors that may threaten them, there is a need for cross-sectoral approach to regulation, land-use planning on the surface is essential in the management of groundwater in the aquifer below the surface.

INTRODUCTION

There are some key questions that need to be addressed before we can begin to develop a framework for groundwater protection:

- Why should we protect groundwater and does it need protection?
- What aspects of groundwater should we protect - its availability; its quality?
- Should we protect all groundwaters even those that are already damaged?
- How should we protect groundwater and does protection include rehabilitation?
- Who should be responsible for protection and who should pay?

In answering all these questions we should be guided by the principle of sustainability. That is the concept of balancing environmental, social and economic concerns, to ensure our actions today do not compromise future decisions. It is clear that the concept of protecting groundwater has environmental, social and economic benefits, but the extent, cost and level of precaution associated with protection may have different and conflicting impacts. For example a reduction in a water supply abstraction licence that may be affecting a sensitive ecological site, will have environmental benefits, but at the same time there may be impacts on security of public water supply and there will be cost implications for customers, there may also be environmental impacts in developing a new water source elsewhere. Therefore there needs to be a holistic view of groundwater protection that looks at it within the framework of policy development, there cannot be an isolated academic approach to protection.

This paper discusses the importance of groundwater, with particular reference to public water supply, then looks at the potential threats to its integrity and the methods we could use for protection.

GROUNDWATER AS A PUBLIC WATER SUPPLY RESOURCE

Clearly, water is the water industry's primary resource and maintenance of its quality and supply is essential. Groundwater is an important source of supply in the UK providing around a third of the country's public water supply, however this nationally averaged figure does not reflect the regional differences and in some areas it accounts for most of the supply. The protection of groundwater is of utmost importance for public water supply but difficult and complex to achieve.

There are a number of major aquifers in the UK, the main ones that are used for public water supply are the Chalk, the Lower Greensand (although the quality of water from this aquifer is often poor), the Jurassic Limestone, the Magnesium Limestone and the Permo-Triassic Sandstone. The vulnerability of groundwater depends on the physical aquifer characteristics and the geography of their location, as the population density and the local industry or agriculture has an impact on groundwater quantity and quality.

The importance of groundwater as a water resource is due to a number of characteristics inherent in its nature and occurrence. Groundwater is an areally distributed resource in contrast to surface water, which is usually concentrated in stream and lakes, and its wide distribution makes it more readily available for resource development. Groundwater is a slow-response, low-velocity medium with a low variability of flow and large residence time. This means that there is also little variability in supply and quality making it a highly reliable resource in terms of both quality and quantity. In addition, since groundwater occurs below the surface it has a natural protection against contamination and most contaminants are attenuated due to filtration through overburden.

The value of groundwater as a public water resource can be assessed by considering the cost to produce the equivalent quantity of water of the same quality. The UK water industry currently has a number of projects that aim to address this issue.

THREATS TO GROUNDWATER QUALITY

Pollution is normally classified as either point or diffuse. Diffuse pollution derives from widespread activities at a low level, which have a cumulative effect upon water quality. These may include, agricultural use of fertilisers and pesticides, road run-off, sewer leakage and contamination from rainfall. Point source pollution arises from an incident at a specific identifiable location or point or line source. Point sources may include leachate from landfill, industrial spillages or illegal discharges, fuel spillages, leaking oil tanks and contaminated land.

Of these two types of pollution, point sources are the most easily addressed. This is because the identifiability of point sources means regulation and remediation can be effectively targeted. The opposite is true for diffuse pollution, it is difficult to identify their source and even more difficult to target solutions at diffuse polluters.

Historically, it has been taken for granted that groundwater is generally of good quality, however there is a general perception that raw groundwater quality is declining. This is difficult to verify due to a lack of national baseline and detailed historical records, but in certain parts of the UK up to 40% of groundwater sources require treatment before being used for public water supply.

The fact that groundwater is a subsurface resource means that it is protected to a certain degree from surface pollution events. However, it also means that when it occurs pollution is difficult to detect. Often we are only aware of polluted groundwater once the contaminants are observed at abstraction points. The low velocity associated with groundwater movement means that it is particularly vulnerable to insidious long-term pollution, and current groundwater quality may observed at an abstraction point may reflect pollution events from many years or even decades ago.

Groundwater quality is becoming a major issue for the water industry and the main areas of concern are:-

- The impacts of diffuse pollution, such as the increased need for treatment or blending to deal with high nitrate levels.
- Uncertainty over contaminated land.
- The threats to groundwater from climate change.
- Problems relating to taste and odour.
- The need to deal with a growing number of new pollutants.
- The lack of Government and regulatory support for rehabilitation.

Of these issues diffuse pollution is the most pressing, it is a major problem and unless it is addressed, could lead to compliance failures with the European Commissions Water Framework Directive. In general, the scientific and technical tools to deal with diffuse pollution are known and accepted. However, where knowledge is lacking is in how to develop communication and regulatory tools to ensure these technical solutions are put into action in catchments. The only way this problem can be addressed is by engaging with polluters, who are often ignorant of the problem and willing to take action if they are given the tools they need. The way forward may be a combination of education, information and regulation.

In North America there are now a number of projects for holistic watershed management or integrated catchment management that aim to involve the local community in the management of water resources (Brenner *et al.*, 1999). Perhaps we should look at adopting a more holistic approach in the UK, and considering source protection via the planning system for roads and agriculture, and the use of positive incentives within the catchment. This would require a rethink of the 'polluter-pays' principle, however in reality this principle is not working and it is the water customer not the polluter who is currently paying for the clean up of diffuse pollution.

There are also threats posed to water resources from historical contamination in the sub-soil. There is legislation covering contaminated land, but as enforcement is the responsibility of local authorities there appears to be some variability in the way contamination is assessed and dealt with.

There is a growing recognition that climate change is beginning to pose new threats to groundwater quality. The trend towards more extreme rainfall events and to prolonged periods of drought or flooding will have a major impact on groundwater quality. Surface water flooding can lead to inundation of public water supply boreholes and direct contamination of groundwater through flow down wells boreholes or casings. Surface flooding can also lead to bypass flow, in which water infiltrates rapidly through vertical surface fissures directly to groundwater, rather than moving through the matrix, this bypass means contaminated water can reach groundwater without attenuation. Groundwater flooding, such as that experienced in the South Downs Chalk near Chichester can also cause problems, as the water table rises to the surface (in confined or semi-confined aquifers) it may mobilise pollutants within the unsaturated zone such as attenuated hydrocarbons and more significantly high nitrate levels in the sub-soil rooting zone of arable crops. High groundwater levels also cause problems for the sewer system, the pressure of water will damage sewer pipes, the ingress of groundwater into sewer pipes can lead to sewer flooding. Once the groundwater level drops the damage to sewer pipes will lead to leaking sewers and potential contamination of the groundwater. There may be potential problems of sewer flooding and of mobilisation of pollutants such as nitrates as high water tables rise into the unsaturated zone.

There is a large body of national and European regulation and legislation to ensure the standards of drinking water. In general these standards are based on ecotoxicity of certain contaminants. However the water industry also faces pollution from non-regulated substances that can affect the taste and odour of drinking water. This is an area where more information and guidance is needed and where regulation of polluters is lacking.

Similarly there is concern over how we address new pollutants. There needs to be greater linkage between Government and Agency research and industry so that potential new contaminant can be flagged up as early as possible to allow the industry to prepare monitoring and remediation systems.

In the UK there is a lack of rehabilitation of boreholes and *in-situ* bioremediation of contaminated supplies. There is a need to assess whether the current regulatory framework favours technical innovation that may require long-term investment.

Given the wide range of threats to groundwater quality and the technical difficulty and high cost of groundwater rehabilitation, it is important that the groundwater resources are protected, both with regard to aquifer vulnerability and source protection. However this will require the integration of all regulation and planning actions across the aquifer.

THREATS TO QUANTITY OF GROUNDWATER

Put simply the amount of water in an aquifer depends on its historical volume and the balance between the amount withdrawn through abstraction and the amount gained through infiltration of rainfall, the interaction with surface water will also effect levels but it is normally groundwater which dominates this interaction. Therefore it is possible that groundwater abstraction can affect the interaction with surface water, such as feeds to wetlands and also in extreme circumstances can lead to long-term dewatering of the aquifer.

In England and Wales, most abstractions from groundwater require a licence from the Environment Agency. Such a licence specifies the volumes of water that can be abstracted and their use. Many licences also have conditions that require reductions in abstraction once groundwater levels fall below a certain level. Therefore the effects of abstraction on groundwater are to a certain extent controlled by the Environment Agency. However, there are a few areas in the UK where there appear to be long-term declines in aquifer water levels due to abstraction for public water supply or farming and industry. In these areas the water industry is working with the national environment agencies towards a sustainable solution and the restoration of water levels. Many of these sites are covered under the National Environment Plan (NEP) under which the water industry is spending £5bn on environmental improvement over the next five years.

Whilst the impact of abstraction for public water supply on groundwater status is recognised and is being tackled in the context of sustainability by the industry in conjunction with the Environment Agency, there are a number of other threats to aquifer status that need to be addressed. These are land-use planning, agricultural and urban drainage, climate change and the loss of wetlands.

Climate change posses a threat to the status of groundwater reserves in a number of ways. Social reactions to climate change may mean changes in demand patterns. However the main impact will be due to changes in rainfall patterns. Although it is likely that the average UK rainfall will remain unchanged, there will be seasonal and regional variations arising due to climate change. The North and West will see increased rainfall, particularly in the winter and the South and East will see little change or an increase in winter rainfall but a significant drop in summer rainfall. More importantly rainfall intensity will increase. It is uncertain how these changes will impact on resources, but it seems that there will be greater run-off and less infiltration. The change in rainfall patterns will also mean that the water industry may have to make infrastructure changes and accommodate greater storage if summer abstractions are restricted.

Changes in land-use have an impact on groundwater status through their impact on run-off and infiltration. The focus on leakage as a major tool in tackling stress on resources should be matched by a focus on the importance of policies such as Building Regulations in aquifer water status and at a higher level, the importance of macro-decisions on development of housing stock.
Planning decisions should include the integration of technology such as permeable car park surfaces to enhance recharge and lessen the load on the sewer system.

Agricultural drainage also needs to be reassessed. The policy for more than 500 years has been to move water off the land as quickly as possible. This has drastically reduced the opportunity for infiltration and interaction between groundwater and surface water and has drastically reduced the amount of UK wetlands. However, this was the intention, and it has produced highly fertile, well drained, agricultural land, which is essential to the local economy of many parts of the UK. It is now time to reassess the role and structure of agriculture in the UK and see how it can play a positive rather than negative role in the protection of groundwater. However, this has to be done within the context of sustainability, with a consideration of the social and economic aspects of action.

Damage to groundwater supply and quality also has an impact upon the wider water and water related environment and also on the integrity of surface water supplies. This is due to the linkage between groundwater and surface water. Aquifers rely upon recharge to replenish reserves over a long time period, and this recharge is dependent on issues such as the presence of wetlands and high river flows to drive infiltration. A slow reduction in the area of wetlands and a reduction in river flows will lead to a long-term imbalance in water entering and leaving the aquifer and this in turn will have a negative feedback on the status of wetlands and the stage of rivers. The maintenance of wetlands should therefore be seen as an essential element of groundwater protection.

CURRENT MECHANISMS FOR PROTECTING GROUNDWATER

Protecting Quality

Most national environment agencies have groundwater well protection guidelines, which utilise protection zones around water supply wells. The general method for protecting water supply wells is through identifying the area associated with the capture of water by the well for different contaminant travel times. Well catchments delineate the area around a pumping well from which water is drawn at a specified pumping rate, and well capture zones delineate the area within this catchment from which water is drawn over a specified time. A range of factors determine the shape and size of a well catchment and capture zone. The external stresses on the aquifer in terms of the pumping rate, the recharge rate and its distribution, the hydrological boundaries, and the physical attributes of the aquifer, namely the depth, the porosity, and hydraulic conductivity, all affect the shape and size of the zone from which water is drawn. The external stresses can normally be explicitly measured and represented, however the aquifer properties are more difficult to characterise. The properties of the aquifer are spatially heterogeneous by nature and, as noted above, it is therefore not possible to establish a full deterministic description of aquifer properties. However protection zones are normally delineated using simple numerical models in which the key features of the aquifer are represented in a deterministic fashion. These zones are then fixed and used to guide planning regulations, despite their disregard for implicit parameter uncertainty.

For example, currently in the England and Wales the Environment Agency utilises a well protection approach in which the well catchment is divided into three source protection zones (SPZ), classified in terms of dependence on travel-time to the well (Environment Agency, 1992). Likewise in the US a range of protection options are used ranging from fixed radius approach to the well head protection area (WHPA) method which is similar to the Environment Agency approach (US Environmental Protection Agency, 1987). These protection zones are derived using numerical models of the well flow field, in conjunction with particle tracking techniques. The time-related zones are obtained by using numerical models to simulate the pathlines formed by tracking a set of particle placed around the pumping well and then tracked backwards in the opposite direction to the groundwater flow for a specified time (in England and Wales this is 50 days for Zone I and 400 days for Zone II, Zone III covers the whole well catchment area). The capture zones are then delineated from the endpoints of the particles.

The Environment Agency are currently developing more advanced methodologies, which consider the variability of aquifer properties, albeit within a deterministic approach based on individual models of supply well catchments. However, due to the lack of knowledge about uncertainty additional buffer zones are often established around the well protection areas.

These current methodologies generally assume that the stresses influencing the size and shape of the well capture zone are constant in time and the aquifer properties influencing the capture zone are spatially homogeneous within zones, isotropic and have a known deterministic value. This leads to specific, but, highly uncertain, deterministic well capture zones.

In terms of groundwater vulnerability and risk assessment it is clear that there is a need to incorporate some form of risk analysis. In general, the highest levels of uncertainty associated with well capture zone delineation relate to the representation of the hydraulic conductivity distribution. Capture zones in Chalk aquifers are seen to be elongated and are particularly sensitive to variations in recharge or variability in the flow direction. Many of the well capture zones currently designated by the Environment Agency have particularly complex characteristics and the associated water supply protection areas may be inaccurate. A deterministic approach is unrealistic in these circumstances. There is clearly a need for a review of source and aquifer protection and a reassessment of the associated modelling so that the inherent uncertainty in aquifer properties can be taken into account. There is also a need to attach costs to specific actions and risks associated with groundwater protection and public supply. This will require not only the quantification of the levels of uncertainty associated with any predictions of capture zones but also a methodology for communicating this uncertainty to the non-scientific community (Butler *et al.*, 1996). Likewise, there is also a need within the fields of law and planning to understand and accept the concept of risk and probability and we must work to translate concepts of uncertainty into a framework of legislative control.

Given the uncertainty associated with aquifer characterisation, it may be that we should move away from wellhead protection towards aquifer protection guided by groundwater vulnerability assessments. This is probably the type of approach that will be adopted in the new European Commission Groundwater daughter Directive of the Water Framework Directive. This is a reasonable assumption based on the holistic catchment based approach of the Water Framework Directive and the EC decision that the UK Government was in breach of the Nitrates Directive for focussing on Nitrate levels in waters for public supply rather than all waters.

Preventing Aquifer Dewatering

The abstraction-licensing regime can be used to prevent aquifer dewatering, however the current approach lacks a framework in which sustainability can be considered. The Environment Agency Catchment Abstraction Management Strategies (CAMS) and National and Regional Water Strategies provide the opportunity to consider abstraction management holistically within catchments. In principle CAMS should improve the allocation of licences in England and Wales and also improve protection of water resources, however there needs to be a national stakeholder steering group to help ensure that the CAMS process is successful, in addition the Environment Agency must do more than pay lip service to the economic and social angles of sustainability and consider the costs of CAMS to abstractors who may have reductions or revocations of licences. There is also a need to link up quality and quantity considerations in the CAMS process.

As discussed earlier drainage and infiltration also have an impact upon aquifer recharge. Currently there is a lack of action on these issues. The Environment Agency is positively promoting sustainable urban drainage systems (SUDS), but there is a lack of commitment by DEFRA to provide a legislative framework that addresses issues such as ownership, maintenance and liability relating to SUDS – the situation is developing somewhat differently in Scotland and this is why we are seeing more SUDS development there. The same is true for agricultural drainage, where it is understood that retaining water on farmland for longer would increase infiltration, attenuate pollutants and help alleviate surface flooding, but there are no Government initiatives to promote a change in current practice. In short the technology is currently ahead of the planning and legislative regimes, indeed the CAMS documents give the impression that the only way to address water resource scarcity issues in a catchment is through reducing abstraction rather than through increasing recharge.

TOWARDS SUSTAINABLE GROUNDWATER RESOURCES

Simply, it seems clear that we must ensure our use of groundwater is sustainable. From an environmental viewpoint this means ensuring that we don't 'mine' groundwater and that we don't compromise its quality. However, since sustainability is about a balance between the economic, social and environmental issues, and sustainable use of water resources is one of the key elements of the EC Water Framework Directive, we must also ask questions regarding the balance between environmental protection and the economic and social benefits of a plentiful water supply. These questions include:

- Are our current practices sustainable?
- Should groundwater protection take precedence over economic growth?
- Should we go beyond protection to restoration and environmental enhancement?
- Should the precautionary principle be applied to maintaining the security of public water supply?
- How should the views of the public be reflected in decisions relating to the sustainable balance of resources?

A lack of data makes it difficult to answer many of these questions, particularly in the face of climate change. However, the approach to addressing the issues must clearly include stakeholder participation and a clear definition of objectives for environmental, social and economic achievements. This means that we need to have public ownership of the issues and public understanding of the behaviour of hydrological systems. This is a difficult task and will clearly cost money, but the Government must make the required financial investments.

If we can achieve these aims we may be able to move towards a balanced approach to groundwater protection. Indeed, the three elements of sustainability are not necessarily mutually exclusive. For example the preservation of wetlands will have benefits to the environment in terms of sustaining ecosystems, benefits to the economy in terms of protecting valuable groundwater resources and also providing tourist interest, and social benefits in terms of the amenity and recreational value of wetlands.

CONCLUSIONS

Groundwater protection is difficult, but essential. Due to the large number of threats to groundwater and the vulnerability and value of the resource it may be necessary that we protect all groundwaters and move towards aquifer protection rather than simply supply protection
It is also clear that the protection of groundwater requires the development and integration of scientific, technical, regulatory and societal solutions.

The tools have been developed in most of these fields but without integration the solutions will fail – technological solutions can work in the short term but for a sustainable solution we must develop an integrated approach.

The scientific considerations relate to questions over how we deal with the characteristics of heterogeneous physical systems, such as geology and vadose zone infiltration. There are also questions over modelling a huge range of potential contaminants. The technical considerations relate to the physical clean up of contaminants and the development of new solutions such as bioremediation of contamination and the rehabilitation of boreholes. They also relate to the protection of supplies. The regulatory considerations relate firstly to how do we deal with uncertainty and probability based decisions within our legal and planning systems (Wheater et al., 1998; Lindsey et al., 1997; Berg and Abert, 1995; *inter alia*) They also relate to land-use planning and the importance of water quality and status within that framework. The societal concerns these relate to making the links between the food we eat, the products we use and the infrastructure we de upon and how this impacts on the water we drink and that supports the natural environment.

The future should be about integrated catchment management. We should move away from end-of-pipe solutions for water (and also for sewage) treatment, to a more holistic approach. To do this we must develop an integrated cross-sectoral approach to groundwater protection, but this requires co-ordinated planning at a catchment scale and coherence between different levels of regulation (Steiner *et al.* 2000). In the UK context, we must ensure that policies developed under at European, Member State, national, regional and local levels are all integrated. More importantly we must also ensure that policies developed in different fields are integrated, this means that housing, environment, agricultural, regional development, and Treasury policy, to name just a few, must all recognise the need to protect groundwater. This cross-sectoral approach to policy development is important for both quality and quantity of groundwater and to do this overarching national water forum must be established to guide decision making. This forum should be sponsored by Government and consisting of stakeholders from industry, NGOs, regulators, consumers and academia and it should have a remit of delivering sustainable water resources management.

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11. GROUNDWATER PROTECTION AND PLANNING POLICY

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ABSTRACT

Town and Country Planning in the United Kingdom has undergone a massive change in emphasis over the last 20 years - from trees and traffic to sustainable development. But it has been a slow process and Local Planning Authorities are still unsure as to what it all means. Is the 'decade of the environment' in danger of being overtaken - as other passing trends have been - by the next intellectual bandwagon?

This paper will assess, (with specific reference to groundwater protection), just how far land-use planning in the U.K. has come in the 1990's and what challenges remain if it is to fully embrace such issues as groundwater protection.

Fragmented control regimes, poor public awareness, and lack of clear Government guidance are three acknowledged constraints which are considered.

The paper also considers how land-use planning needs to progress if the aims of the Government's current sustainable development strategy are to be achieved.

CHANGING ATTITUDES AND AWARENESS

The British land-use planning system has come a long way in the last 20 years in so far as environmental issues are concerned. In 1981, I was an aspiring young Planner working in Norfolk, and 10 years ago, I was teaching aspiring young Planners at Birmingham Polytechnic.

In neither position did the term "Groundwater Protection" mean much either to me or to my colleagues. We were familiar with the concept of "pollution" and were tolerant of interference from "the water boards" when issues of drainage were being discussed. Much more than that and it was true to say that we lost interest.

When dealing with planning applications, I would consult with the planning authority's own drainage engineers, and, on occasions, with the Regional Water Authority. They would, occasionally, even reply!

But the level of understanding of water related issues amongst Planners was lamentable, and the usual response was to impose a standard planning condition regarding the means of foul drainage to be employed in the proposed development.

Water and in particular groundwater that couldn't be seen, was something that simply existed. Always had done, and would continue to do so. If water became polluted, then that was someone else's problem, not ours!

THE 1970S AND 1980S

To my knowledge, the term did not appear in any local or structure plan policies of the time, and, while the concept of water pollution was acknowledged in the 1971 Town and Country Planning Act, this was only in respect of wastes from mines and quarries (ss 264-5). I recall one, probably typical, local plan of the time having a chapter on landscape and environmental issues containing 36 policies, none of which contained the word "water"!

DoE Circular 55/76: "Waste on Land (Disposal Site Licences)" (later superseded by Circulars 13/88 and 11/94), did at least mention the issue of pollution in a Planning context. However, it too was limited to waste issues and dealt primarily with site licensing in an administrative sense, reinforcing the view that Planners had no role to play in environmental regulation and control. –

The Planning Law "bible" in the late 1970's was a seminal text by Professor Patrick McAuslan, entitled "Land, Law and Planning" (1). The term "Groundwater Protection" does not appear in the text and the word "water" is not even in the index!

It is debatable, therefore, whether or not the concept of groundwater protection or pollution of the water environment was capable of being a material planning consideration, let alone the subject of planning policy, as recently as 1981.

The reason for the lack of interest by local planing authorities lay in their belief that the 10 Regional Water Authorities (RWA's) were the appropriate bodies to deal with such matters and that there was no role for the planning system: that Planners dealt with the "what?" and "where?" leaving others to consider the "how?" issues - and to mop up the mess when it all went wrong.

To be fair to the Planners of the day, this was not an unreasonable approach, given the legislative background, the division of responsibilities at the administrative level, and the absence of any integrating elements in government guidance.

Indeed, I do not recall any particular pressure from the RWA's themselves for any greater involvement in the Planning process than they already enjoyed.

As far as consultations were concerned, it is interesting to note that in 1981 the RWA's were statutory consultees on planning applications involving the following forms of development: -

(ii) works to the bed or banks of a river or stream;
(iii) use of land for the storage or refining of mineral oils;
(iv) use of land for the deposit of waste;
(v) development for the retention treatment or disposal of trade waste, sewage, or sludge; or,
(vi) the use of land as a cemetery

(Paraphrased from the Town and County Planning General Development Order, 1977: Article 15(1)(f))

Compare this with the *current* wording in Article 10(1) of the Town and Country Planning (General Development Procedure) Order, 1995, and try to spot the differences! What does this say about Government's priorities and understanding of the issues as far as groundwater protection is concerned?

In 1986, David Hughes, in his book, "Environmental Law" (2) wrote:

> "The legitimacy of using planning powers for purposes covered by water legislation is questionable. A restraint on development policy ***may be justifiable*** in order to preserve the existing high quality of water in a river or estuary, or to prevent further deterioration in an already polluted stretch of water" (page 373 - emphasis added).

Clearly, the situation with regard to groundwater protection was improving, but many doubts remained on the legal side.

Hughes went on to describe an early example of collaboration between Severn Trent Water Authority and Leicestershire County Council on a Minerals Subject Plan in the following terms: -

> "Consultation began some time before the plan was made to satisfy the water authority that the County Council was aware of the need to protect water resources, means of water supply, and land drainage issues" [p.373]

The very fact that such collaboration merited a mention suggests that it was not normal practice for such early consultation to occur between the RWA's and Minerals Planning Authorities at the time.

THE INFLUENCE OF EUROPE

European Community Directives provided an important impetus to the subsequent embracing of environmental concerns by the planning system. In 1982, Directive 4/82 on the Protection of Groundwater provided impetus in so far as the current issue is concerned, (to be followed by 20/90 on the same topic), while others played a similarly influential role. None more so, perhaps, than the 1987 Directive on Environmental Impact Assessment (EIA).

The introduction of EIA to the planning system provided a massive boost to environmental protection, bringing it to the forefront of the minds of both local planning officers and, more importantly perhaps, of developers – many "discovering" the existence of groundwater for the first time!

THIS COMMON INHERITANCE AND THE RIO SUMMIT

By the late 1980s the emerging environmental influence over Town and Country Planning decision-making was beginning to be seen as a growing force.

The Government White Paper "This Common Inheritance" (HMSO: 1989), considered by many to be a crucial point in the process, furthered the cause with seven simple words when considering the relationship between land-use planning and pollution control: -

"But in practice there is common ground", At last there existed official Government recognition of the need to combine the "Where?" and "What?" questions, with the issue of "How?" new development is to proceed, *through the planning system.*

This approach, in my opinion, provides us with a foundation for achieving sustainable development.

THE 1990S: "THE DECADE OF THE ENVIRONMENT"

From this point on, the drive towards ever more influential and integrated planning and environmental decision-making is well documented and, hopefully, accepted by all parties concerned.

The successful introduction and refinement of Planning Policy Guidance Notes (in 1988) and Minerals Policy Guidance Notes, Regional Planning Guidance, and Technical Advice Notes (in Wales), together with a succession of Circulars, E.C. Directives, Government Regulations, and a new Town and Country Planning Act, (in 1991), all combined to make the 1990s "the decade of the environment".

The 1991 TCP Act *required* Development Plans to include policies in respect of: -

The conservation of natural beauty and amenity,
Improvement of the physical environment, and,
The management of traffic.

However, while PPG12, "Development Plans" (1992) required Structure Plans to include policies for the conservation of the built and natural environment, and for the treatment and disposal of waste, it failed to mention either water quality or water resources.

Indeed, in para. 5.37 a fundamental misunderstanding was revealed in the statement that:-

> "The utilities (and, in the case of water supply and sewerage, the National Rivers Authority) should be consulted about these questions...."
>
> since the NRA were responsible for neither of the two services mentioned!

PLANNING AND OTHER REGULATORY CODES

Even after the 1991 Act, the question of responsibility continued to stimulate academic debate. Ball and Bell in "Environmental Law" (3) begin a chapter of their book on the agencies engaged in enforcing environmental law with a section on the Town and Country Planning system where "potential pollution problems" are listed as a legitimate material planning consideration.

Subsequently, in a section dealing with "Planning conditions and pollution control" [p.195] they state that:

> ".... planning conditions should not be used to deal with problems which are the subject of controls under separate environmental legislation".

This frequently stated view – shared by Government in successive Circulars, (previously 1/85 and currently, 11/95), on "The Use of Planning Conditions" suggests that it is not the imposition of conditions per se that is discouraged but the use of such conditions where alternative powers exist.

This rather ambiguous situation gives rise to considerable misunderstanding between LPA's and other regulatory bodies, such as the Environment Agency, when the precise nature and extent of available powers is not appreciated by the parties concerned or where both parties claim responsibility.

The "common ground" perceived in "This Common Inheritance" might not be so "common" after all!

PPG 12

Returning to PPG 12 (1992), and despite its occasional inaccuracy, one finds much to encourage the belief that the Government and Town Planners were really beginning to appreciate, (if not fully understand), the issue of groundwater protection.

For instance, para 6.7 states that:

"Increased scientific understanding and better estimating are showing us that the cost to the community of many forms of pollution are more substantial than we had been accustomed to think"

Para. 6.19 is, however, quite unambiguous in stating that: -

> "Particular attention should be paid to the protection of groundwater resources which are susceptible to a wide range of threats arising from land-use policies. Once groundwater has been contaminated, it is difficult if not impossible to rehabilitate it. Changes in land use may also affect the availability of groundwater resources by restricting recharge or diverting flows. The NRA is preparing a series of maps to identify those areas of particular concern; these will become available over the next three years. They should be taken into account in drawing up development plans"

This statement heralds the arrival of groundwater protection as a fully-fledged planning issue: a material planning consideration in all senses.

THE "POLICY AND PRACTICE FOR THE PROTECTION OF GROUNDWATER"

In 1992, the NRA published a large scale Groundwater Vulnerability Map for England and Wales, together with the Authority's "Policy and Practice for the Protection of Groundwater" (PPPG). Useful as this was, it failed to have any great impact upon local planning policies for several years exemplifying the need for better communications between the Agency and local planning authorities.

Those local authorities that did attempt to use the PPPG to substantiate planning decisions were often frustrated by its lack of precision, and, it has to be said, occasionally by the NRA itself, through lack of support and inconsistency.

PPG 23

In 1994 the publication of PPG23 "Planning and Pollution Control" left no doubt that the issue of groundwater protection had become integral to the Planning system. Indeed, this remains the main source of advice to Planners on the prevention of pollution to groundwater (and to other "controlled" waters) providing guidance on Development Control decision-making and the formulation of Development Plans.

Nevertheless, significant areas of ambiguity still remained, even after the publication of PPG 23. These were not concerned so much with the *principle* of groundwater protection as a legitimate planning aim, which had been clearly established. Rather, doubts continued to be raised on matters of detail and on the division of responsibility between planners and other regulatory and enforcing agencies.

For instance, Annex 3 of PPG 23 entitled "Water Quality" contains 19 paragraphs, 16 of which are about Discharge Consent procedures, not about Planning! Furthermore, the remaining three paragraphs, (17, 18 and 19) refer **only** to pollution from sewage disposal, with no mention of other potential sources of contamination.

PPG 10

In an attempt to clarify one particular area of misunderstanding, namely the division of responsibilities on waste site licences and planning permissions, Government published PPG 10 "Planning and Waste Management" in 1999. It would appear, however, that most users remain confused with regard to this particular area of "common ground" (e.g. the list of planning issues in Para. A11, many of which are considered by Agency staff to be matters more appropriately, dealt with through the site licence).

The new PPG 12

The most recent opportunity for Government to further develop and clarify the relationship between the planning and regulatory systems of control with regard to groundwater protection came in a revised version of PPG 12, issued in December, 1999.
In para 3.5 Government re-states the long-held view that: -

> "Development plans should not contain policies for matters other than the development and use of land, (and should not contain policies which duplicate provisions in other legislative regimes...."

However, the guidance then continues with the proviso that development plans should,

> "...have regard to wider sustainable development objectives".

In paragraph 4.2, LPA's are exhorted to take into account the social, economic and environmental aims of sustainable development with policies in development plans seeking to:

"...implement the land-use planning aspects of sustainable development"

However:

"Where non-land use considerations have land use implications.... they may be included in the explanatory memorandum of structure plans or in the reasoned justification of a local plan or UDP" (paragraph 4.2)

Interestingly, para 3.6 of PPG 12 requires all plans to indicate any land-use policies to be applied within any areas designated *through other regimes* – which should include designations for groundwater protection purposes such as Nitrate Sensitive Areas, and, (potentially) source protection zones.

Chapter 4 lists some of the issues that may be addressed in plans. These include:

"the need to protect groundwater resources from contamination or over-exploitation (advice available from the Environment Agency)"

The reference to "over-exploitation" in paragraphs 4.4 and 4.5 and the subsequent discussion of locational implications in paragraphs 6.19 – 6.21 represent a significant step towards the achievement of a sustainable approach to groundwater protection.

It is incumbent upon all LPA's (and the Environment Agency) to ensure that all future development plans seek to achieve a sustainable level of groundwater protection. To do this we have to ensure not only that future generations have access to the resource, but also that the needs and demands of the present day are satisfied. This is never easy – and it requires an approach to policy making that enables LPA's to say "yes" as well as "no".

In the past, (broadly speaking), planning policy has been based on an "either / or " approach: Either we have had development, or we have protected the environment. The *current* trend in policy making at Governmental level is towards the "and" approach – in this case development and groundwater protection. This is in line with the Government's interpretation of the definition of sustainable development found in PPG1 (para.4).

In the future, the use of criteria based policies that seek to facilitate development that is "*good enough to approve*" rather than preventing development that *is "bad enough to refuse*" will be encouraged by Central Government.

This trend should be seen as a massive opportunity for environmental improvement rather than as a threat. The funding opportunities offered by new development are there to be used. I suggest we do just that!

THE CURRENT SITUATION PLANNING POLICY

The situation today, therefore, is a great improvement upon what it was twenty years ago: "Groundwater Protection" is an accepted part of planning policy formulation and therefore also an important material planning consideration in individual development control decisions, through the operation of s.54A of the 1991 Act.

Most, if not all, development plans contain policies seeking to protect (and occasionally to improve) the quality of groundwater, no doubt encouraged to do so by the increasing level of collaboration between local planning authorities and the Environment Agency. Examples of such policies can be found in all areas of the country. The following policy, taken from the revised Devon County Joint Structure Plan (1999) is a good example: -

> "Proposals for development should not be provided for where:
>
> 1. Such development would lead to an unacceptable deterioration in the quality, quantity or natural flow of underground, surface or coastal waters.
>
> 2. Adequate water resources do not already exist, or where their provision is likely to pose an unacceptable risk to existing abstractions, water quality, fisheries, nature conservation, amenity or inland navigation interests or any facet of the natural water environment"

Given the advice in PPG's 10, 12, and 23, and the over-arching theme of sustainable development, there is no reason why similar policies should not appear in all Development Plans.

The Environment Agency is currently engaged in a research project seeking to identify "best practice" in development plans in order to disseminate ideas throughout the Agency as well as to all local planning authorities.
A new PPG?

If, however, groundwater issues can be addressed at a national scale, as the PPPG seems to indicate, why not complete the picture and issue a PPG on groundwater protection? The recent publication of PPG 25 on flooding provides an excellent precedent and, (one hopes and presumes), relationships between the Agency and Central Government are now well established in order to facilitate such a publication.

Structure and local plans would then refine the general approach set out in the PPG, aided and abetted by the Agency's excellent source protection maps, to produce a desired pattern of new development taking into account groundwater issues.

This approach to groundwater protection offers several important advantages:-

(ii) Consistency,
(iii) Certainty, and,
(iv) Complete coverage.

It would also allow Government to introduce a precautionary approach towards groundwater protection into the planning system – as they have done in PPG 25 on the issue of flooding.

CONSULTATIONS

(a) Development Control

I have already mentioned the fact that the current statutory basis for development control (DC) consultations is almost identical to that under the 1971 Act.

Whilst acknowledging the existence of various agreements between the Agency and LPA's, these remain non-statutory, and adherence to them is patchy.

It is time, in my opinion, that both the Agency and LPA's sought to place the issue of DC consultations on a sounder footing – and it is Government's role to oversee this process.

Initially, this should be approached through a complete overhaul of the statutory provisions set out in Article 10 of the GDPO. Subsequently, a (locally agreed) transfer of responsibilities could occur whereby responsibility for less critical and "routine" issues is transferred back to the LPA's from the Agency.

This would save time and money, speed decision-making, and raise the profile of groundwater (and other) issues within LPA's without any serious threat to the environment.

DEVELOPMENT PLANS

The statutory provisions with regard to consultations on Development Plans are much more satisfactory. In this case, the Environment Agency is a statutory consultee at key issues, first, and second deposit stages of local and unitary plans, while PPG 12 requires that consideration be given to groundwater protection issues.

Even with such provisions in place, however, LPA's occasionally fail to appreciate the importance of groundwater issues in development plan policies and allocations, and consequently, there remains a need for ***early*** contact between the Agency and LPA's at a stage of policy formulation well in advance of any draft publications.

In this way the Agency are able to introduce the issue of groundwater protection into the fundamental ***thinking*** behind development plans, at a time when strategies and overall aims and objectives are being considered. In such a model subsequent policies and allocations come to be driven by environmental issues, rather than having to accommodate them at a later stage of plan formulation.

PLANNING LAW

No discussion of change can occur without recourse to planning law, which is unwieldy, unreliable and extremely complex.

The precautionary principle

I have already mentioned the precautionary principle and there have been numerous references to sustainable development.

While we have a planning system encumbered with the concept of demonstrable harm, and refusing to embrace, fully and openly, the precautionary principle, (as required by the EC), there will be confusion as to how environmental issues are resolved.

And it is unlikely that we will achieve truly sustainable development.

In 1997, Government backed off from adopting the precautionary principle as the basis for all planning decisions in its revision of PPG 1 "General Policy and Principles" (HMSO: 1997). If, as recent PPG's seem to indicate, such a change in emphasis can be achieved as a matter of policy rather than law, the next revision of PPG 1 can set matters straight for all environmental issues, not just groundwater protection.

Precedent

The concept of precedent often causes problems when groundwater issues are involved. Arguments around the potentially significant cumulative effects of development on groundwater resources and the immeasurably small effects of a single development, are often determined on the basis of "demonstrable harm" (and therefore allowed) as opposed to the precautionary principle, which would suggest that any harm, however small, should be avoided.

The solution to the precedent problem lies, therefore, in the adoption of the precautionary principle in planning law.

A 'one-stop' approach

Finally, I suggest that we may need a more radical approach if issues such as groundwater protection are to be given greater weight in decisions relating to new development. This involves a harmonisation of environmental, planning, and other regulatory regimes designed to provide a "one-stop" approach to new development.

Would it be possible, I wonder, to issue a ***single permit*** for all new development dealing with land-use, pollution, traffic, environmental health, economic, social exclusion, and all the other aspects of sustainable development which are currently the responsibility of various authorities and regulatory bodies?

I would like to think it is.

CONCLUSIONS

1. The British planning system has responded to the "decade of the environment" and will continue to do so at all levels;

2. The protection of groundwater is a material planning consideration, and, providing that policies are in place to support them, LPA's and Planning Inspectors will give weight to such issues in their decisions;

3. At a detailed level of operation, however, there are still some anomalies which need to be addressed, especially with regard to Development Control procedures and planning law;

4. Planning policies in the future are likely to be more flexible, with a greater use of criteria, in order to satisfy LPA's that development proposals are "good enough to approve";

5. LPA's and other regulatory bodies will need to be aware of the opportunities that are available to them to achieve sustainable development, and to pursue such opportunities ambitiously, responsibly and reasonably.

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12. THE LEGAL FRAMEWORK, AND TECHNOCRATIC VERSUS DEMOCRATIC ISSUES, FOR GROUNDWATER PROTECTION

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ABSTRACT

It is accepted that sustainable development requires a balanced assessment of environmental as well as social and economic factors. The current system of development control in view of its historical evolution, is, it is now realised, not appropriate for this new role - hence the current major review on environmental planning by the Royal Commission on Environmental Pollution.

Protecting groundwater has to be considered within the context of sustainable development. The current and evolving legal framework for groundwater protection and for development (the latter primarily through the vehicle of land-use planning) are critically reviewed.

It should be reasonably straightforward if we start with a clean sheet to see what sort of system we should be aiming for. The question is - do we go for a radical or an evolutionary change?

Sustainable development requires holistic approaches within an integrated system, in which the main difficulty is the integration of the technocratic and the democratic elements. With this in mind the case for a radical change is put forward for debate.

INTRODUCTION

In discussing the legal framework for the protection of groundwater, two important issues of context arise – that is the need take an integrated approach and the need to satisfy the requirements of sustainable development.

Integration

A simple view of the natural water cycle leaves no doubt that groundwater is part of the continuum of the cycle and cannot be managed and protected properly if dealt with in isolation. The water cycle, even without considering the impact of human interference, is however a very, spatially and temporally, complex system. This reality has in the past lead to the disintegration of the science of the water cycle (hydrology) with the creation of new branches of science (e.g. groundwater hydrology / geohydrology / hydrogeology) in order to examine parts of the cycle in more detail. Whilst many valuable advances in knowledge and understanding have arisen because of such steps, hydrogeologists have significantly failed to re-integrate their work within the overall study of the natural water cycle. A key consequence is the relatively poor understanding of the processes of groundwater recharge; i.e. processes at the interface between surface water and groundwater hydrology, especially water movement through the unsaturated zone.

This problem can be illustrated by the variations in legal definitions of groundwater. In the UK Water Resources Act 1991, s.104 sensibly defines groundwaters, as "*any waters contained in underground strata*". Whereas European Union law (in the Groundwater Directive EEC 80/68 and the Nitrates Directive EEC 91/676) defines groundwater as "*all water which is below the surface of the ground in the saturation zone*". The important difference is that the latter definition does not cover the water in the unsaturated zone, i.e. soil water and percolating water yet to reach the water table (saturation zone). This is simply wrong and certainly not conducive both to dealing with the water cycle in an integrated manner and to dealing with groundwater pollution. Unfortunately the UK has moved towards adoption of the European Union's, wrong definition of groundwater.

The continuum of the hydrological cycle is also a factor that poses problems when trying to legally define and allocate discrete volumes of water. This dilemma, is particular relevant to groundwater which unlike surface water in more-or-less easily definable water courses, is out-of-sight and much less easy to delineate.

By mentioning legal issues this discussion is moving towards demonstrating that the term integrated must go beyond the scientific and technical issues relating to the natural water cycle and our interference with it, to include economic, political, institutional, social and legal issues.

Integration in the wider context is about the interface between two prime elements - the **democratic** (social and political behaviour - i.e. society's needs, demands, and use, of water) and the **technocratic** (scientific knowledge and technical capability, with respect to the physical water cycle). Thus the previous discussion on integrating groundwater properly within the whole water cycle is primarily a technocratic issue.

Sustainable Development

Sustainable development means dealing in an integrated and balance manner with economic social and environmental needs.

Development in the past has been dominated by economic and social issues. Despite an abundance of sustainable development rhetoric the institutional and legal framework for development is still, to too greater an extent, constrained by historical baggage and is not appropriate to deliver sustainable development.

Sustainable development requires the integration of both technocratic and democratic elements. Legislation is meant to be the effective mechanism of interface between these elements, but institutional arrangements and professional attitudes also have a key influence, as do political ideology and public perceptions. Issues include the need for better integration of planning and economic development with environmental protection; financial penalties with financial obligations to remediate (i.e. real application of the polluter pays principle); public perceptions with application of the precautionary principle.

On top of this there is the constraint, all too often ignored when forming policy or making democratically acceptable legislation, of lack of knowledge and understanding about parts of the water cycle and their interaction. The legal profession in trying to formulate effective legislation demand a degree of scientific/technical certainty which does not exist. This is compounded by an unwillingness by individual professionals to admit when they don't know;

and by intra- and inter- professional and institutional rivalry, which in turn constrains consultation, co-operation and confidence.

PAST DEVELOPMENT SYSTEM

This section reflects on legal provisions available prior to 1972.

Development control and land use planning law and practice

Initial principles of statutory development control relate to the mid-19th century when the law came to recognise the right of a landowner on the outright sale of land (sale of the freehold) to impose restrictive covenants as to the use which might be made of the land sold, for the benefit of retained adjoining land. Such restrictive covenants are enforceable by and against successors in title to both the land affected and the land benefited. The first statutory controls were brought in with the Town and Country Planning Acts of 1932, 1947, 1971).

In 1947 the right to develop land was nationalised. This was a radical political step and introduced the principle that no owner or occupier (with some exceptions e.g. in agriculture and forestry) was able lawfully to develop their land unless they obtained planning permission.

Groundwater protection law and practice

Although the introduction of statutory legislation for the protection of surface water goes back to the 14th century Act for Punishing Nuisances in towns (1388), that relating to groundwater has come much latter.

The first significant piece of statutory legislation for the protection of groundwaters was the 1963 Water Resources Act when controls on discharges to groundwaters were introduced in. Statutory controls on groundwater (and surface water) abstraction was not introduced until 1973 under the far-sighted Water Act, which introduced integrated water management under 10 Water Authorities based on hydrological boundaries. Principles of modem pollution control measures were introduced a year later in the 1974 Control of Pollution Act but were rarely applied.

While statutory legislation has provided little protection for groundwaters until relatively recently, Common law has been available for much longer on groundwater protection - Plato's (c427-347 BC) work on Laws includes reference to groundwater pollution.

Common law, a form of private civil law, provides an alternative for groundwater protection. Common law however focuses on the protection, in terms of both quantity and quality, of the rights of individual water users but only in the case of riparian owners, i.e. those who own land adjacent to a surface watercourse or containing underground water. The rights extend to an imprecisely defined reasonable use of water. Common law unlike written statutes, is established by judgements in the higher courts which become legally binding precedents applicable to future appropriately similar cases. In general the legal principles, derived over time have stood the test of time, because they focus on basic elements of social behaviour - the relationships between people and the protection of their property and rights. Under common law one party can take an action (sue) against another under the torts of trespass, nuisance and negligence.

The key Common law provisions relating to groundwater stem from cases arising in the 19th Century. The case of *Rylands v Fletcher [1868]* provides one of the better known rules of Common law, imposing a strict liability form of nuisance. Indeed its logic has been the basis of subsequent statutory water protection legislation. The rule from Judge Blackburn's judgement, is that *"the person who for his own purposes brings on to his land and collects and keeps there anything likely to do mischief if it escapes, must keep it at his peril, and, if he does not do so, is prima facie answerable for all the damage which is the natural consequence of its escape" This* principle of strict liability for water pollution was reinforced in *Ballard v Tomlinson [1885]*. The case related to a contaminated artesian chalk well belonging to a Brewery (Ballard) in London. Tomlinson had a similar well 90 metres way into which he directed waste from a toilet and his printing works. Lindley L.J. stated " *If a man chooses to put filth on his own land he must take care not to let it escape on to his neighbour's land."* He went to say *"So if a man chooses to poison his own well he must take care not to poison waters which other persons have a right to use."*.

These potentially powerful provisions were however limited by three facts. The first was the prevailing limited understanding of hydrogeology as evidenced in *Chasemore v Richards [1859]*. In this case Lord Chelmsford ruled that riparian surface water rights did not apply to groundwaters because " *the principles which apply to flowing water in streams or rivers, the right to the flow of which in its natural state is incident to the property through which it passes, are wholly inapplicable to water percolating through underground strata, which has no certain course, no defined limits, but which oozes through the soil in every direction in which the rain penetrates*". The second was that only the owner of land affected by the nuisance could bring an action and the third was that liability does not exist for harm that was not reasonably foreseeable at the time the nuisance occurred.

CONCLUSIONS

Control on development was established but with a presumption in favour of development and economic and social prosperity and rarely with much concern about protection of groundwater.

CURRENT DEVELOPMENT SYSTEM

This section on the current development system reflects on legal provisions available from 1972 to 2002.

DEVELOPMENT CONTROL AND LAND USE PLANNING LAW AND PRACTICE

Primarily under the Town & Country Planning Act 1990, development control and land use planning powers are exercised through:

Development plans

They provide background and structure against which individual plans can be judged; they need to accommodate present and future conflicting needs: social – residential, recreational; economic – industrial, commercial, agricultural; and environmental.

Planning permission

Local authorities can impose additional environmental enhancement works on a developer as a condition to granting planning permission. Whereas the granting of planning permission invariably imposes an enhanced value to the land, refusal of planning permission attracts no right to compensation.

Development is defined in legislation, in two parts, as:

> "the carrying out of building, engineering, mining or other operations in, on, over or under land."
> "the making of any material change of use of any buildings or other land."

material change:- courts have defined this in a planning sense, i.e. it is the likely effects of a change of use on local amenity which determines its materiality.

change of use: -courts have held that this might occur by the intensification of a use, by the abandonment of a use, as well as by a change of use of land, or buildings.
Good reasons have to be given if planning permission is not given.

For the developer there is a right of appeal against a refusal of planning permission, to the Secretary of State for the Environment, but which would be in practice dealt with by an inspector. There is a further right of appeal to the High Court but only on matters of law not on matters of planning policy. In practice the DETR's Planning Policy Guidance notes (PPGs) are of considerable importance and are widely used in practice.

No neighbour or affected person has any right of appeal against a grant of planning permission. However they can make their views known in a planning inquiry where the developer has appealed against a refusal of planning permission, as of course they can at the time of the original planning application.

There are about 500,000 applications per year of which 85% are granted – there is still very much a presumption in favour of development. Furthermore certain activities are automatically granted planning permission under statute via:

General Permitted Development Orders - agricultural and forestry land use and buildings (but not large livestock units or slurry storage or where EIA is required); and laying of / repair to, water and gas mains, electricity and communication cables.

Special Development Orders - with respect to new Towns, Urban Development Areas and Enterprise Zones.

Such measures are seen by some as a move way from a democratic and consensual basis for planning by providing greater central Government control, over-riding local decision making and therefore any semblance of local democracy and community participation.

In accordance with the statutory obligation (s.70) to take all material considerations into account it appears that there has always existed a duty positively to consider the likely environmental implications of any application for planning consent and/or to attach environmental or amenity conditions to the grant of planning permission. However since 1988 there has been an obligation to go through a more formal Environmental Impact Assessment (EIA). This arises from the EC Directive incorporated into UK law as the Town and Country Planning (Assessment of Environmental Affects) Regulations 1988.

The law defines two types of projects: those where EIA is mandatory (Annex I - e.g. oil refineries, thermal power stations, radioactive, toxic and dangerous waste storage/disposal, motorways) and those (Annex II) where the Local planning Authority (LPA) should consider the need for an EIA. However the impression is that the impact of developments on groundwater resources has often been ignored.

Enforcement of development controls comes in the form of serving an enforcement notice requiring the developer to stop the offending operations or change of use and return to the status quo ante OR in the case of breach of condition requiring compliance with that condition. It is the failure to comply with the enforcement notice that constitutes the offence not the breach of planning regulations. But a person can appeal against an enforcement notice but in the meantime can lawfully carry-on with the development. The LPA can issue a stop notice that means the developer may be charged with criminal penalties if the development continues. The LPA has to be careful with these though since if the appeal against the enforcement notice proves successful it will be liable to give compensation for any losses suffered in complying with the stop notice.

For many developments the developer has gain two sets of authorisations often from two different authorities; i.e. planning permission from LPA and some form of environmental authorisation from the Environment Agency. The co-ordination between these two authorities is not always what common-sense might suggest should prevail. The granting of planning permission does not automatically mean that environmental authorisation will be forthcoming, and sometimes the granting of planing permission and/or the conditions attached make consideration of environmental pollution control more difficult.

GROUNDWATER PROTECTION LAW AND PRACTICE

The current pieces of UK statutory legislation most relevant to groundwater resources and groundwater pollution are the 1991 Water Resources Act, the 1995 Environment Act, and the 1998 Groundwater Regulations. These in many ways have evolved as a direct response to groundwater specific and some less-specific EU Directives. The Groundwater Directive (1980) lagged, as so often in the past, sometime behind those relating to surface waters (six 1975-79), and the integration of surface water and groundwater has only recently (2000) been addressed via the Water Framework Directive.

In the UK there are many other pieces of statutory legislation which impact directly or indirectly on groundwater. Examples include the 1985 Food and Environment protection Act (pesticide use); the 1991 Land Drainage Act (water-table control); the 1990 Environmental Protection Act (waste disposal), the 1991 Water Industry Act (groundwater quality); the 1990 Town and Country Planning Act; the1994 Habitat Regulations.

The Water Resources Act 1991 remains however the most important legislation. Its scope is the conservation and protection of water resources. The legislation applies only to "controlled waters" and control is principally exercised through abstraction licenses and discharge consents. Offences for groundwater pollution are covered by s.85, which sounds straightforward enough i.e. a person commits a criminal offence "if he causes or knowingly permits any poisonous, noxious or polluting matter or any solid waste to enter any controlled water". Whilst there has been many successful s.85 prosecutions, dominantly applied to surface waters, it has taken the courts many years to decide exactly what "cause" means.

In a land-mark case - *Alphacell v Woodward* [1972], which was concerned with a river pollution incident under the Rivers (Prevention of Pollution) Act 1961, the House of Lords decided that Alphacell "*were guilty of the general offence of causing pollution simply by carrying on the activity which caused the pollution...there was no need to prove negligence or fault.*", i.e. imposing strict liability for pollution offences. However since 1972 the courts have not been able to consistently apply this precedent which favours environmental protection over social and economic considerations. Following rulings by the Attorney General (1994) and House of Lords in *Empress Car Co. (Arbertillery) v NRA* [1998]
the law is now back to its 1972 intended position.

S.85 offences are of course reactive, applicable after the groundwater has been polluted. The 1991 Act does also contain some pro-active or preventative provisions namely:

S.92 which allows the regulator to make regulations to impose precautionary interventions - but this provision has yet to be made use of.

S.93 allows the regulator to designate Water Protection Zones - but this potentially powerful provision has yet to be applied specifically to groundwater systems, even though similar provisions had been available since 1974 in s.31 Control of Pollution Act. The groundwater vulnerability maps recently produced for most of the UK do however provide a useful, albeit without statutory authority, planning and management tool.

Experience in the rest of Europe is variable with fairly comprehensive coverage of groundwater protection zones in force for many years in the Netherlands, France (since 1963) and Germany (since 1933).

S.94 allows for the designation of Nitrate Sensitive Areas - this has been applied but under a system which is in essence voluntary and includes compensation to farmers - unfortunately there is little evidence to suggest that this sensible sounding measure will have much affect on reducing nitrate contamination of groundwaters in the short to medium term. Stricter , compulsory/no compensation measures, have since been introduced under the EU Nitrate Directive. The new Nitrate Vulnerable Zones as currently designated will affect 4.5 M acres in the UK and the Government's approach, following the NFU's unsuccessful challenge in the European Court of Justice, is yet to be seen.

S.161 – provides the Environment Agency with powers to carry out anti-pollution works – both preventative and remedial.

The Environment Protection Act 1990 deals indirectly with groundwater. Through the secondary Waste Management Licensing Regulations - a licence can be refused in order to prevent pollution; and license conditions require control of landfill leachate and prevention of pollution. It is a criminal offence under s.33.1(c) to treat, keep or dispose of controlled waste in a manner likely to cause pollution. This Act also introduced Integrated Pollution Control (IPC) authorisations for certain prescribed processes. This system, which controlled discharges to any of the environmental media, i.e. air, land and water (both surface and groundwater are now being reformed under the provisions of the IPPC Directive.

The Environment Act 1995 has addressed the loophole in the Water Resources Act that exempted pollution from abandoned mines. It has given the regulator more confidence to make use of strengthened prevention and clean-up powers (s.161) that include cost recovery under civil liability.

Most important however are the new s.78 provisions for contaminated land (now incorporated in the Contaminated Land (England) Regulations 2000). Contaminated land is increasingly regarded as a potential major threat to groundwater. The legislation is environmentally bold in that in theory it allows liability to be imposed on an "appropriate person", which may or may not be the originator of the contamination. In practice however, especially with contaminated land often having a complex history involving complex science, the application of the law is likely to be disrupted by a variety of challenges in the courts.

The 1999 Groundwater Regulations were brought in to cover outstanding obligations under the EC Groundwater Directive, which had not been implemented under other UK legislation (described above). The purpose of the Directive is to prevent or limit the entry of dangerous substances into groundwaters. It is considered that the current mixture of bits of legislation meant to control groundwater pollution, is cumbersome and confusing for the regulated, and even with the new Regulations still do not fully meet the obligations of Art.3 and 4of the Directive. The requirement for prior investigation, in the case of indirect discharges to groundwaters for instance, is variable amongst the provisions available. In the case of some developments not requiring IPPC or WML authorisation and not applying for an authorisation under the Groundwater Regulations, the only controls are through conditions attached to planning permission. In these circumstances there is in practice insufficient opportunity for prior investigation to take place. The Environment Agency has no obligation to be pro-active and can only act in its capacity as Statutory Consultee, or react after the event using the water pollution offence provisions of s.85 of the 1991 Water Resources Act.

Another area of concern that has an impact on groundwater, because of the importance of the soil/water interface in groundwater movement and quality, is the current lack of soil protection legislation, although a Soil Protection Directive could be in place by 2003/4.

The draft Water Bill likely to become law by 2002 proposes the removal of immunity from liability for harmed caused by groundwater abstraction.

Common law provisions although increasingly supplanted by statutory legislation, do still have a role to play in groundwater protection. Indeed the rules of law arising from the 19th Century cases referred to early were invoked in the much reported and relatively recent case of *Cambridge Water Co v Eastern Counties Leather [1994]*. In this case Cambridge Water took actions against ECL under nuisance and negligence to recover the 1 million pounds costs incurred in replacing a groundwater source which had been made unusable because of contamination by solvents originating from historical spillages at tannery works in Sawston. The case, which was finally decided by the House of Lords in favour of Eastern Counties Leather Co., rested on the issue of forseeability and retrospective liability for historical pollution. This decision in itself may not appear to help the cause of reducing groundwater pollution but it is unlikely given current levels of awareness that any modem polluter will be able to hide behind the defence of lack of foreseeability of the consequence of their activities.

CONCLUSIONS

With regard to development planning and control and groundwater protection, the current system is less effective than it needs to be, because:

The development control system while making steps to embrace environmental impact has failed to fully embrace the concept of sustainable development.
Development control is still entrenched in a land/property based system that is biased towards economic and social demands, with environmental protection partly within and partly without.
There is confusion over the boundaries between technocratic and democratic authority and responsibilities.
Groundwater protection legislation is fragmented and uncoordinated.

Within the context of sustainable development, environmental protection needs to be properly integrated into planing and development control - it cannot persist as present as an add-on to a system which still embodies a presumption in favour of development. The separate granting of planning permission and of environmental authorisations cannot be justified in the context of sustainable development.

"The accountability of pollution control decisions has been compared unfavourably with that of planning controls." (RCEP 2000). There is a danger that the technocratic authority of the Environment Agency is, or could drift towards becoming, too dominant, under a perception that all judgements are primarily scientific/technical matters. Decisions on sustainable development ultimately have to be made by an authority with a democratic mandate.

Responsibility for monitoring and managing sustainable development (which includes environmental protection) should rest at the local and regional level with local authorities and community groups. There is a need for an independent expert technocratic environmental body - not dissimilar to the current Environment Agency's headquarters plus its specialist centres.

FUTURE DEVELOPMENT SYSTEM

From different stand-points it could be argued that groundwater is at risk from:
the absence of appropriate and effective legislation
the dominance of economic/land-based proprietary rights over environmental benefits.
entrenched and misguided both professional and public attitudes

Despite considerable advances in knowledge, a better understanding of the groundwater system and hydrogeological processes is still need so that nobody can hide behind past myths and misconceptions, both legal and scientific. Application of the law to groundwater systems, which are scientifically and technically complex, and not fully understood, is difficult. The courts find it difficult to deal with scientific uncertainty and application of the precautionary principle. There is therefore a strong case for the introduction of an environmental court or tribunal, composed of legal, scientific and management experts, to deal with complex groundwater (and other environmental) cases.

So what are our options for the future?

OPTIONS

Evolution - building on and improving current system;
This may be the easier, cheaper, less disruptive option but it will only compound the limitations of the current unwieldy, confusing, uncoordinated partly parallel systems of development and pollution control.

Revolution - starting with a clean sheet;
Legislation should be simplified and rationalised - focus on a single set of primary tools providing control of potentially harmful activities - i.e. permitting/restricting abstraction from and discharges to, groundwaters; designation of protection zones; The new Swedish Environmental Code demonstrates that such simplification and rationalisation is feasible and could indeed be bolder to include all environmental legislation.

Development should be sustainable development – this requires a holistic, integrated, balanced consideration of economic, social and environmental factors. This must be dealt with by and within a single authority. The impact of new and past development needs to be continuously monitored and re-evaluated. Decisions (made on best available information) and controls need to be adjustable in order to be able to respond to new knowledge or changed circumstances.

Development requires a democratic planning and decision making process within a single authority. The recent decision on Alconbury case highlights the potential impact of the new Human Rights Act on planning and development decisions. The EU has always promoted the legal rights of individual citizens and have stressed "the vigilance of individuals interested in protecting their rights creates an effective control additional to that entrusted to the Commission and the Member States"

Development therefore has to be controlled by authorities working within environmental boundaries rather than the historical local government boundaries. With the current underlying move towards regional government (Government of Wales Act 1998, Regional Development Agencies Act 1998 etc) the opportunity is right to restructure administrative boundaries. Basin Districts as required under the Water Framework Directive would provide a suitable structure for future local/regional government boundaries.

Combining planning and pollution controls under a single authority will simplify the process, operationalise sustainable development decision making and will permit a clearer delineation of both democratic and technocratic roles.

Many administrative, monitoring and regulatory responsibilities and resources currently with the Environment Agency regional offices could be transferred to local/regional authorities responsible for the social, economic and environmental needs of the communities they serve. Local authorities have experience in public health and environmental health - it is necessary and logical that health of the environment, which is inextricably linked with these issues, should be integrated with these functions. After all the majority of environmental legislation has been driven directly or indirectly by public health concerns rather than by concerns over the environment itself.

Protection of the environment can only be achieved by a combination of both official and public participation, especially in monitoring impacts - a direction reinforced by the 1998 Aarhus Convention on Access to Information, Public Participation in Decision-making and Access to Justice, in Environmental Matters.

The Environment Agency will be an independent national technocratic body, a statutory consultee at central government level helping to formulate policy and legislation, and providing technocratic opinion in resolving conflicts between national and local/regional needs via inspectors and a form of environmental court/tribunal. (Versions of the environmental court system can be seen in Australia and New Zealand and more recently in Sweden and Ireland.).

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13. GROUNDWATER PROTECTION IN WESTERN AUSTRALIA

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ABSTRACT

Western Australia depends on groundwater for public and private water supplies, industry, and sustenance of its environment. Strong protection policies are required to ensure the maintenance of water quality. This paper outlines the range of mechanisms employed by the Water and Rivers Commission to protect the resources. Public water supply sources are protected through specific plans, and private and environmental water resources through the development of specific policies, guidelines, and water quality protection notes to deal with industries and land uses prone to contaminate resources. With others it produces whole-of-government codes of practices for targeted land uses. The Commission also works closely with environmental agencies to ensure contaminating industries are restricted to hydrogeologically safe areas and that requirements are in place to limit any contamination. Most importantly it works closely with the State planning agencies to ensure that groundwater protection requirements are an integral part of the land-use planning process. Together with eight other agencies the Commission has developed a State Water Quality Management Strategy to implement the National guidelines recently developed for the whole of Australia. Above all the Commission maintains a high community consultative approach that ensures the ready acceptance of its water quality protection role.

INTRODUCTION

Western Australia, occupies about one third of Australia, (2.5 million km^2) but has a relatively small, population (1.7 million in 1998) 90% of which are concentrated in the southwest of the State (Fig 1). Population distribution, and the location of the capital city Perth, is governed by available water supplies. In particular the readily available shallow groundwater around Perth was instrumental in the initial settlement of the area in the nineteenth century, and the presence, and subsequent development, of artesian water and surface water storages in the nearby ranges, ensured the region's growth. As the population of Perth and other regional centres grew, there came an increasing dependence on groundwater, so much so, that it is now the major source of water supply for drinking, stock, irrigation, industry, and gardens. Groundwater is used for more than 50% of the potable drinking water, and more than 70% of all water used in the Perth Metropolitan Region,

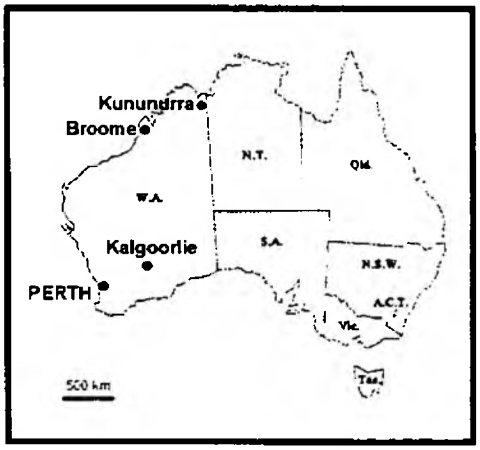


Figure 1 Location

While the geological framework is highly significant for the development of groundwater to sustain the State's demand, it is also the reason why contamination can occur readily. The presence of sand and karstic limestone within the shallow surficial sediments of the coastal areas in the south west of the State and elsewhere, and the fractured rock aquifers of inland

Western Australia, can provide an easy path for contamination to occur (Hirschberg 1991, Appleyard 1993, Hirschberg and Appleyard 1996). These resources are facing increasing demands to meet the needs of the community, industry and agriculture. Where these activities occur over recharge areas and catchments there is potential for contamination, an impact on the quality of drinking water and a restriction of the economic growth of the State.

THE WATER INDUSTRY IN WESTERN AUSTRALIA

Structure and roles

The industry in Western Australia was restructured during 1995 to enable better regulation, control, conservation and protection of the State's resources. The industry's assets exceed A$9 billion, it expends more than A$450 million on capital each year and A$530 million on operations, and collects more than A$600 million per year in revenue (Office of Water Regulation, 1999). It is a major industry requiring efficient management and protection.

The **Water and Rivers Commission** is responsible for the management of the State's water resources to support sustainable development and conservation of the environment for the long-term benefit of the community (Water and Rivers Commission, 2000a). It allocates resources between competing interests to ensure sustainable use and conservation, to protect water quality, and to conserve and manage of the State's rivers and waterways. It investigates the health and extent of groundwater resources, measures surface water flow and quality, and investigates, measures and assesses the State's water resources.

The **Water Corporation** is responsible for the supply of water and wastewater. The biggest corporation in Western Australia, with over A$9 billion of assets, it has one of the largest geographic utility domains in the world (Water Corporation, 2000). It supplies drinking water across the State to standards set by the Office of Water Regulation and the Health Department, it provides wastewater collection, treatment and disposal services, urban drainage and flood protection, and provides reticulated irrigation (although several schemes are now becoming privatized). It is not the only supplier of water, as two smaller utilities and several mining companies supply resources to other parts of the State.

The **Office of Water Regulation** regulates the industry through a system of licenses that apply to all providers of water supply, sewerage, drainage and irrigation services, and encourage and promote efficiencies and technical standards, while facilitating improved levels of customer services and customer information. It also monitors the performance of water service industries.

Relationship with other agencies

The water industry works closely with numerous other government agencies to ensure proper ecologically sustainable development of the State's water resources. In particular the relationships with the Department of Environmental Protection and the Health Department are vital for the maintenance of water quality and the setting of drinking water standards for the State. Public drinking water source protection is recognised in administrating the Environmental Protection Act 1986 and the Department licenses land uses that can cause contamination, can impose requirements for pollution prevention, and can prosecute and impose penalties. The Health Department sets the standards for drinking water and through its chairing of a Purity of Water Committee maintains a strong monitoring role on the effectiveness and efficiency of the water service providers to deliver these levels.

The Commission in particular works very closely with the Ministry for Planning and the West Australian Planning Commission to provide the link between planning and water quality protection which has been identified as an essential tool for management. The Commission also works closely with other government agencies when developing codes of practices and operating guidelines for various industries and land uses to ensure water quality protection.

THE NEED FOR WATER QUALITY PROTECTION

Western Australia is the second driest State in the world's driest continent; fresh water is one of our most important natural resources, but it is important that it is not taken for granted. We need to recognise that there are many activities occurring over the groundwater recharge areas that can impact on the quality of drinking water. Where resources are unaffected by land use and human activities, there is less risk of contamination, but as the pressure for urban, rural and industrial development increases so does the risk of contamination.

Recognising this, in 1994 a Parliamentary Select Committee reviewed the mechanisms for groundwater resource protection particularly as it applied to the Perth Metropolitan Area and the pressures for water supplies in a rapidly growing urban area. Reviewing experience from around the world the Committee concluded, "an ounce of prevention is worth a pound of cure". (Western Australian Legislative Assembly, 1994) while the Chairman noted, "experts around the world expressed their envy of our relatively pristine water supply and advised us to protect our groundwater supply at all costs"

The Committee made 28 recommendations, but the most significant focussed on:

- strengthening legislative mechanisms protecting groundwater resources
- incorporating source catchment protection into statutory land planning mechanisms
- ensuring consistent by-laws applied to both surface and groundwater catchments
- defining and fixing immutable Priority Zones, particularly to protect pristine resource recharge and extraction zones,
- defining a range of Acceptable and Unacceptable Activities in the priority zones, and
- establishing a consultative process across Government agencies

Though the Select Committee was reviewing Perth's development and groundwater supplies, these recommendations have equal applicability across the State, and to surface water supplies, and have indeed formed the focus of the Commission's work in water quality protection. In addition considerable emphasis has been placed on close community consultation, a process that is evident across the complete range of Commission activities.

A subsequent Standing Committee on Ecologically Sustainable Development delivered a report in 2000 (Western Australian Legislative Council, 2000) that also commented upon the quality of Perth's water supply. Though there was a clear focus on the surface water catchments that also supply Perth, the report also recommended that the by-laws and source protection plans be progressed as a matter of priority, and that the Water Corporation should include water quality in its community education programs.

CURRENT LEGISLATION

Public drinking water source areas (PDWSAs) are protected from pollution by proclaiming Water Reserves, Catchment Areas or Underground Water Pollution Control Areas (UWPCA) under the Metropolitan Water Supply Sewerage and Drainage (MWSSD) Act 1909 or Water Reserves or Catchment Areas under the Country Areas Water Supply (CAWS) Act 1947. Activities with the potential to contaminate public drinking water sources are controlled by by-laws in the Acts, and enforced by surveillance, but as the Select Committee noted there are discrepancies between the metropolitan and country related Acts.

The Commission also administers catchment protection legislation in PDWSAs, and under the Water and Rivers Commission Act 1995 can delegate certain catchment functions, such as enforcing by-laws and restricting entry on to land to the Water Corporation.

The Rights in Water and Irrigation Act 1914, also applies in groundwater areas. The Commission uses this legislation to allocate water resources through abstraction licences and there are provisions for these to contain conditions to protect the resource for its beneficial uses and safeguard other users.

The Environmental Protection Act 1986 is the principal act dealing with pollution in Western Australia, and is administered by the Department of Environmental Protection (DEP) and the Environmental Protection Authority (EPA). It recognises public drinking water source protection and allows the DEP to manage potential polluting activities and to enforce remedial clean-up work of both accidental and deliberate contamination of groundwater.

The Health Department of Western Australia under the Health Act 1911 is responsible for all aspects of public health and is the regulatory agency for the quality of drinking water in Western Australia. The Department chairs the Advisory Committee for the Purity of Water which maintains a watching brief on the quality of drinking water being supplied to consumers. The Commission plays an active role on this committee.

DEVELOPMENT OF PRIORITY ZONES

In keeping with the recommendations of the Select Committee the Commission has adopted three levels of priority classifications for PDWSAs, namely Priority 1, 2, and 3 (P1, P2, P3). The classification follows what is essentially a risk-based approach to source management on the basis that it may not be appropriate to apply the same level of protection across all areas. The description of each classification as it applies to the water resource is given in Table 1.

Table 1 Priority classifications for public drinking water source areas

Classification	Level of risk	Description
P1	Risk avoidance	• No degradation of the resource • Strict limitations on land use – most development not permitted • Provision of highest quality drinking water is prime beneficial use
P2	Risk minimisation	• No increased risk of contamination of the resource • Low intensity development exists (eg rural) • Protection of high quality water is a high priority • Some development allowed under guidelines
P3	Risk management	• Manage the risk of contamination of the resource • Water sources need to co-exist with other land uses • Protection through management guidelines not restrictions on land use

WATER QUALITY PROTECTION TOOLS

In order to assist the managers of the State's water resources, as well as those responsible for land management and planning, the Commission has developed a series of documents that provide guidance in water quality management related issues. In particular the Commission is producing water source protection plans (Water and Rivers Commission, 2000b) aimed at providing protection for PDWSAs, and a series of policies, guidelines and protection notes aimed at developing best management practices for various land uses that could cause contamination of groundwater resources.

Water Source Protection Plans

Water Source Protection Plans (WSPPs) are being prepared for some 140 individual sources that provide drinking water to towns and communities across Western Australia. Some of these sources are small and may consist of a single bore, while others are large (e.g. Perth) and may consist of several wellfields each containing many bores. To date about 70 of these plans have been completed or are in progress.

WSPPs are produced to establish the level of protection required within a PDWSA, and identify development pressures in the area and the vulnerability of the source to contamination. Each plan sets out the boundary of the source area – the water reserve - and assigns one or more of the priority classifications across the area. The size of each reserve also depends on the aquifer type. Water sourced from deep artesian aquifers, whose recharge area may be 10s to 100s of kilometres away may have a reserve that extends no further than 10s of metres around the bore head. Unconfined aquifers generally result in larger water reserves whose boundaries are related to significant recharge areas, and may be determined from an estimate of the groundwater catchment to the wellfield, from capture zone modelling, or in some circumstances from cadastral and existing land use considerations.

In keeping with the recommendations of the Select Committee a set of Land Compatibility Tables (Taylor, 1999) have been developed to guide the community, developers and planners to determine acceptable development within each Priority Area in PDWSAs. In addition to the WSPPs wellhead protection zones are designated around each bore in the wellfield. Generally these are circular and in P1 areas they are 500m in radius, and 300m in P2 and P3 areas. Extra conditions exist within these radii to prevent contamination at the bore head.

The development of WSPPs allows for existing community issues to be addressed and a lengthy period of consultation is undertaken to ensure existing land uses in the area are recognised. This is particularly important because limitations may be placed on future land uses for landowners. With compensation being unavailable under the current legislation, unless purchased if the land is declared P1, it may take many months to secure total community support in particularly sensitive areas.

Best Management Practices

In order to ensure best management practices are utilised to protect groundwater quality of not only public drinking water supplies but also private water supplies, the Commission prepares a wide range of policies, water quality protection notes and guidelines.

Policy documents set out the Commissions statutory, philosophical and operational approaches to industrial, commercial and urban activities, and are produced in close liaison with stakeholders, conservationists, industry and community in order to achieve as wide a range of acceptance as possible within a short time frame. Draft documents are also released for public discussion and comment prior to finalisation.

Water Quality Protection Notes address activities that have a strong likelihood of impacting upon the quality of the State's water resources. They represent the Commission's views on various land use activities and related water protection issues that are constantly referred to the Commission, and serve to ensure that consistent advice is given. They are not prepared through the normal consultative process and in this form are not fully adopted as policy. They are frequently updated as new information becomes available. Essentially short documents of 2-3 pages length, they are not released as publications but made available through the Commission's web site. They act as precursors to the more official guidelines.

Guidelines are prepared to represent a whole of government approach to particular land use activities, such as commercial, industrial and agricultural, and are compiled by a team from two or more agencies. Where the key issues with the particular land use have a direct relationship to the water resource conservation, management and protection role of the Commission the lead agency is the Commission. In other areas where issues from the land use may impact on agriculture or fisheries the lead agency would be Agriculture WA or Fisheries Department respectively. Again a detailed consultative process with representatives of the particular activity, is undertaken to develop the initial draft and deliver final document.

Examples of the above documents are given in Table 2. Full lists of available publications and access to unpublished documents can be obtained from the Commission's web site – www.wrc.wa.gov.au.

Table 2 Examples of water quality protection tools

Type	Examples	
Policy	• Policy on construction and silica sand mining in PDWSAs (Boniecka and Franz 1999a)	• Pesticide use in PDWSAs (Coleman 2000)
Water source protection plans	• Esperance water reserve (Ryan C, 1999a)	• South Coast water reserve (Coleman , 2001)
	• Gingin water reserve (Taylor, 1997)	• Jurien water reserve (Boniecka and Franz, 1999b)
Water quality protection notes – Guidelines	• Aquaculture Projects (Ryan P 1998)	• Industrial sites near sensitive water resources (Ryan C 1999b)
	• Extractive industries (Franz and Miller 1999)	• Toxic and hazardous substances in PDWSAs (Marsden 1999)
	• Mining and mineral processing (Water and Rivers Commission 2000c)	• Waste management of kennel operations in Jandakot UWPCA (Coleman 1998)
	• Horse activities (Chase 2001)	• Pastoral leases in water catchments (Miller 2001)

WATER QUALITY PROTECTION AND LAND USE PLANNING

Water resource protection is a major planning consideration in Western Australia. The link between source protection and statutory land planning mechanisms was one of the key recommendations of the Select Committee's report referred to earlier. The effects of land use and its interaction with and impacts on groundwater and the quality of groundwater, was clearly recognised by the Committee. In particular the Committee recommended the development of land and water management plans for the main two unconfined groundwater sources supplying Perth – the Gnangara Mound and the Jandakot Mound (Figure 2).

The planning statutes afford protection to groundwater resources in several ways, but particularly by incorporating the groundwater protection priority zones in town planning schemes and establishing special control areas. By using land planning legislation catchment land use can be managed to protect groundwater and groundwater inputs to dependent environments. There is therefore a concerted effort to align land use planning to land capability and aquifer vulnerability and in particular to align water-demanding land uses to areas where groundwater is readily available.

In the planning process the Metropolitan Regional Scheme (MRS) 1963 set the broad pattern for land use in the metropolitan region of Perth, and is managed by the Ministry for Planning (MfP). The Department provides advice to the Minister for Planning, the Western Australian Planning Commission (WAPC) and Government on a wide range of issues, including strategic land use planning and environmental planning under the MRS.

The WAPC has a broad role to formulate and coordinate land use strategies for Western Australia across all aspects of the states planning process.

Regional Planning Schemes (RPS) and local Town Planning Schemes (TPS) are administered by Local Government Authorities to control local development and planning outside of the metropolitan area. TPSs are required to be aligned with the MRS and the detail for amending

PROJECT DECISIONS AND RECOMMENDATIONS

The allocated models have allowed the following tasks to be defined:

- To define the main reasons for the changes of groundwater hydrogeochemistry and hydrogeodynamical regimes changes within urban territories: wastewater discharge to surface water bodies (Angara river), leakage from the underground communications, change of groundwater level as a result of fluctuation of a water level (up to 12 m) in the Angara reservoirs (Irkutsk, Bratsk).

- To develop recommendations directed at the stabilization of the current environment including improvement of the water treatment structures of the industrial enterprises and restoration of municipal underground services.

- To optimize the hydrogeological research necessary for groundwater remediation and monitoring. To achieve this objective two stages are necessary. The first stage is implementation of large-scale complex hydrogeological and engineering-geological studies of the urban territories to allow specification of the boundaries the allocated ground hydrosphere standardmodels. The second stage is the arrangement of an observation borehole network that is appropriate t to these standard models. This will reduce the number of observation holes and associated financial costs, and also will raise the reliability of the information obtained.

CONCLUSIONS

These investigations have allowed the assessment of natural conditions, identification of the main human activities and evaluation of their impacts on the environment in urban areas.

- Changed parameters of environment were classified into 4 groups: geomorphological; hydrogeodynamic; hydrogeochemical and engineering-geological.

- Human activity impact factors are: water level variation in the Irkutsk and Bratsk storage reservoirs and leakage in round about filtration, leakage from underground communication services, construction works and deep building foundations which interfere with natural groundwater flow impeding natural drainage, change of water and physical-mechanical properties of ground during quarry dewatering, unregulated consumption of groundwater, discharge of poorly-purified and polluted wastes into surface water.

- The most significant results of technogenous impacts are: groundwater contamination, increase of groundwater levels, depletion of groundwater resources, changes in the physical-chemical properties of the ground, development of engineering- geological processes.

- Evaluation of different natural and technogenic factors made it possible to define four types of standard models for natural- technogenic conditions of an urban environment:

Figure 2 The scheme of Irkutsk town hydrosphere zoning (standard models)

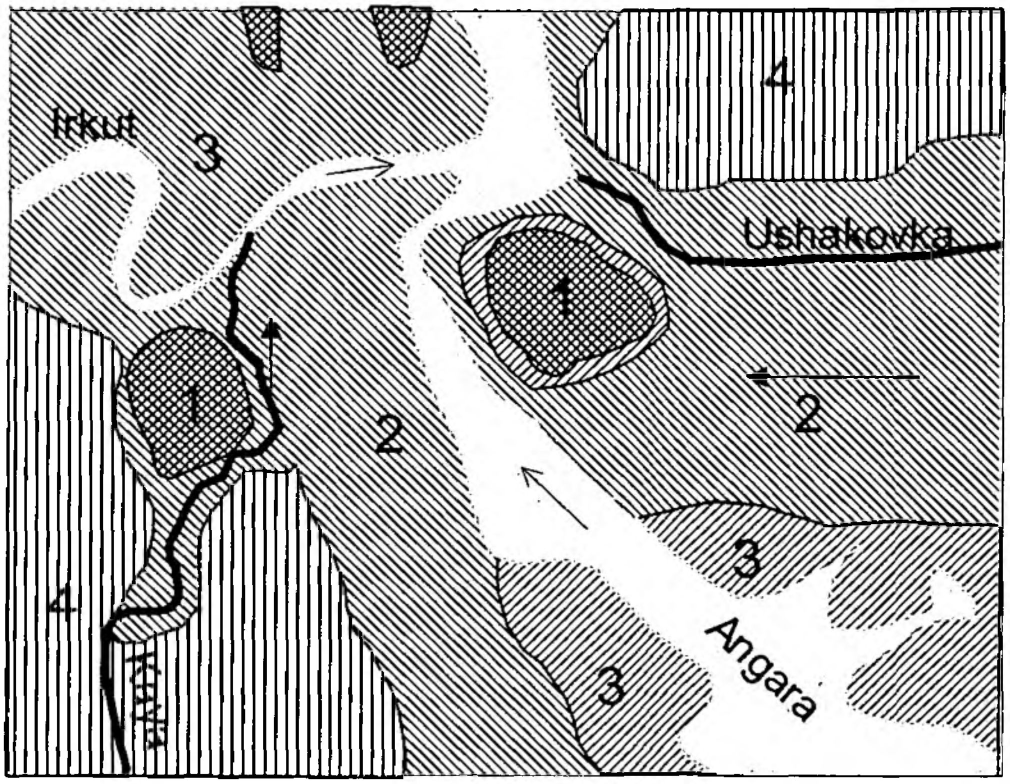


Figure 3 The scheme of hydrosphere zoning of Irkutsk central part (standard models)

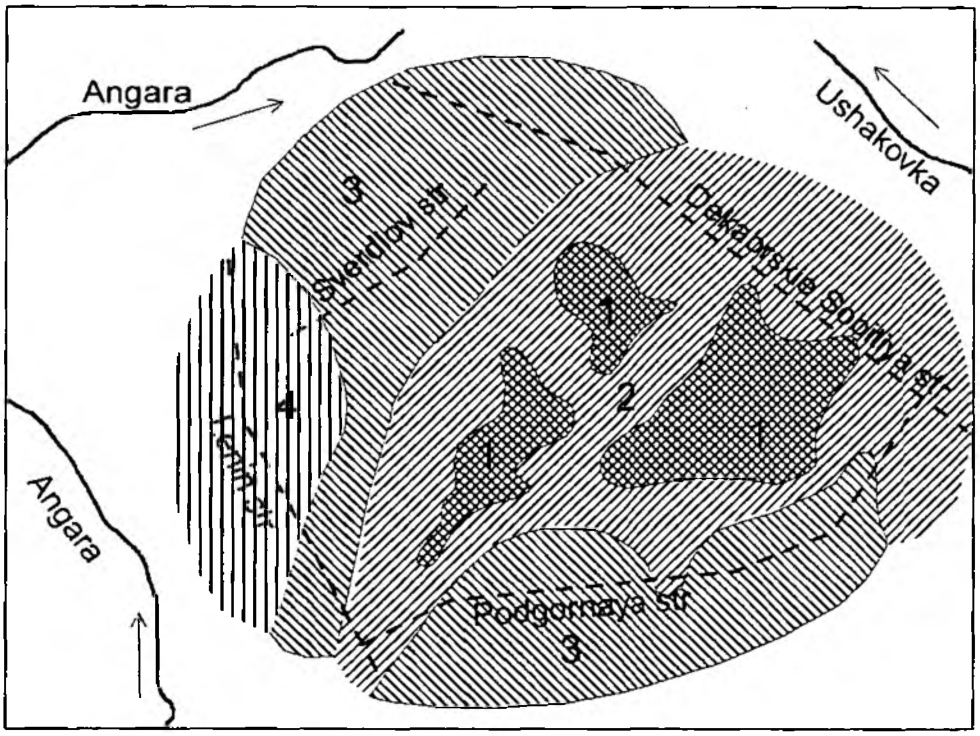


Table 1 Characteristics the standard models of hydrosphere within urban region

Model type	Geomorphological structure	Excess over the base level of erosion, m	Ground water level, m	Temperature, °C	Mineralization, mg/l	Engineering-geological processes
4	Water shed	> 160	>6	5-9	< 1000	permafrost
3	Slopes	80-100	5-6	9-11	1000 -2000	erosion, landslides
2	3 and 4 terraces	60-80	3-5	11-15	2000 -4000	suffosion and abrasion
1	2 terrace	< 60	< 3	< 3 > 15	> 4000	subsidence, suffosion, bogging up, karst

Model type 1 is characterized by quite simple natural conditions, and technogenic factors have a negligible influence on the ground hydrosphere, i.e. first group of the factors of CIH are relatively homogeneous, and the second group has little significance. The system is stable and is unlikely to change as a result of technogenic impacts.

Model type 2 has complex natural conditions, i.e. heterogeneity of the first factor group and the second group has insignificant importance. In this case the stability of the system can change sharply due to technogenic impacts.

Model type 3 is characterized by quite complex natural conditions and the second factor group have appreciable importance. The stability of the system is appreciably reduced and will continue to change due to human activity impact factors.

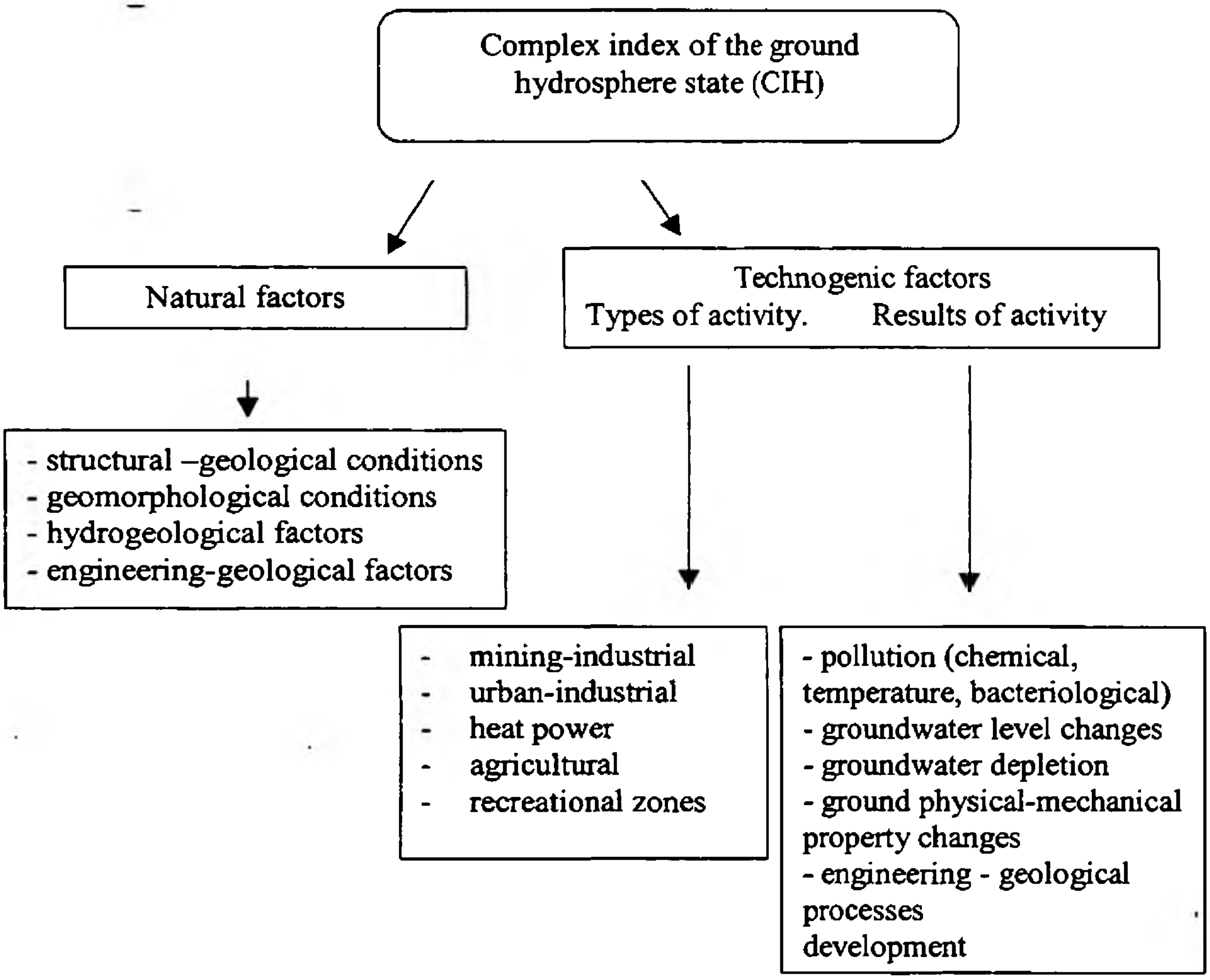
Model type 4 is characterized by very complex natural conditions which changed due to technogenic impacts of a various nature, i.e. the first and the second groups of factors have an extremely non-uniform nature. The system is unstable, and further noncontrollable technogenic impacts will lead to its destruction.

This technique has made it possible to determine that up to 40% of the study area can be classified as complex and very complex naturally- technogenic conditions. The area boundaries have somewhat conditional character by virtue of insufficient detailed investigations. With this method it is possible to zone the ground hydrosphere at different scales as illustrated by Figure 2 (territory of Irkutsk town) and Figure 3 (central part of Irkutsk town).

centre of Irkutsk the predicted increase in groundwater levels resulting from maintaining the existing technogenic impacts is from 0.5 to 3 mm/year. As a consequence, the strength properties of the deposits (the angle of internal friction, collection) will be 6-7% worse per year.
The results obtained from modeling allowed the identification of the principal natural and technogenic factors which have an impact on the present day state of the ground hydrosphere and determination of the components of the complex index (Figure1).

Figure 1 The structure of the complex index of the ground hydrosphere state (CIH)

The standard models of ground hydrosphere



Analysis of the impacts from technogenic activities helped to single out the typical areas with the principal technogenic impacts (Figure 2). The following standard models of the ground hydrosphere were identified based on the natural conditions and the main technogenic impacts in the Angara basin region. These standard models are: simple (4), complex naturally geological (3), complex naturally-technogenic (2), very complex naturally-technogenic (1).

round-about filtration, civil engineering work and deep building foundations, which creates a barrier effect by upsetting the natural drainage, by changing water and physical-mechanical properties of ground during quarry dewatering, and by erecting railway and major highway networks, which alter the character of surface water run-off. For example, shallow groundwater levels (0 to 2 m below ground surface) are observed below river terraces located in areas with a high urban development (and extensive network of underground services) situated at distance from the Angara river and where the rock blocks are lowered.

In comparison deeper groundwater levels (6 to 7 m below ground surface) are observed in flood plain deposits in similar urban settings but which are situated near to the river and where the rock blocks are raised. In general rising groundwater levels are associated with urban areas.

Groundwater depletion is associated with several factors: non-regulated groundwater supply for drinking and domestic purposes, and the water level oscillation in the river storage reservoirs. The latter which causes an abrupt development of solution in carbonate rocks with the formation of karst (the area of Svirsk town). This also increases the permeability of water-bearing deposits increasing the rate of groundwater discharge and promotes the ingress of contaminating substances to groundwater.

Ground physical-mechanical property changes. These processes have a considerable effect on the evolution of the engineering-hydrogeological conditions of the municipal areas. The ground's physical-mechanical property changes result in a deterioration in the state of building foundations increasing the potential danger of consequences from seismic activities (Lobatskaja ,1997). For instance during the last 15 years, the natural moisture content of soils at sampling points in Irkutsk city changed from 18.7 to 20.6 %, and the cohesion, the angle of internal friction and the deformation modulus became lower (Chernov *et al.* 1998).

Engineering-geological processes development. The creation of the Bratsk and Irkutsk storage reservoirs and fluctuation of the water level position in these reservoirs has led to the development of erosion processes associated with the magnitude of surface water run-off, waterlogging, abrasion, leaching of carbonate rocks and karst formation. The increase in erosion has increased the risk of flooding. The extraction, transportation and deposition of rocks for the purposes of construction (from the bed and flood-plain sections of the Angara and the Irkut rivers, and the river tributaries, islands and terraces) has altered the river profile, destroyed the natural geodynamic conditions of the region and developed suffosion.

Numerical simulation

The next step is the development of a database for the project, creation of the database, and numerical simulation (modelling). Numerical simulation was carried out in three stages. The first stage is past status simulation of natural conditions based on data from field observations. For some components of the natural system this simulation period was up to 30 years. This simulation stage also allowed the reliability of the numerical model to be checked. The second stage was the modern status simulation of current conditions to determine the modern impact of the main technogenic factors. The main components of the model-system analysis were multifactor analysis, method of main components and cluster analysis (Auzina, 1997). This allows the different components of the complex index as identified by the initial analysis of the database to be quantified. The last stage was the prediction simulation to forecast the changes in the individual components of the complex index with time. For instance, in the

- modern status simulation corresponding to the existing conditions of ground hydrosphere,
- prediction simulation evaluation the perspectives for the changes in the existing status under the influence of impacting factors),

- the analysis of the obtained results combined with revealing the prevailing natural factors and technogenic impacts, determining the modern status of individual components of the regional system;
- geo-ecological zoning considering the complexity of naturally-technogenic conditions and based on the complex index; development of protection measures.

Geological conditions of the investigation region

Application of this technique began within the urban areas in the Angara basin. In hydrogeological terms, the territory belongs to the largest structure of the Angaro-Lensk artesian basin named the Priirkutsk depression. The main water-bearing sediments are sand and gravel (Quaternary period), sandstone, mudstone, siltstone (Jurassic period) and dolomite, salt-bearing rocks (Cambrian period). These sedimentary deposits have a block structure inherited from the crystalline basement rocks. Within the study areas, the position of the sedimentary blocks determined the formation of general geomorphological structures. The combination of this structure with a system of tectonic faults and erosion has a significant influence on engineering and hydrogeological conditions in the area.

Leading technogenous impacts and its results within urban territories

Analysis of the modern geological and engineering-hydrogeological conditions, which are characteristic of the region, and their evolution, under the influence of changing technogenic impacts, made it possible to identify the modern problems of the investigated area.

Groundwater pollution (chemical, temperature, bacteriological) is associated with the discharge of sewage water into the Angara river. This is the main river in the region and groundwaters are hydraulically connected with it. The volume of sewage is 3 km^3/year of which only 50% is purified. 75 % of sewage is discharged into the Angara river which is one of the main sources for public and drinking water supply in the region. Chemical wastes has also altered to a considerable extent the groundwater quality. In one of the districts of Usolie-Sibirskoye town, mineralization of groundwater amounts to 60 g/l. Additional detrimental changes in the groundwater regime result from leakage from municipal underground services which are in an extremely unsatisfactory state. In groundwater the concentrations of nitrate, nitrite, phosphate, iron, and petroleum products are elevated. For example, in the centre of the Irkutsk city mineralization of ground water reaches 320 mg/l (NO_3 concentration of 258 mg/l), and a temperature of 30°C to 60°C.

Groundwater levels increases are a result of anthropogenic factors and are controlled by natural factors. Natural factors include the peculiarities of geological-tectonic conditions caused by the block structure of this area, the rather diverse lithological composition of the water-bearing deposits (from gravel-pebble to argillaceous deposits); and hydrogeological conditions (the degree of interaction with rivers, infiltration parameters, ground water levels).

Anthropogenic factors include: leakage from underground services, water reservoirs associated with the Angara river hydroelectric stations (the amplitude of water level oscillations in these reservoirs during a year amounts to 2-3 m), leakage resulting from a non-regulated groundwater development. The exploitation of most water resources infringes technical and sanitary requirements. In the largest cities (Irkutsk, Angarsk, Usolye-Siberian) localised increases in groundwater levels have been observed and are likely to continue in the future. The results of this process causes a change in the physical and mechanical properties of the ground, affecting the stability of building foundations, sometimes even to their destruction.

Many industrial complexes have closed, others continue to function, but their ecological protection measures have ceased to work, such that natural-technogenic processes have exacerbated environmental problems in urban and in other technogenically-impacted territories. It also means that the conflict in the system "environment and society" has become worse.

In this situation, one of the main problems is the development of a complex estimate of the ground hydrosphere. This is followed by: zoning of the area in accordance with the degree and nature of the technogenic impacts, the prediction of behavior of the ground hydrosphere in the future, and development of project recommendations aimed at the regulation of the technogenic impact effects on the environment.

For this reason a complex index of the ground hydrosphere state (CIH) has been developed based on the natural, geological conditions for a particular region (geological structural, geomorphological, hydrogeological, engineering-geological), on the one hand, and technogenic factors (type of impact and its results) on the other hand.

Research was carried out by numerical simulation, which included past status simulation based on the field observation data, modern status simulation corresponding to existing conditions and prediction simulation of the current status evaluation impacting factors. This made it possible to identify the main impacting factors that can be classified into two groups: natural and human activity impact (technogenic). These factors provide a basis for the naturally-technogenic complex index of the ground hydrosphere conditions investigated. Zoning of the area according to this complex index make it possible to prioritize areas. This demands that prompt action should be taken with the aim of stabilizing and improving the environmental state of technogenically-impacted areas of the ground hydrosphere.

This paper describes the principles of development of the complex index and the estimation of the complex technogenically-impacted territories ground hydrosphere.

PROCEDURE OF INVESTIGATION

Investigations are based on a systematic approach which includes the study of the region as a whole and its individual components. The technique underlying the research is sufficiently universal and comprises:

- the collection of data on regional geological conditions,
- the selection of information on the actual technogenic impacts and the results of these impacts,
- the creation of a database according to the developed form,
- the development of typical models for the investigated objects,
- simulations:
  - numerical simulation (past status simulation based on the data of permanent field observations,

16. GROUNDWATER REMEDIATION AND MONITORING FOR URBAN AREAS, EAST SIBERIA, RUSSIA

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ABSTRACT

The expansion of urban areas in East Siberia has resulted in a significant negative impact on the geological environment and especially on the hydrosphere. In hydrogeological terms, the territory belongs to the Angaro-Lensk artesian basin. The sedimentary deposits have a block structure. The combination of this structure with a system of tectonic faults and erosion has a significant influence on current engineering and hydrogeological conditions in the area.

In general, groundwater management in Russia and in East Siberia is based on the analysis of data from an extensive network of observation boreholes. An alternative approach is proposed in this paper. Development of the most effective groundwater monitoring and remediation strategy is based on evaluation of the main factors impacting the urban environment. There are two groups - natural factors and human activity impact factors. The approach involves identification and evaluation of the main natural and technogenic factors, which then form components of a complex index of the ground hydrosphere. The components are then used to classify an area into different standard model types ranging from simple to very complex naturally technogenic. The approach is illustrated for a number of territories in East Siberia. This zoning, according to the complex index, has made it possible to identify areas that should be prioritized for prompt actions with the aim of stabilizing and improving the environment.

INTRODUCTION

Urbanization is a process of creation of urban settlements including largest cities with a multimillion population and a complex urban infrastructure. This process has affected all continents and will proceed in the third millennium with even greater force.

The Irkutsk district is not an exception. Its territory is 775,000 km^2, its population is 2,773,000, 79.5 % of whom live in 22 cities. The largest cities are Irkutsk (~596,400), Angarsk (~266,600), Bratsk (~278,600), Ust-Ilimsk (~105,500), Usolie-Siberskoye (~104,100), Cheremhovo (~89,000), Shelehovo (~53,900). Most parts of the cities and the urban population are concentrated near the large transport highways - Transsib and BAM. A zone of "ecological risk" was singled out in this region. In addition six cities located in the central part of this district are included in the list of the most polluted cities of Russia. There are 957 industrial enterprises within this territory which emit toxic substances to the atmosphere and to surface water. 91 % of these waste streams exceed release limits. The emergency release of wastewater has increased by 62 % during the last 3 years. The total annual emission of harmful substances into the atmosphere is 1200-1300 thousand tonnes/year and includes dust, oxides of sulfur, nitrogen, carbon, chlorine.

Land within the industrial cities is polluted with lead, mercury, zinc, aluminium, tin, and surface waters with mercury, iron and copper. Depletion and pollution of groundwaters occurs extensively within these territories. These problems are connected with wastes and

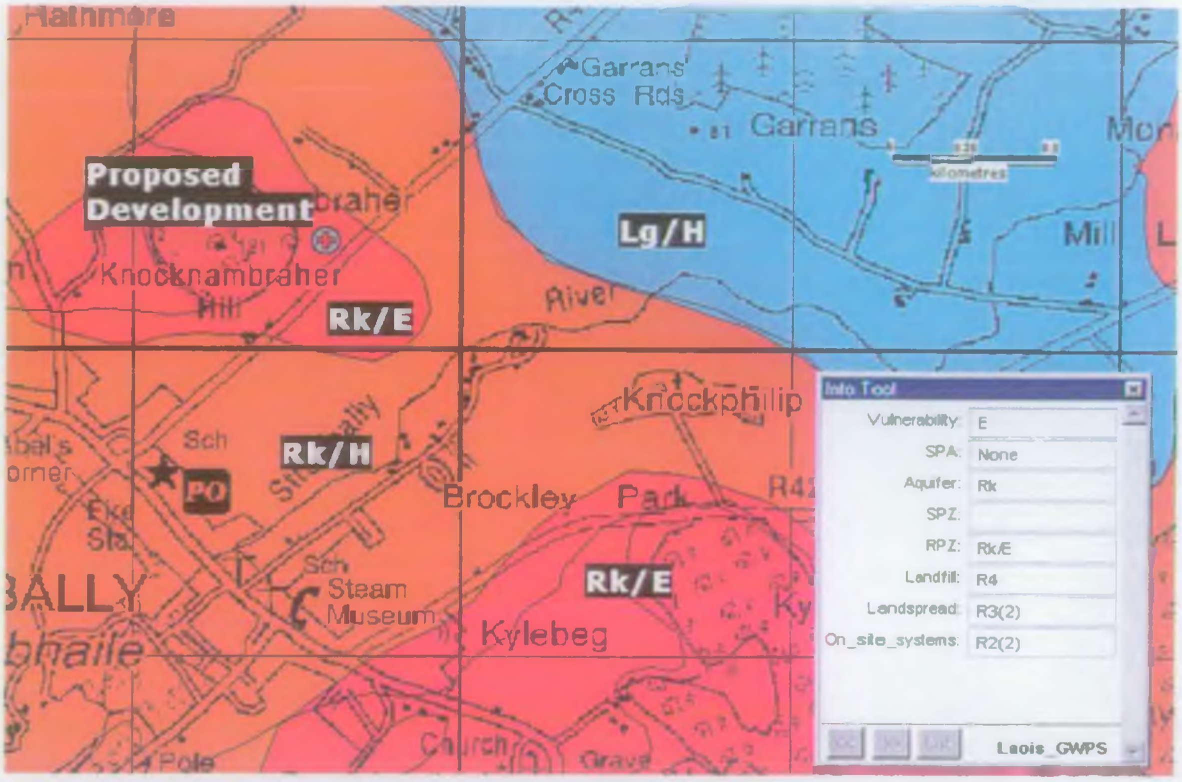

Figure 2 Screen output, converted to black and white, showing protection zones and responses a proposed development.

Table 6 Examples of groundwater protection responses

Groundwater Protection Zone	Proposed Development	Groundwater Protection Response (summary only)	
SO/E	Landfills	R4	Not acceptable
	Landspreading	R4	Not acceptable
	On-site systems	R3[1]	Not generally acceptable, unless: A conventional septic tank system is installed with a minimum thickness of 2 m unsaturated soil/subsoil beneath the invert of the percolation trench ; OR A treatment system other than a conventional septic tank system, as described in EPA (2000), is installed with a minimum thickness of 0.6 m unsaturated soil/subsoil with P/T values* from 1 to 50 (in addition to the polishing filter which should be a min. depth of 0.6 m), beneath the invert of the polishing filter; and subject to the following conditions: • the authority must be satisfied that, on the evidence of the groundwater quality of the source and the number of existing houses, the accumulation of significant nitrate and/or microbiological contamination is unlikely; • No on-site treatment system should be located within 60 m of the public, group scheme or industrial water supply source, • A management and maintenance agreement is completed with the systems supplier.
Rk/E	Landfills	R4	Not acceptable
	Landspreading	R3[2]	Not generally acceptable, unless a consistent minimum thickness of 2 m of soil and subsoil can be demonstrated.
	On-site systems	R2[2]	Acceptable subject to normal good practice and the additional condition: 1) There is a minimum thickness of 2 m unsaturated soil/subsoil beneath the invert of the percolation trench of a conventional septic tank system; OR 1) A treatment system other than a conventional septic tank system as described in EPA (2000) is installed, with a minimum thickness of 0.6 m unsaturated soil/subsoil with P/T values* from 1 to 50 (in addition to the polishing filter which should be a minimum depth of 0.6 m), beneath the invert of the polishing filter.
Pl/E	Landfills	R2[2]	Acceptable subject to guidance outlined in the EPA design manual or conditions of a waste licence. Special attention should be given to checking for the presence of high permeability zones. If such zones are present then the landfill should only be allowed if it can be proven that the risk of leachate movement to these zones is insignificant. Special attention must be given to existing wells downgradient of the site and to projected future development of the aquifer.
	Landspreading	R3[1]	Not generally acceptable, unless a consistent minimum thickness of 1 m of soil and subsoil can be demonstrated.
	On-site systems	R2[1]	Acceptable subject to normal good practice. Where domestic water supplies are located nearby, particular attention should be given to the depth of subsoil over bedrock such that the minimum depths required (EPA, 2000) are met and that the likelihood of microbial pollution is minimised.

Note* P/T values are percolation test values, essentially the time in minutes for water in a specified trial pit to fall 25 mm

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DISCUSSION AND CONCLUSIONS

Good planning decisions require accessible, reliable information on all relevant issues. In the past in Ireland, the appropriate geoscientific information was not used in decision-making, either because it was not readily available, or was not considered to be relevant. The groundwater protection concept, and the production of groundwater protection maps and reports, have become a means of highlighting the need for the consideration of geoscientific information and a means of providing it. The schemes encompass not just information on groundwater, but also bedrock and subsoils, in a form that is specifically oriented to decision-makers in local authorities and the Environmental Protection Agency.

A groundwater protection scheme has the following uses for regulatory bodies and hydrogeologists:

- it compartmentalises relatively complex and variable information on areas into relatively simple hydrogeological settings and conceptual models;
- it provides a hierarchy of levels of risk and, in the process, assists in setting priorities for technical resources and investigations;
- it contributes to the search for a balance of interests between groundwater protection issues and other special and economic factors;
- it can be adapted to include risk to surface water;
- it acts as a guide and provides a 'first-off' warning system before site visits and investigations are made;
- it shows generally suitable and unsuitable areas for potentially hazardous developments such as landfill sites and piggeries;
- by controlling developments and enabling the location of certain potentially hazardous activities in lower risk areas, it helps ensure that pollution legislation is not contravened;
- it can be used in preparing Emergency Plans, assessing environmental impact statements and the implications of EU directives, planning and undertaking groundwater monitoring networks and in locating water supplies;

The use of GIS has increased the value and power of groundwater protection schemes in decision-making by making vital groundwater information readily accessible on the computers of planners.

In conclusion, humankind has much to lose if the relationship with the geological environment is not managed effectively. Decision-makers and developers must use relevant geoscientific information and expertise as a means of achieving maximum long-term benefit to all. Groundwater protection schemes in Ireland are becoming a powerful means of not only providing the information, but also of linking appropriate decisions to the geological environment.

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ecosystems. In Ireland, a GIS is required as the means of integrating and presenting the datasets and maps.

As groundwater protection schemes involve the compilation of geological, hydrogeological, vulnerability and water quality maps, these will provide much of the required information for groundwater characterisation of RBDs. Also, the GIS can readily become part of the RBD GIS.

Issues for the Future

In the longer term, there are many other issues that need to be addressed to ensure adequate groundwater protection and hence sustainable resource development. Issues that are considered to be important in Ireland include:

- a better understanding of the complexities posed by groundwater flow in heterogeneous aquifers, especially conduit flow in the karst aquifers that are common in Ireland;
- a better understanding of the interrelationships between groundwater and surface water, with the potential need to develop integrated groundwater and surface water protection schemes;
- the need for accurate recharge assessment in the delineation of source protection areas; and
- the need for standard procedures for delineating protection areas around private groundwater sources, where abstractions are normally small and intermittent, and there is a scarcity of hydrogeological data.

Many of the above are also relevant to groundwater protection in the UK and in other European countries. A major issue confronting all EU Member States is the requirement for closer integration of groundwater and surface water protection measures, since groundwater and surface water are to be managed in an integrated manner under the Water Framework Directive. One approach which has been used for the protection of surface waters involves the setting of Environmental Quality Objectives and Environmental Quality Standards. In Ireland, a discussion document has been circulated containing proposals for EQOs and EQSs (EPA 1997).

A similar approach can be applied to groundwater. Recently, work has been undertaken to develop specific guideline values for the protection of groundwater in Ireland. Exceedances of these guideline values would act as a trigger for a risk-based assessment of any further actions required. The GVs are likely to be based on drinking water criteria, but also to take account of the expected background concentrations for different parameters in Irish groundwaters. The setting of GVs can be regarded as a 'bottom up' approach to groundwater protection, in that it is responding to what is actually detected in the groundwater. As such, it can augment the 'top-down' approach to groundwater protection that underlies the type of scheme described in this paper, in which planning restrictions are applied to potentially polluting activities based on land surface zoning and the appropriate risk management response.

investigation details. For instance, landspreading is not allowed within 50 m of wells or within 30 m of karst features.

USE OF GIS

In recent years, the delivery of groundwater protection schemes to local authorities has been enhanced by the incorporation of the land use zoning maps and the responses into a digital GIS dataset, registered to the Ordnance Survey map base (Fitzsimons *et al.* in press). This GIS dataset can be readily incorporated in the GIS used in the Planning, Environment and other sections in the local authorities. The GIS dataset delivered to users (in particular, local authorities and the Environmental Protection Agency) includes complete county coverage by discrete polygons, where each polygon contains values for the following:

- vulnerability rating;
- aquifer category;
- source protection zone classification;
- resource protection zone classification; and
- response codes for:
  - landfill;
  - landspreading;
  - on-site wastewater treatment systems.

The GIS dataset can be used in one of two modes (Fitzsimons *et al.* in press):

1. A complete county or area of interest can be viewed with any one of the above parameters used in a thematic analysis, which shows the area colour-coded based on the values of that parameter. This is particularly useful when preparing development plans or in general planning for locating potentially polluting activities, as it allows the decision-maker to identify areas, which are appropriate or inappropriate for particular activities. Maps can be generated for each activity, showing the areas covered by specific response codes (R1, $R2^1$, $R2^2$ etc, as appropriate for the area). For example, in a recently completed county scheme, 50% of the area is shown as unsuitable for landfills. This enables the short-listing of sites for ground investigation in areas that are more suitable and provides a scientifically defensible, impartial basis for decision-making.

2. An individual location can be queried and the values for all the above parameters can be obtained instantly for that location. This can be of particular value when a regulator is considering a specific planning or licensing application for a development at a site. In Figure 2, a portion of a county groundwater protection scheme is shown with the land surface zoning and responses for a site marked on the map.

GROUNDWATER PROTECTION SCHEMES AND THE EU WATER FRAMEWORK DIRECTIVE

The new EU Water Framework Directive (WFD) requires River Basin District (RBD) Plans to be drawn up and implemented (European Commission 2000). The WFD requires an integrated approach to monitoring and managing all waters in an RBD. Groundwater (and all water) must be characterised in terms of hydrogeology, protection, pressures and dependent

R3m,n,o,	Not acceptable in principle; some exceptions may be allowed subject to the conditions in notes m,n,o, etc.
R4	Not acceptable.

Three groundwater protection responses have been published to date (DELG *et al.* 1999b, 1999c, 2001). Tables 3, 4 and 5 show the groundwater protection scheme matrices for the landspreading of organic wastes, landfills and on-site wastewater treatment systems for single houses, respectively. Two further responses are being produced at present for storage tanks and farmyards.

Table 3 Response Matrix for Landspreading (DELG *et al.* 1999b)

VULNERABILITY RATING	SOURCE PROTECTION AREA		RESOURCE PROTECTION Aquifer Category					
			Regionally Important (R)		***Locally Important (L)***		***Poor Aquifers (P)***	
	Inner	***Outer***	***Rk***	***Rf/Rg***	***Lm/Lg***	***Ll***	***Pl***	***Pu***
Extreme (E)	R4	R4	R3[2]	R3[2]	R3[1]	R3[1]	R3[1]	R3[1]
High (H)	R4	R2[1]	R1	R1	R1	R1	R1	R1
Moderate (M)	R3[3]	R2[1]	R1	R1	R1	R1	R1	R1
Low (L)	R3[3]	R2[1]	R1	R1	R1	R1	R1	R1

Table 4 Response Matrix for Landfills (DELG *et al.* 1999c)

VULNERABILITY RATING	SOURCE PROTECTION AREA		RESOURCE PROTECTION Aquifer Category					
			Regionally Important (R)		***Locally Important (L)***		***Poor Aquifers (P)***	
	Inner	***Outer***	***Rk***	***Rf/Rg***	***Lm/Lg***	***Ll***	***Pl***	***Pu***
Extreme (E)	R4	R4	R4	R4	R3[2]	R2[2]	R2[2]	R2[1]
High (H)	R4	R4	R4	R4	R3[1]	R2[1]	R2[1]	R1
Moderate (M)	R4	R4	R4	R3[1]	R2[2]	R2[1]	R2[1]	R1
Low (L)	R4	R3[1]	R3[1]	R3[1]	R1	R1	R1	R1

Table 5 Response Matrix for On-site Treatment Systems (DELG *et al.* 2001)

VULNERABILITY RATING	SOURCE PROTECTION AREA		RESOURCE PROTECTION AREA Aquifer Category					
			Regionally Important (R)		***Locally Important (L)***		***Poor Aquifers (P)***	
	Inner (SI)	***Outer (SO)***	***Rk***	***Rf/Rg***	***Lm/Lg***	***Ll***	***Pl***	***Pu***
Extreme (E)	R3[2]	R3[1]	R2[2]	R2[2]	R2[1]	R2[1]	R2[1]	R2[1]
High (H)	R2[4]	R2[3]	R2[1]	R1	R1	R1	R1	R1
Moderate (M)	R2[4]	R2[3]	R1	R1	R1	R1	R1	R1
Low (L)	R2[4]	R1	R1	R1	R1	R1	R1	R1

Examples of groundwater protection responses for the three potentially polluting developments are given in Table 6 at the end of this paper. In addition, the responses include requirements such as minimum distances to private wells and karst features, and site simple, but useful, conceptual hydrogeological model of the area delimited by the zone. In land surface zoning for groundwater protection purposes, regionally important sand/gravel (**Rg**) and fissured aquifers (**Rf**) are zoned together, as are locally important sand/gravel (**Lg**) and bedrock which is moderately productive (**Lm**).

Table 2 Matrix of Groundwater Protection Zones (DELG *et al.* 1999a)

VULNERABILITY RATING	SOURCE PROTECTION		RESOURCE PROTECTION Aquifer Category						
			Regionally Imp.		Locally Imp.		Poor Aquifers		
	Inner	*Outer*	*Rk*	*Rf/Rg*	*Lm/Lg*	*Ll*	*Pl*	*Pu*	
Extreme (E)	Sl/E	SO/E	Rk/E	Rf/E	Lm/E	Ll/E	Pl/E	Pu/E	↓
High (H)	Sl/H	SO/H	Rk/H	Rf/H	Lm/H	Ll/H	Pl/H	Pu/H	↓
Moderate (M)	Sl/M	SO/M	Rk/M	Rf/M	Lm/M	Ll/M	Pl/M	Pu/M	↓
Low (L)	Sl/L	SO/L	Rk/L	Rf/L	Lm/L	Ll/L	Pl/L	Pu/L	↓
	→	→	→	→	→	→	→	→	→

In Table 2, the arrows on the matrix indicate directions of decreasing risk: the arrows from top to bottom indicate decreasing likelihood of contamination (decreasing vulnerability), and the arrows from left to right indicate decreasing consequences of contamination (decreasing value of the target/receptor).

Protection schemes are undertaken in partnership with local authorities on a county by county basis. Groundwater protection zones have been delineated or are in the process of being delineated for about 45% of the country. However, for areas not currently mapped, the groundwater protection zone for any location can be determined by undertaking a site investigation to evaluate the vulnerability and contacting the Geological Survey of Ireland to give a provisional aquifer designation.

Groundwater Protection Responses

The matrix format is also used to illustrate the groundwater protection response for any potentially polluting activity within a groundwater protection zone. The response matrix is the risk management element of the Irish groundwater protection scheme. The level of response depends on the different elements of risk: the vulnerability, the value of the groundwater (with major sources being more valuable than resources and regionally important aquifers being more important than locally important and so on) and the contaminant loading.

By consulting a response matrix, a planner or developer can determine:
(a) whether or not such a development is likely to be acceptable on that site;
(b) the further investigations that may be necessary to reach a final decision; and
(c) the planning or licensing conditions that may be necessary for that development.

Four levels of response (R) to the risk of a potentially polluting activity are determined:

R1	Acceptable subject to normal good practice.
$R2^{a,b,c,.}$	Acceptable in principle, subject to conditions in notes a,b,c, etc. (The number and content of the notes varies depending on the zone and the activity).

The Inner Protection Area aims to protect the well against the effects of human activities that might have a rapid effect on the source, especially microbiological pollution. This is similar to the Inner Zone 1 in England and Wales (Environment Agency 1998). A 100 days time of travel is allowed for bacteria die-off, rather than the 50 days incorporated in groundwater protection schemes in England and Wales. This conservative, 100-day time of travel, is considered to be appropriate for Ireland in view of the heterogeneity of the aquifers, and the possibility that some bacteria, viruses and other microorganisms may survive for longer than 50 days in groundwater.

The Outer Protection Area (**SO**) covers the total source catchment area, or zone of contribution of the well or spring. It is the area needed to support the long-term abstraction, and hence is strongly dependent on the amount of recharge. This is equivalent to the Source Catchment Zone III in England and Wales. There is no equivalent to the intermediate 400-day Outer Zone II in Ireland.

Aquifer Categories

All bedrock units in the Republic of Ireland are classed as aquifers, even those such as the Lower Palaeozoic formations which have a relatively low permeability but provide water supplies for domestic wells. The total land area is subdivided, based on the value of the resource and the hydrogeological characteristics, into eight aquifer categories:

Regionally Important (R) Aquifers

(i) Karstified aquifers (**Rk**)
(ii) Fissured bedrock aquifers (**Rf**)
(iii) Extensive sand/gravel (**Rg**)

Locally Important (L) Aquifers

(i) Sand/gravel (**Lg**)
(ii) Bedrock which is Generally Moderately Productive (**Lm**)
(iii) Bedrock which is Moderately Productive only in Local Zones (**Ll**)

Poor (P) Aquifers

(i) Bedrock which is Generally Unproductive except for Local Zones (Pl)
(ii) Bedrock which is Generally Unproductive (Pu)

GROUNDWATER PROTECTION ZONES

Groundwater protection zones are produced by combining maps of vulnerability with both the source protection areas and the aquifers (or resource protection areas). They can be displayed in the form of a matrix (Table 2). In practice, this is achieved by superimposing the vulnerability map on the source protection area maps and the aquifer map. The groundwater protection zones, which can be applied to the total land surface of the Republic of Ireland, compartmentalise the hydrogeology of the country into 32 settings. Each zone is represented by a code e.g. **Rf/M**, which represents areas of *regionally important fissured* aquifers where the groundwater is *moderately* vulnerable to contamination. In essence, the code represents a

GROUNDWATER VULNERABILITY

Vulnerability is a term used to represent the 'intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities' (DELG *et al.* 1999a). Vulnerability mapping is 'the technique of assessing the geological and hydrogeological factors and displaying these on a map in a manner that is understandable and useful' (Daly and Warren 1998).

The vulnerability of an aquifer to contamination may depend on many factors including the leaching characteristics of the topsoil, the permeability and thickness of the subsoil, the presence of an unsaturated zone, the type of aquifer and the amount and form of recharge. In Ireland, groundwater vulnerability is determined mainly according to the thickness and permeability of the subsoil that underlies the topsoil (subsoil is equivalent to the term 'drift' widely used in Britain.) The nature of the recharge is also important, especially in karstic areas where 'point recharge' may occur through swallow holes or sinking streams. The unsaturated zone of bedrock aquifers is not relied upon for attenuating contaminants, since virtually all bedrock formations in Ireland possess secondary rather than primary porosity. However, the vulnerability classification in sand and gravel aquifers does take account of an unsaturated zone.

Four groundwater vulnerability categories are used in the scheme - **extreme (E), high (H), moderate (M)** and **low (L)**. The hydrogeological basis for mapping these categories is summarised in Table 1.

In summary, the entire land surface is divided into four vulnerability categories - extreme (E), high (H), moderate (M) and low (L) - based on the relevant geological and hydrogeological factors. This subdivision can be shown on a groundwater vulnerability map or can be assessed on a site by site basis.

Table 1 Vulnerability Mapping Guidelines (adapted from DELG *et al.* 1999a)

Vulnerability Rating	**Hydrogeological Conditions**				
	Subsoil Permeability (Type) and Thickness			**Unsaturated Zone**	**Karst Features**
	High permeability (*sand/gravel*)	Moderate permeability (e.g. *sandy till*)	low permeability (e.g. *clayey till, clay, peat*)	(*sand/gravel* aquifers <u>only</u>)	(<30 m radius)
Extreme (E)	0 - 3.0 m	0 - 3.0 m	0 - 3.0 m	0 - 3.0 m	–
High (H)	>3.0 m	3.0 - 10.0 m	3.0 - 5.0 m	>3.0 m	N/A
Moderate (M)	N/A	>10.0 m	5.0 - 10.0	N/A	N/A
Low (L)	N/A	N/A	>10.0 m	N/A	N/A

Notes: i) N/A = not applicable.
ii) Precise permeability values are being evaluated at present.
iii) Release point of contaminants is assumed to be 1-2 m below ground surface.

Source Protection Areas

In the Irish groundwater protection scheme two source protection areas (SPAs) are delineated around wells: an Inner Protection Area (SI), defined by a 100-day travel time within the aquifer, and an Outer Protection Area, encompassing the whole source catchment area.

THE NATIONAL GROUNDWATER PROTECTION SCHEME IN IRELAND

The Irish groundwater protection scheme is based on the experience of groundwater protection in England and Wales (e.g. Selby & Skinner 1979, National Rivers Authority (NRA) 1992 and Environment Agency 1998) and elsewhere (e.g.Office féderal de la protection de l'environment, 1982, US Environmental Protection Agency 1994,), but with significant modifications to take account of the hydrogeological conditions and the main types of contaminants found in Ireland. A comparison of the Irish scheme and the groundwater protection policy for England and Wales can be found in Misstear and Daly (2000). While the scheme was not formally published until recently (Department of Environment and Local Government (DELG) *et al.* 1999a), the Irish methodology has been in use since the early 1990s. As in the NRA/Environment Agency policy, the concepts of risk assessment and risk management underlie the Irish scheme (Misstear *et al.* 1998). In the risk assessment element, the source of contamination, the groundwater vulnerability and the value of the groundwater (be it an aquifer, well or spring) are evaluated in terms of a source-pathway-receptor model. Once the nature and extent of the risk have been assessed, a response to that particular risk can be prepared which might involve a code of practice for landspreading of organic wastes or an engineered barrier for a landfill site. This is the risk management element.

The two main components of the Irish scheme are land surface zoning (risk assessment) and response matrices for potentially polluting activities (risk management). These are integrated together as depicted in Figure 1, and described below.

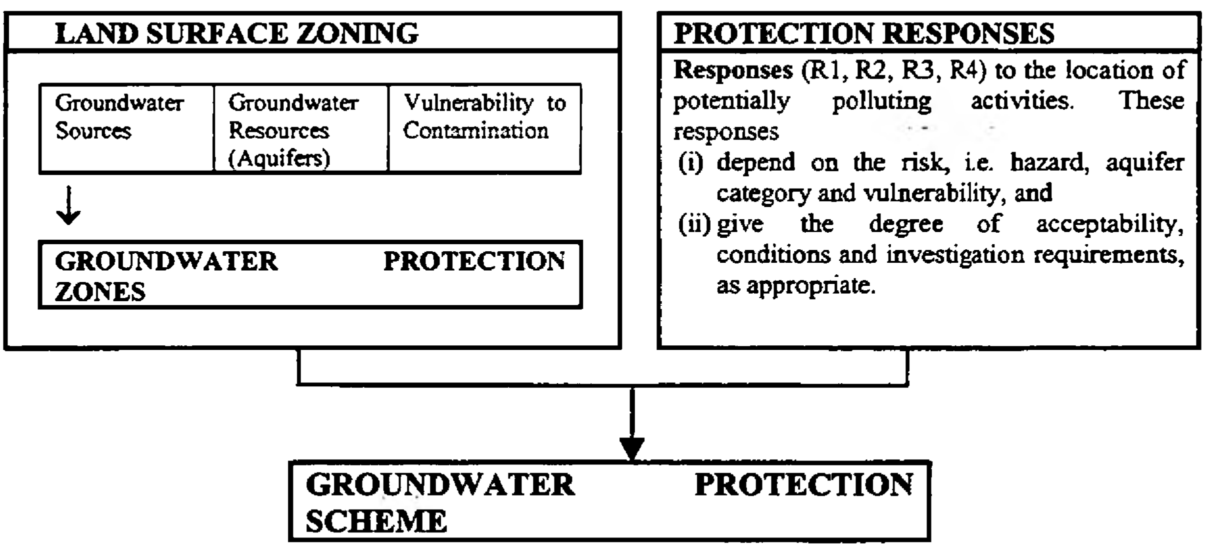

Figure 1 Main components of the Irish groundwater protection scheme

LAND SURFACE ZONING

Land surface zoning comprises:

- mapping the groundwater vulnerability;
- defining protection areas around major wells and springs;
- classifying the value of the groundwater resource in terms of aquifer categories;
- combining the vulnerability, source protection area and aquifer maps to produce groundwater protection zones.

15. THE GROUNDWATER PROTECTION SCHEME IN IRELAND: A RISK-BASED TOOL FOR EFFECTIVE LAND-USE PLANNING

Donal Daly[1] and Bruce D. Misstear[2]

ABSTRACT

The groundwater protection scheme in Ireland provides an effective means of assessing the impacts of potentially polluting activities on groundwater resources, and hence of providing appropriate guidance on development. The scheme involves the classification of land into different zones according to the level of risk of groundwater pollution (based on maps of groundwater vulnerability, resource classification and source protection areas), and the production of development guidelines, or 'responses', for each zone for activities such as landfills and on-site wastewater treatment systems. The scheme has a number of features in common with the groundwater protection policy in England and Wales, but includes features specific to hydrogeological conditions and pollutant sources found in Ireland. The preparation of schemes for individual counties is facilitated by the use of GIS systems, and much of the information produced will be useful also in the preparation of plans for River Basin Districts, as required under the new EU Water Framework Directive. The directive requires that groundwater and surface water are managed in an integrated way, and the integration of groundwater protection schemes with measures for the protection of surface water is one of the challenges to be addressed in the future.

INTRODUCTION

Land-use planning and environmental planning (which in this paper is taken to encompass environmental impact assessment, integrated pollution control licensing, waste licensing, water pollution legislation, and so on) are the main approaches used in Ireland for trying to achieve a balance between the need to protect the environment and the need for development. However, land-use planning is a dynamic process with social, economic and environmental interests and impacts influencing to varying degrees the use of land and water. In a rural area, for example, farming, housing, industry, tourism, conservation, waste disposal and water supply are potentially conflicting interests, and may compete for priority.

A key requirement in good decision-making, at all levels of environmental planning (including developers and regulatory authorities), is the availability of reliable information on all relevant issues, in a form that can be readily used. In Ireland, groundwater protection schemes are becoming an effective means of providing relevant information on groundwater (including resources, vulnerability and general hydrogeology), and of integrating geoscientific information on rocks and groundwater into land-use planning. Schemes are prepared on a county by county basis, and follow the guidelines laid down in the national groundwater protection scheme.

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- Build institutional capacity to sustain implementation by providing a mandate to act, as well as information and other resources that recognize and encourage ecosystem perspectives.

CONCLUSIONS

The policy issues facing Ontario are not unlike many other jurisdictions. These include the need to increase understanding and awareness of groundwater, address information gaps, manage water takings on a watershed basis, enhance source protection, manage cumulative risks such as from land applied nutrients, and support local and regional strategies. To be successful in the long term, groundwater strategies should be based on an ecosystem approach. This is based on improved characterization of groundwater systems, measurable objectives for human and ecosystem health, increased source protection and prevention, and support for community-based solutions. These guiding principles provide a strong normative basis for long term management and protection of groundwater. The challenge is to identify and seize opportunities to put them into practice. There is strong evidence that conditions are right to make tangible progress on this broad and exciting agenda for change.

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- From one ministry having sole responsibility for environmental protection to a high-level, government-wide vision and goals with implementation shared across different departments.
- From an orientation to political and jurisdictional boundaries to a place-based approach with boundaries that make environmental planning sense and facilitate a total cross-media, cumulative approach (such as watershed management).
- From a primary emphasis on ensuring compliance with minimum standards for large stationary facilities to a new and broader emphasis on strategies to promote continuous improvement in environmental outcomes and accountability across all sources of pollution.
- From traditional program delivery according to municipal or ministry/department area or regional boundaries.
- From a primary reliance on traditional investigation, enforcement, and abatement tools to a more comprehensive, flexible set of regulatory and non-regulatory compliance tools and incentives.
- From a reliance on government to do it all to an approach based on shared responsibility with the regulated community, non-government organizations, the public, and the scientific/technical community.

Elsewhere I have addressed how these types of principles apply to planning for groundwater protection (Neufeld 1991, 1987). From the perspective of groundwater, an ecosystem-based approach can address many long-standing issues: traditional management approaches that rely on end-of-pipe controls, lack a prevention focus, lack a common vision, and have limited coordination among public, private and non-government sectors. It involves moving from the site-specific to a groundwater system focus, transforming reactive controls to preventative planning, integrating goals of human health and ecosystem integrity, and improved coordination of programs and decisions of government and non-government actor groups, with a focus on strengthening community capacity for action.

Key principles of an ecosystem approach that should be incorporated in the design and implementation of groundwater protection strategies are summarized below.

- Plan across jurisdictional boundaries to encompass ecological processes and functions directly related to the goals being pursued and the activities that are impacting valued ecosystem functions.
- Link sustainable human uses with a long-term vision for maintaining and restoring essential ecological functions.
- Integrate information on discrete components of the ecosystem through analysis of processes that knit them together - the movement, storage and cycling of water, the support provided to biological habitats and the provision of clean water.
- Seek to understand complex relationships among multiple human stresses and concomitant changes in groundwater-ecosystem functioning over time at multiple levels of ecosystem organization.
- Favour precautionary and flexible measures that ensure future options are not precluded by a failure to act in the absence of complete information and understanding.
- Apply an integrated set of instruments that work together to achieve the long-term vision through four key management functions: protection, prevention, control and remediation.
- Increase the responsibility and accountability of all actor groups for achieving collective outcomes.

sufficient information for pursuing cost-effective alternatives. The specific objectives of the EOWRMS project include:

- putting together an environmental data base on the state of water resources;
- developing data management protocols;
- assessing the capability of key areas to support development on private services;
- identifying potential cost-effective servicing alternatives on a regional basis;
- developing community demonstration projects that provide integrated solutions to water resource issues on a local and regional basis; and
- promoting tools to protect the quality and quantity of regional water and related land resources.

The final report should provide the counties, local municipalities and non-government stakeholders the information base and the tools to conserve and protect water resources in a cost-effective manner.

Watershed Approaches

In Ontario, it also is becoming more common for groundwater resources to be assessed in the context of watershed management planning activities. Watersheds refer to the area of land drained by a river and its tributaries. A watershed management plan is a document developed cooperatively by government agencies and other stakeholders that seeks to protect the health of the ecosystem through the management of water and improved land use practices. The watershed approach promoted by Ontario's 38 Conservation Authorities concentrates on reducing or eliminating problems at the water's source and at each potential contaminant source in rural and urban areas of the watershed. Between 1990 and 1995, 87 watershed (and sub-watershed) projects were initiated in Ontario. Groundwater quality was assessed in 44 of the 87 projects and groundwater quantity was examined in 39 of the 87 projects (Ontario 1997).

In 2000, the Grand River Conservation Authority completed a major regional groundwater-mapping project that will set the standard for future studies. By updating the 72 000 water well records in the watershed, consolidating geological maps of the subsurface, and mapping analysis, and regional groundwater conditions in the watershed were described and mapped. A series of map sheets for the watershed was produced at a 1:50 000 scale. These maps described physical conditions (e.g. location of bedrock valleys, thickness of sand and gravel deposits), hydrogeology (e.g. potential recharge and discharge areas), and areas vulnerable to contamination (where the depth to water table and first aquifer <10 m). These maps provide a regional scale understanding of groundwater conditions and are available to local municipalities and others involved in managing growth and land use activities.

PRINCIPLES TO GUIDE FUTURE PROGRESS

Both experience and theory suggests the need to evolve toward more comprehensive and integrated approaches to environmental planning and management. A recent independent review of best practices to meet current environmental challenges and execute various management responsibilities confirmed important characteristics of this type of approach (Executive Resources Group 2001). The contrast between the old and the new paradigm is summarized, as follows:

- a water budget for Oxford County that estimated current supply and general availability of additional groundwater supply for existing and future demands of all potential urban and rural users;
- emergency preparedness and contingency planning to deal with evidence of groundwater contamination, spills, etc. or the disruption of supply due to mechanical problems, accidents or catastrophic events;
- a data management system, with a geo-referenced data made publicly accessible via internet-based applications;
- a public consultation exercise to provide a comprehensive and thorough vetting of public opinion on the issues surrounding the groundwater protection initiatives and water conservation measures for the County;
- analysis of nutrient management options for all livestock farms as well as to non-domestic users of organic commercial nutrients; and
- a management plan for old underground storage tanks.

The study recommended an aggressive public awareness campaign, and incorporation of municipal Wellhead Protection Areas and Highly Vulnerable Aquifers (HVA) into municipal planning documents. The study also recommended that the County amend its Official Plan to include effective land use policies in WHPAs to ensure development does not compromise groundwater recharge; impair groundwater quality; and or over-tax groundwater supply.

A system of sentinel monitoring wells was recommended in the municipal WHPAs to help identify contaminants in the groundwater before they reach the wells. The priority for establishing these wells was to be decided by the County, based on aquifer vulnerability and risk
management principles. The study also recommended that Oxford County encourage the provincial government to enact Agricultural Standards legislation in order to provide the legal framework for expansion of the County's Nutrient Management Planning Program. Additional recommendations related to supporting data management, contingency planning, and examination of an incentive program for removal of leaky underground storage tanks.

The Eastern Ontario Water Resources Management Study (EOWRMS) was co-funded by the Ministry of the Environment along with two groups of counties in the eastern most part of southern Ontario, between the Ottawa River and the St. Lawrence River. It involves many partners, including three levels of government, two conservation authorities, and numerous farm and rural organizations. The United Counties of Prescott-Russell spans the northern half of the study area. It has eight local municipalities with a total population of 74 000. While dairy and beef operations predominate, a significant number of residents work outside the counties in the national capital region of Ottawa. The United Counties of Stormont, Dundas and Glengarry span the southern half of the study area It has six local municipalities with a population of 64 000 persons. The region also is largely agricultural with over 800 dairy and cash crop farms. This supports the food processing and oilseed sectors and some manufacturing. An emerging sector in the region is that of advanced agriculture technologies including biotechnology.

The need for the study arose from significant pressures on their water resources and continuing water and servicing problems. Even though almost 70 percent of the population use private wells, 33 small communities within the study area have municipal water systems. In a five-year period (1985-1990) capital expenditures on individual water and sewage problems exceeded $90 Million. Action was being taken on a case-by-case basis, without

LOCAL AND REGIONAL STRATEGIES

Municipalities in Ontario have at their disposal a range of tools that can be applied to groundwater protection (Neufeld 1998). At the same time, prior to 1998 municipalities were largely on their own to determine how best to use their responsibilities and authority. The number of municipalities undertaking assessments of their groundwater conditions has increased in the past three years, following the provincial grant program.

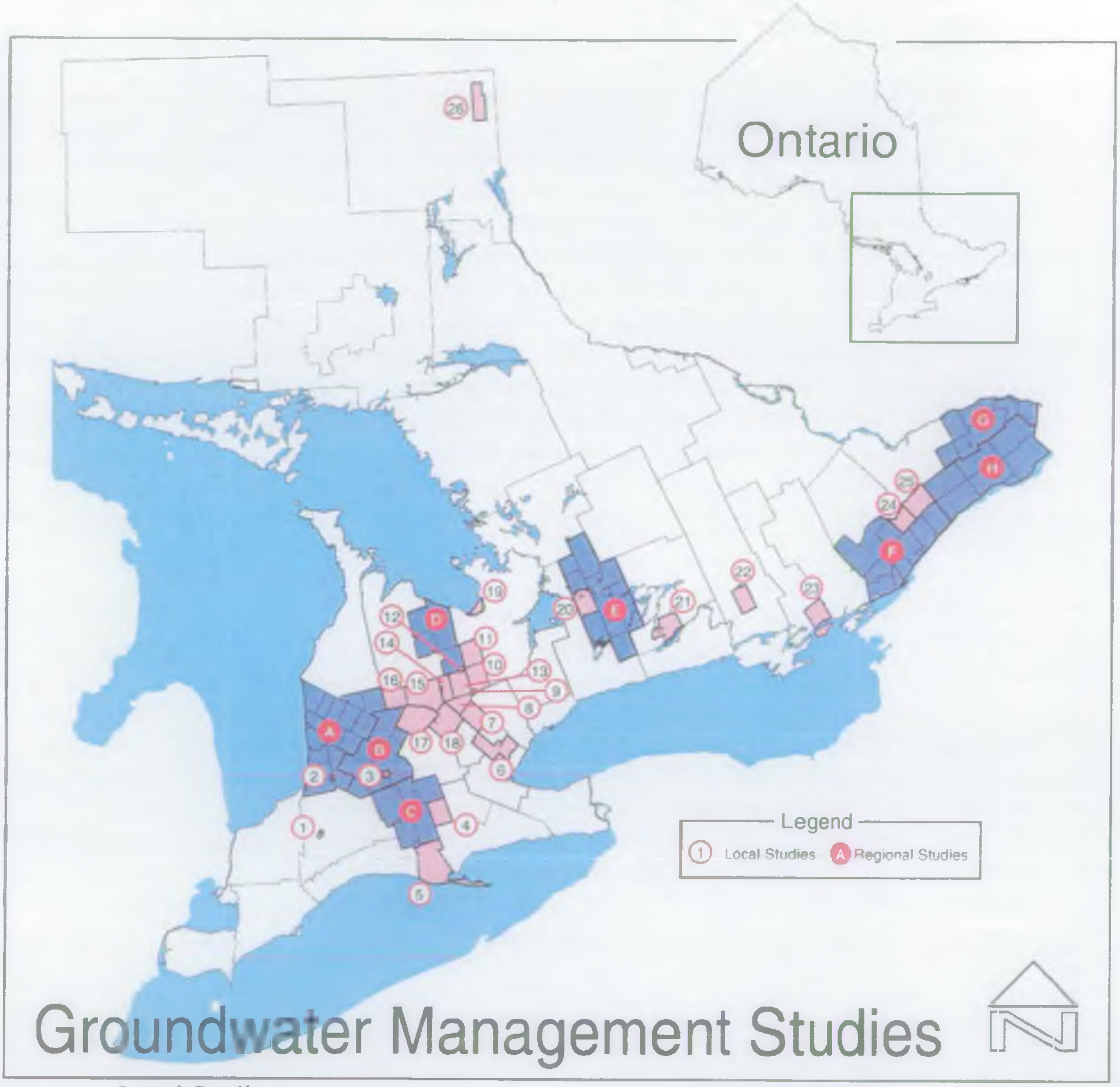
Independent of provincial funding assistance, some of the larger regional municipalities in Ontario have made significant progress in mapping and assessment of groundwater resources. In particular, Waterloo, Halton, and Peel regions have advanced the farthest in groundwater protection planning. Waterloo Region, with a population approaching 400,000 that enjoy the benefits of groundwater for their water supply, has the most advanced groundwater protection strategy of its kind in Ontario (Neufeld 2000). A contamination event in 1989 that cost taxpayers almost $50 Million (Cdn.) convinced the Region of the need to do more to protect groundwater. By 1994 it adopted a multi-year implementation plan with the following components: groundwater mapping and assessment, contaminant source inventories, monitoring and data management, policies for water resources protection, and emergency planning. By 1996, preliminary capture zones for all municipal well fields were mapped, as was the region's major surficial aquifer of the Waterloo Moraine. That same year it produced a draft policy paper on protection area policy. However, it took four years of hard work before policies defining acceptable uses in sensitive capture zones of municipal wells were approved. The region also lobbied the provincial government to provide additional tools to the municipality to promote pollution prevention and environmental management systems in its urban industrial areas. In May 2001, the Ministry of Municipal Affairs and Housing responded by announcing a pilot project to test the application of development permits[17] to protect sensitive wellhead areas in the regional municipality of Waterloo.

Out of the studies receiving provincial grants in 1998-1999, two examples illustrate the potential for regional approaches to groundwater protection: the Groundwater Protection Study in Oxford County, and the Eastern Ontario Water Resources Management Study. Oxford has a population of 97 000 people spread over eight municipalities. It has over 1 450 commercial farms and 100 commercial and industrial agri-business ventures. Dairy, hog and tobacco farms account for nearly half of the farms. A wide range of other farming activities include cash crops, poultry and specialty products like emu, ginseng, fruits, vegetables, maple syrup and garlic are becoming more popular. In addition to agriculture, there are a significant number of limestone quarries and sand and gravel-pit operations. The manufacturing sector employs 1 in 4 persons in the labour force by companies specializing in automotive, metal fabricating, specialty equipment, textiles, plastic products and food processing.

Oxford's groundwater management study, co-funded by the Ministry of the Environment and the County government, was carried out over a period of 16-months (Golder 2001). It was completed in May, 2001, and has many different components, including:

- mapping of Wellhead Protection Areas (WHPA's) for the county's 80 municipal wells;
- characterization of groundwater aquifers, water quality, vulnerability, and identification of Groundwater Recharge Areas (GWRA's) across the county;
- assessment of potential sources of contamination within the WHPA's and GWRA's;

[17]Development permits are issued, in lieu of zoning by-laws, as a flexible means of adapting development controls to individual site conditions.



Local Studies

1. Strathroy
2. Exeter
3. Stratford
4. Brant
5. Norfollk
6. Milton
7. Erin
8. East Garafraxa
9. Orangeville
10. Mono
11. Mulmur
12. Shelburne
13. Amaranth
14. East Luther - Grand Valley
15. North Wellington
16. Minto
17. Mapleton
18. Centre Wellington
19. Wasaga Beach
20. Eldon
21. Otonabee - South Monaghan
22. Centre Hastings
23. Loyalist Township
24. Merrickville - Wolford
25. North Grenville
26. Larder Lake

Regional Studies

A. Huron County
B. Perth County
C. Oxford County
D. AEMOT Study Area
E. Victoria County
F. United Counties of Leeds and Grenville
G. United Counties of Prescott and Russell
H. United Counties of Stormont, Dundas and Glengarry

The quality and quantity of groundwater and surface water and the function of sensitive groundwater recharge/discharge areas, aquifers and headwaters will be maintained or enhanced.

In June 2000, the Ministry of the Environment issued a regulation specifying drinking water standards, drinking water treatment requirements, and water testing and reporting for communal water works. This regulation strengthens the long-standing requirement that those municipal or private water systems serving more than 5 homes obtain a certificate of approval from the Ministry of the Environment. There are standard terms and conditions for groundwater sources, to ensure that the level of operation and maintenance is commensurate and sufficient to meet the performance criteria of the works for protection of public health and the environment. Where groundwater sources are under the direct influence of surface water, the Ministry recommends that the owner take all necessary steps, within their authority, to ensure protection of the source of water supply (groundwater aquifer) from contamination (MOE 2000.) This condition provides a limited basis for encouraging further actions by municipalities to assess and manage risks to their source of water supply through a variety of tools, including land use planning. The province has not yet provided guidelines for interpreting or applying this policy, leaving communities to develop their own unique approaches.

In a bid to support municipal efforts to assess and protect their groundwater resources, the Ministry of the Environment announced a grant program in 1998. The following activities were eligible for funding:

- mapping and assessment of groundwater resources;
- identification of potential sources of contamination to aquifers supplying the municipality;
- assessment of current uses of groundwater: in the municipality and the watershed;
- economic evaluation of protection alternatives and management and protection measures;
- development of management plans dealing with land use, watershed stewardship, and monitoring; and
- Contingency plans/emergency response to contamination.

Specific outcomes of these studies include:

1. Establishment of an information base for understanding the environment on a groundwater/watershed basis, for understanding potential threats to groundwater resources, for developing innovative protection and management approaches and for anticipating future infrastructure needs;
2. Improved municipal understanding of the benefits and costs of groundwater protection
3. Development and implementation of municipal action plans to manage and protect groundwater resources and municipal drinking water supplies; and
4. Shared best management practices on groundwater management and protection.

Municipalities were encouraged to work with their adjacent municipalities, conservation authorities and public utility commissions to submit joint applications. To date, 34 groundwater studies have been funded across southern Ontario, with the province picking up over 60 percent of the total costs (Figure 1). Over 50 percent of the approved applications involve the local conservation authority. Most studies are scheduled for completion by September 2001. The studies will give municipalities and their local partners the information and the tools to conserve and protect water resources in a cost-effective manner over the long-term.

the past ten years, they are becoming more concentrated in fewer, larger operations. In the absence of provincial controls, some municipalities have adopted Nutrient Management by-laws to govern operations that generate a large amount of animal waste.

In July 2000, the Ontario government released a proposal for clear, enforceable province-wide legislation for intensive agricultural operations. It also undertook public consultation in response to ongoing concerns about the effects of intensive agricultural operations on water quality and the quality of life in rural Ontario. At that time, farm organizations expressed support for legislation that would enforce standards for all agricultural operations and prevent the use of poor practices (Ontario 2000). In May 2001, the government announced it would introduce a comprehensive nutrient management strategy that will provide Ontario's agricultural industry with clear environmental protection guidelines (Ontario 2001).

The provincial government also has a $90 Million (Cdn.) program called *Healthy Futures*. It is focussed on enhancing the safety and quality of Ontario food products, capitalizing on marketing and export opportunities, as well as improving rural water quality and making efficient use of water resources. The Ontario Ministry of Agriculture, Food and Rural Affairs announced one specific water project under this fund in May 2001 (Ontario 2001). A total of 357 Best Management Practices on farms in Wellington County will be implemented by a partnership including the municipalities, local farmers and the Grand River Conservation Authority. The project includes site visits, water quality sampling and final inspections on the participating farms.

Protecting Groundwater Sources

Under the *Planning Act*, municipalities are directed to adopt official plans that contain goals, objectives and policies to manage and direct physical change and the effects on the social, economic and natural environment of the municipality (*Planning Act* s. 16(1)). Official plans designate lands for certain specified uses, and outline policies to guide future development. Policies can be included in specific sections of an official plan pertaining to infrastructure requirements, performance measures for water quality and quantity management, storm drainage, and groundwater protection.

Local zoning by-laws give legal force to designations and policies in the official plan. These bylaws restrict the use of land, the erection, location or use of buildings or structures, and the density of development. In 1996 the Planning Act was amended to give local councils the authority to pass zoning by-laws for prohibiting land uses and buildings or structures on land is a sensitive groundwater recharge area, a head-water area, or on land that contains a sensitive aquifer (PA s. 34). In addition to zoning controls, municipalities control the division of land through the approval of plans of subdivision. In the development review process, municipalities can prescribe the information that must accompany an application, including environmental information such as soil conditions, water supplies, and sensitive natural features.

In exercising their authority under the Planning Act, municipalities are directed to have regard for policy statements issued by the Province on matters of provincial interest (*Planning Act* s. 3). The *Provincial Policy Statement* (1996) includes a brief reference to water, as follows:

number of pressures. The Big Creek Water Management Strategy is being led by the Norfolk Federation of Agriculture, with participation by provincial officials, and the local conservation authority. One of the goals is to establish procedures for making decisions on water taking permits and cooperation among users when addressing situations where insufficient water exists to meet current demands. A significant part of this effort is finding methods for taking into account all water inputs, storage, consumption, and outputs on a watershed basis.

To promote leading science in this area, the province produced a technical reference manual on water budget analysis in June 2001. The manual describes leading methodologies for calculating water budgets for a watershed, taking into account interactions of surface water and groundwater as well as potential influence of human activities on the water cycle. Two additional pilot studies in the Grand River Watershed and the Credit River Watershed are testing methods for estimating water balances that can be applied in other areas of the province.

Managing Pollution Risks

Historically, the provincial government has focussed on end-of-pipe controls for visible and stationary contaminant sources rather than prevention activities to reduce the use, creation and discharge of contaminants. The provincial government has a large number of policies and guidelines for activities subject to environmental legislation. These guidelines address a broad range of matters, such as potential impacts, facility designs and descriptions of proposed works, treatment methods, sampling and analysis, and effluent discharge criteria. Treatment requirements are often determined on a case-by-case basis, in consultation with the applicant.

In 1986, the Ministry of the Environment released its policy for applying the concept of reasonable use to landfill sites and specific types of sewage lagoons and subsurface sewage disposal systems. The policy describes the basis for limiting contaminant levels in groundwater on properties adjacent to landfill sites. For example, where the designated reasonable use of groundwater is drinking water and background water quality is above Provincial Drinking Water Objectives, a reduction in quality by 25 percent of the difference between background levels and the provincial objectives is considered acceptable. Where groundwater units contain water of naturally poor quality, have yields that are too low for practical use, or have been previously contaminated, it may be deemed to be suitable for use as a contaminant attenuation zone. In these defined zones dilution, dispersion, assimilation or other biological, physical and chemical processes are relied upon to reduce contaminant levels to acceptable levels.

Recently, there has been increasing concern about the potential impact of agricultural operations on the environment. One indicator of a potential concern is that the frequency of farm wells in Ontario where the harmful bacteria E.coli has been found, has increased significantly since the 1950's. One possible source may be liquid manure applications, suggestive of correlation found between shallow groundwater contamination under active farm fields and farm well quality degradation (Goss, M.J., *et. al* 1998).

While various types of land-applied nutrients, such as sewage bio-solids and pulp and paper waste are regulated by the Ministry of the Environment, provincial environmental legislation exempts "normal farming practice" from many of the standards and controls the other sectors are subject to. While the total number of livestock in Ontario has not risen dramatically over

Ministry of Consumer and Business Services has authority over the rules governing underground petroleum storage tanks, and the Ministry of Health has oversight over defining potable water supplies and public health regulations. The Ministry of Natural Resources has an interest in wetlands, aggregates, and fisheries. The federal government exercises jurisdiction over trans-boundary waters, fisheries and the regulation of toxic contaminants. It also undertakes scientific research, and recently announced a $15 Million (Cdn.) fund directed at clean water research.

Municipalities in Ontario have delegated responsibilities that impinge on groundwater management and protection in a number of important areas. They are responsible for providing public drinking water, waste water treatment, septic system permits, and land use planning. Under provincial legislation, regional health authorities are responsible for promoting public health and potable drinking water. Conservation authorities are another significant actor in water management; 38 conservation authorities have been established covering all major watersheds across southern Ontario. Over time, their role has broadened considerably from flood control to watershed management.

Managing Water Takings

There continues to be cumulative pressures from water withdrawals on water resources in specific areas of the province. The Ministry of the Environment controls the use of groundwater through a permit system and various regulations. The Ontario Water Resources Act requires that wells be constructed by a licensed well technician, and in accordance with standards prescribed by regulation. Proposed takings of surface or groundwater above 50 000 litres per day require a permit from the Ministry of the Environment.[16] There are currently 5 000 valid permits to take water in Ontario, with up to 1 000 or more applications reviewed or renewed each year on a case-by-case basis. A groundwater assessment can be required for proposed groundwater takings to assess the potential for interference with other users or impacts on nearby watercourses. Reviews take into account, among other matters, the effects on other users, such as existing and planned livestock and other agricultural uses, municipal water supplies, and private domestic needs. Another consideration is the potential impact of proposed takings on the natural functions of the ecosystem.

Individual assessments of proposed takings often occur without a good understanding of the entire groundwater flow system or the relationship of groundwater to other ecosystem features. The ability to characterize groundwater flow systems and their interaction with surface water on a practical level is limited due to the complexity of the subsurface (Ontario 1995). The ability to predict groundwater responses to human activities (pumping) and natural factors (drought) is increasingly based on computer models, which depend on the quality of the data that are input to the model and the validity of the model being applied to a specific setting.

Following a number of years of successive low water levels, the province established a process whereby teams of local officials identify and promote ways to conserve water and manage multiple demands on the water system. As conditions get more severe, the province can step in and restrict or rescind permitted withdrawals. Currently the province is supporting a pilot project to manage water takings among different users where there are a significant

[16] Withdrawals of water for individual household use, livestock, and for firefighting are currently exempt from permits.

The cost of data collection, particularly where drilling of additional wells is needed, and the investment of time required discourages necessary studies needed to obtain an appropriate database. However it also pointed out positively that new approaches are increasing the ability to characterize groundwater systems, by using longer time frames and a wider variety of hydro-geological tools to assess larger scale groundwater flow systems.

In the spring of 2000, the Ministry of the Environment launched a province-wide groundwater-monitoring network. During the next three years, the Ministry will work with local conservation authorities and municipalities to install approximately 400 electronic monitors to measure water levels in wells across Ontario. The network will provide an early warning system for changes in water levels caused by climatic conditions or in response to human activities as well as provide for an early warning system for changes in water quality from natural or human sources.

Public Understanding

There is a significant need for groundwater outreach and education. The lack of technical understanding by decision-makers and stakeholders and mistrust by the public has reduced the ability to resolve issues, establish values and make choices related to groundwater (Ontario 1995). The tragic events in the Town of Walkerton in the spring of 2000, has renewed public awareness and concern about the safety of their drinking water. One expression of this is the dramatic increase in the number of private water samples sent to public health labs in the months following. In response, the Ministry of Health and Long Term Care, together with the Ministry of the Environment and the Ministry of Agriculture, Food and Rural Affairs, launched a public outreach campaign beginning with the development of a series of publications and fact sheets on wells and water quality.

In a bid to address the broader lack of awareness of groundwater issues, the Ministry of the Environment launched an educational project in 1997 to encourage local communities to pro-actively manage and protect their groundwater resources. Using a national science personality as the on-camera host, an educational video was produced about the benefits of groundwater protection. Public input was received through the direct participation of more than a dozen organizations with an interest in groundwater, public health and the environment. In October 1999, the Minister of the Environment officially released the video "*Groundwater: our hidden treasure*" at a major conservation conference in Ontario. Since that time, hundreds of copies have been distributed through the offices of conservation authorities to local municipalities, citizens groups, and Boards of Education.

Clarifying Roles and Responsibilities for Groundwater Protection

Responsibilities for managing and protecting groundwater are divided among different agencies and levels of government. Provincial governments have constitutional responsibility for the supervision of groundwater resources and for governing human activities, which affect the environment within provincial borders. This includes regulating emissions from industrial activities, controlling use of private and public (non-federal) lands, extraction of resources, and setting enforceable standards for human health and environmental protection.

The Ministry of the Environment sets enforceable limits for discharges of contaminants to air, land, water, and waste sites. The Ministry of Municipal Affairs and Housing has authority over municipal planning as well as the building code and standards for septic systems. The wells (>60yrs.) more impacted by human activities than drilled wells, deeper wells, newer wells (<60yrs.).

Historic problems have demonstrated that Ontario's groundwater is susceptible to contamination from many potential sources. Things like poorly managed municipal and industrial waste sites, badly maintained underground storage tanks, pipelines containing petroleum products, sewage sludge disposal, road de-icing, dry cleaning operations, mining activities, spills, urban drainage, and excessive use of nutrients or chemicals have contaminated groundwater (MacRitchie, *et. al.* 1994).

The vast majority of public expenditures have been on groundwater redemption rather than prevention. The provincial Environmental Clean-up Fund provides money for projects involving remedial measures to protect against environmental damage and reduce risks to public health or safety. Between 1985 and 2000 the fund allocated approximately $97 Million (Cdn.) to over 100 groundwater contamination projects across Ontario. Petroleum products are one of the most common sources of groundwater contamination. Other sources of contamination include dry-cleaning solvents, nitrates and industrial contaminants. Each of these accounted for three-to- eight percent of the total number of remediation projects. The Province also receives approximately 50 or more claims per year from individual well owners related to potential impacts of winter road salting activities along provincial highways.

Information Gaps

It is difficult to assess the magnitude of risk to communities and to groundwater in Ontario because of limited information. Unlike other resources of provincial interest, such as farmland, mineral aggregates, few of Ontario's aquifers have been assessed for their quality, quantity and vulnerability. At a meeting in 1996 of organizations with an interest in groundwater the lack of information and understanding of groundwater was identified as a priority concern. The current data are not readily available to everyone (limited access), there is a lack of interpretation of existing data (what the data mean, their significance), and there are insufficient data in many parts of the province (data gaps). This leads to a lack of public understanding and limited technical understanding by all those who manage the resource.

A review of the state-of-the-art science related to watershed planning and its application in Ontario also identified major deficiencies in the groundwater information base (Ontario 1995). It characterized the groundwater database for Ontario as limited and disjointed. There is no clearing house where this information can be obtained and no practical method of knowing where data currently exist. The report suggests that substantial effort may be required in assembling the groundwater database, especially in sparsely populated areas of Ontario.

A critical source of groundwater information is the 500,000+ well records contained in a provincial database. The information submitted by well drillers includes general descriptions of the location of the well, geological materials encountered, depth to the water table, freshness of the water, the proposed use, and specific construction-related information. However, the quality and reliability of these records is inconsistent, particularly with respect to recorded elevations and location. For example, a recent groundwater study in southern Ontario removed 21 percent of the 72,000 well records due to errors (Holysh *et al.* 2000).

Newmarket. In rural Ontario, approximately 90 percent of the population rely on groundwater for a clean and secure source of drinking water. An additional 1 million persons draw water from private individual wells, with an average of 15 000 new wells recorded each year.

Groundwater is vital to many industries in Ontario, especially the agriculture and agri-food sectors. In the $7 Billion (Cdn.) farm sector [14], it helps improve crop yields and increases farm efficiency. Wells provide low cost water to an estimated 40 percent of the 65 000 ha of irrigated farmland in Ontario. In addition there are over 40 000 livestock wells across the province. Groundwater is a preferred source of water in the $25 Billion (Cdn.)[15] food and beverage processing industry in Ontario. There are over 10 000 industrial, commercial and manufacturing wells in the province, including the bottled water, beer and soft drink industries. Groundwater also is a source of water supply for numerous golf courses and other recreation facilities.

Groundwater plays an important ecological role and is vital to the survival and health of Ontario's wetlands, lakes and rivers. Either directly or indirectly, groundwater contributes between 24 percent and 32 percent of the total flow of the Great Lakes. Therefore, any changes in groundwater quality and quantity may seriously affect the health of the Great Lakes ecosystem. Many of the rivers, streams and wetlands in Ontario would dry up during the hot summer months and during the winter without groundwater contributions. For example, during drier periods, such as the summer months, up to 100 percent of the total flow in some streams is provided by groundwater discharge. This discharge sustains aquatic habitat and moderates the effect of periods of low precipitation on surface water flows and water quality. In periods of high precipitation, streams and rivers may recharge the groundwater system, and gradually raise the groundwater table. In turn the groundwater will support the stream at a higher level for an extended period following these precipitation events.

POLICY ISSUES AND RESPONSES

The tragic events in the Town of Walkerton in the spring of 2000, has renewed public awareness and concern about the safety of their drinking water. Submissions to public health labs of water samples from private wells increased by a factor of 100 between May and August of 2000. In addition, the Ministry of Health and Long Term Care, together with the Ministry of the Environment and the Ministry of Agriculture, Food and Rural Affairs, launched a major public outreach campaign using various guidelines and fact sheets on wells.

Threats to Groundwater

Groundwater is naturally better protected than surface water from direct human impacts. At the same time, it is not immune from the effects of human neglect or mismanagement. The quality of water found in rural domestic wells is generally comparable to other jurisdictions in Canada and the USA with similar agricultural intensity. Studies show 20 - 30 percent of rural domestic wells exceed drinking water standards for coliform bacteria; 10 - 20 percent exceed standards for nitrates (Goss, M.J., et. al 1998). Occurrence of water quality degradation in Ontario directly related to type, depth and age of the well (dug wells, shallow wells, and older

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[14]Total farm cash receipts for 1999 were $7.2 Billion (Cdn) (Statistics Canada, Catalogue No. 21-603.)

[15] The total value of shipments in the food and beverage processing industry in Ontario in 1999 was $24.9Billion (Cdn) (Statistics Canada, Catalogue No. 31-203.).

14. GROUNDWATER IN ONTARIO, CANADA: POLICY ISSUES AND POTENTIAL SOLUTIONS

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ABSTRACT

In Ontario, Canada's largest province, groundwater policy has garnered recent attention. A number of key policy issues, common to many other jurisdictions, confront Ontario. These include limited public understanding, indicators of stress, lack of resource data, cumulative pressures on the resource, reliance on end-of-pipe controls, and the need for source protection. Land use planning has the potential to play a supportive role in groundwater management and protection.

From the perspective of land use and groundwater policy, the Provincial government plays an important role. It is responsible for legislation and standards impacting on groundwater, provides financial assistance to municipalities, and is establishing a groundwater-monitoring network. Municipal governments in Ontario are responsible for providing public drinking water, waste water treatment, septic system permits, and land use planning. Regional health authorities promote public health and potable drinking water. Conservation authorities promote water management on a catchment basis.

Case examples from Ontario illustrate how these institutions have strong potential to manage and protect groundwater. However, stakeholders have identified a number of long standing issues, common to many other jurisdictions. Traditional management approaches point to lack of resource data, reliance on end-of-pipe controls, substantial groundwater remediation, and limited coordination. To be successful in the long term, groundwater strategies should be based on an ecosystem approach. This is based on improved characterization of groundwater systems, measurable objectives for human and ecosystem health, increased source protection and prevention, and support for community-based solutions.

INTRODUCTION

Groundwater is a hidden, yet vital, part of everyday life in Canada. It provides a relatively inexpensive source of drinking water because there is little need for large surface storage reservoirs, extensive purification or treatment facilities and long distance pipes.[13] Groundwater is a source of drinking water for almost eight million Canadians (Environment Canada 1999). Within each province, the percentage of the population using groundwater ranges from 100 percent in Prince Edward Island to 22 percent in British Columbia. In Ontario, more than 200 communities are served by a public groundwater supply. Municipal water works provide groundwater to an estimated 1.9 million people. The vast majority of these communities are villages and towns with less than 5 000 population. However there are about a dozen larger communities with populations between 80 000 and 180 000, using groundwater, including the cities of Kitchener, Cambridge, Barrie, Guelph, Waterloo, and

[13] A recent Canadian study found that the capital cost of developing a groundwater supply can be at least 50 percent cheaper than the cost of developing surface water supplies. Operating costs were also found to be lower for groundwater, as it often requires less treatment. (Watson and Associates 1997).

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Throughout the development of the various tools and mechanisms employed by the Commission, close consultation is maintained with other agencies, industry, community groups and the others, to ensure that policies and plans are accepted, the philosophy and science behind them is understood, and resulting requirements are embraced. While this may result in an extended timeframe for their development, by adopting this approach the Commission has achieved considerable respect with the Community and Government.

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For example, when a water source protection plan is developed, community involvement is initially through public workshops, where the issues and concerns of effected landowners can be voiced. In some instances a draft plan may be produced at this stage taking these issues into consideration. On other occasions it may be necessary to develop a small working group which, with the Commission's guidance and assistance, can work through the expressed issues to reach common ground. The completed draft report is also subjected to public scrutiny and meetings and further development until it can be released for general public comment. If the Commission has been successful in its consultation program public submissions at this stage are minimal, the plan can be finalised and the water reserve gazetted.

The consultation process is extremely important in this scenario. On many occasions the development of a protection plan or a land use and water management strategy will involve the provision of priority classification to the water catchment, be it groundwater or surface water. Priority classification, while acknowledging and allowing continuation of current land uses, can place restrictions on future land uses, to the extent that some landowners may feel that their future livelihood is being jeopardised and that their land has lost its value. This concern is further accentuated by the lack of provision for compensation under the MWSSD and CAWS Acts. Unless the land is classified P1, which then provides an opportunity for affected landowners to approach the Commission to purchase the land for the Government, there is no scope, and no political willingness, for compensation to be paid for the loss of possible future land uses.

The problem becomes more difficult for landowners to accept when the water resource being protected is going to supply a townsite some 30-50kms away. The Commission however must seek a negotiated agreement with the affected landowners prior to the final publication of the protection plan. Failing this the impasse can be overcome by incorporating the plan into an amended RPS and adoption as a water reserve. To date, this situation has not arisen.

CONCLUSIONS

Groundwater is extremely important to the future economy, well being, and growth of Western Australia, as well as to the protection of its environment. The Commission and the Government of Western Australia recognise that for the resource to remain available as high quality water for future generations it must be protected from contamination.

The Commission protects these resources through a wide range of mechanisms. These include legislation, and the development of policies, guidelines and water source protection plans. While the emphasis may appear to be firmly on the protection of public drinking water sources many of the policies and guidelines have equal importance for private water supplies.

Following recommendations of the Parliamentary Select Committee, water source protection plans are now being linked directly to the State planning legislature to ensure future land development in Public Drinking Water Source Areas does not compromise future drinking water supplies. While they are not legally enforceable, the environmental guidelines, which the Commission prepares with other agencies, are seen by respective industries as being ideal best management practices to which they should aspire. Complementing this work will be further guidelines prepared under the State Water Quality Management Strategy, which will direct the way the State will implement the National Strategy.

Table 3 Guiding principles and general strategies

Guiding Principles of the NWQMS	Supporting Strategies of the SWQMS
1. Adopting and integrated framework to address water quality management	1. Use an integrated resource management approach (Principle 1 & 7)
2. Being cautious in decision making process	2. Determine environmental values or beneficial uses (4, 5 & 7)
3. Recognising global impacts or impacts beyond State boundaries	3. Prepare water quality management guidelines (3, 4, 5, & 7)
4. Enhancing environmental protection through economic growth	4. Use a mixture of market and regulatory measures (6)
5. Maintaining international competitiveness on a sound environmental basis	5. Avoid pollution and require the polluter to pay for clean up (6)
6. Adopting a mix of market and regulatory instruments	6. Involve and inform community and stakeholders (7)
7. Involving the community	7. Adopt a cautious approach and encourage continuous improvement (2 & 8)
8. Adopted for the SWQMS – continually improving performance	

COMMUNITY CONSULTATION

Since its inception in 1995 the Water and Rivers Commission has always adopted the principle of close community consultation in all aspects of its work. This is recognised within the Mission Statement of the Commission – To manage the water resources of Western Australia for the benefit of present and future generations in partnership with the community. The extent of consultation ranges from a Stakeholder Council of Senior Government Agency staff and leading industry representatives, which consults, advises, and supports the Commission at Executive level, to local community groups and landowners whose comments are sought for many programs and projects, and to school children.

The Commission is developing strong partnerships with the community by developing a common vision (for water resource management and protection), by sharing information, and by empowering the community. It does this by promoting awareness of water resource issues, by involving the community in policy development through consultation, by supporting integrated catchment management, and by providing technical support and information to community groups. It places particular importance in the ongoing development of school curricula and actively supports schools and community in environmental education programs, including the Ribbons of Blue program. While this program is essentially one that focuses on water quality monitoring and managing local waterways, the importance of developing an understanding of groundwater, how it occurs and how it can be managed or damaged, is recognised. Groundwater occurrence and processes are still a concept hard to understand by many.

The community consultative approach is particularly in evidence in most of the work carried out to protect the State's water resources. From the development of best management practice guidelines through to water source protection plans and ultimately to land and water management strategies the views of the local community and appropriate industry representatives are sought.

developed the National Water Quality Management Strategy (NWQMS). These councils represent the agricultural, environmental, health, and water resources portfolios.

The NWQMS comprises 21 documents that together establish a national framework through which stakeholders can contribute to better water quality management. It provides information and tools with which government and community, in partnership, can manage and protect their water resources to meet current and future needs. The NWQMS provides policies, a process, and a series of national guidelines for water quality management. Three key documents outline the policies and principles (ARMCANZ & ANZECC, 1994) the implementation guidelines (ARMCANZ & ANZECC, 1998) and the guidelines for groundwater protection in Australia (ARMCANZ & ANZECC, 1995).

Western Australia is a signatory to the NWQMS and its implementation, and this has formed the basis of a State Water Quality Management System (SWQMS). The SWQMS has adopted the prime objective of the National Strategy – **to achieve sustainable use of the nation's (state's) water resources by protecting and enhancing their quality while maintaining economic and social development.** This objective will be achieved through the specific water management principles of:

- ecologically sustainable development
- an integrated approach to water quality management
- community involvement in setting water quality objectives and developing management plans, and
- government endorsement of the water quality objectives.

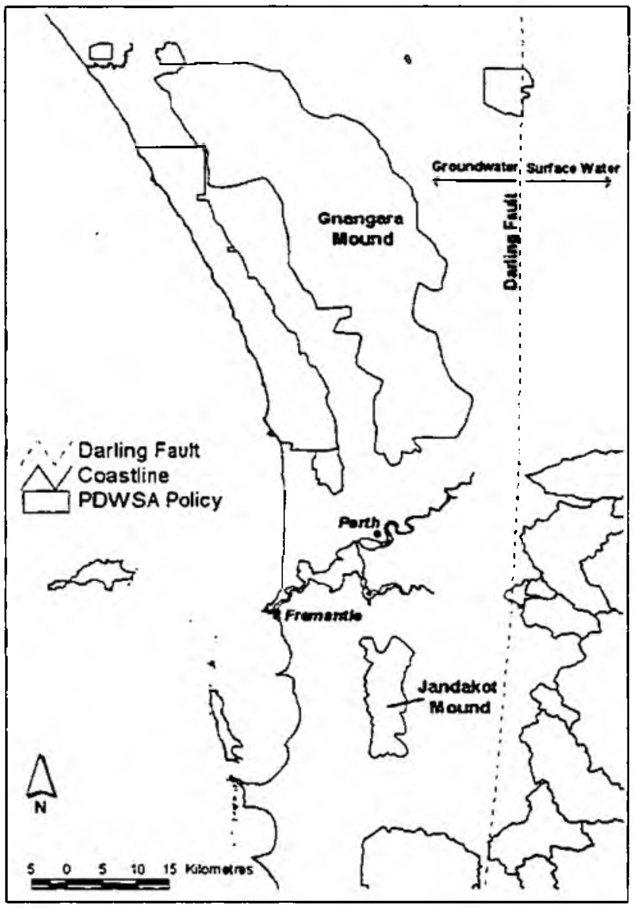
The guiding principles set out in the NWQMS (ARMCANZ & ANZECC, 1994) together with general strategies that have also been proposed to give effect to these principles form the basis for water quality management in Western Australia (Table 3).

During 2000 the SWQMS was developed by a Senior Review Panel (SRP) of senior officers from key government agencies, chaired by the Commission. Each of these agencies has a key role in implementing the NWQMS. The initial draft was developed over a lengthy consultative process during 1999 with contributions from more than 65 individuals and organisations. Submitted to the State Government in early 2000, it was endorsed by Cabinet for release for a public discussion and submission period prior to resubmitting to Government for endorsement as State policy. Final endorsement was achieved in April 2001.

The document endorsed by Government is the first in a series, and outlines the framework for implementation (Government of Western Australia 2001). The second document will form the implementation plan, which will set priorities for implementing the guidelines, and subsequent documents will mirror those of the NWQMS guidelines and setting out the method of implementation. It is anticipated that there will be different lead agencies for some of the guidelines, but the SRP will be retained and a Community and Industry Advisory Committee (CIAC) will be set up to ensure involvement at this level.

TPSs is to be provided through a Statement of Planning Policy being developed by the WAPC in cooperation with the WRC and others (WAPC 2001a).

Figure 2 Gnangara and Jandakot Mounds



Amending the schemes to align with the water source priority protection zones means that land use decisions will be consistent with water protection strategies – thus avoiding contradiction between legislation and costly management solutions. It also gives landowners a clear statement of all of the constraints in one place. Under the amended TPSs and RPSs, LGAs will be required to refer proposals for land development to the Commission for comment and approval. If the LGAs do not wish to accept the advice of the Commission they are required to refer the dispute to the WAPC who will make the final determination, although LGAs are aware that the WAPC firmly support the advice provided by the Commission where it is founded on the principle of water quality protection.

In recent years considerable effort has been placed on working with the MfP to link the proclaimed UWPCAs covering the Jandakot and Gnangara Mounds to the strategic land planning process and developing combined land and water management strategies. The Jandakot Land Use and Water Management Strategy (WAPC 1995) clearly set out the link between land development and water quality protection. It outlined those areas that could be further developed in accordance with the priority classification. The Gnangara Land Use and Water Management Strategy (WAPC 2001b) has subsequently been released and covers Perth's largest and most important source of groundwater in the metropolitan area. The Gnangara Mound also supports a wide variety of environmental features. Fortunately a large proportion of this area is Crown land and can be classified P1, but other privately owned land similarly classified is currently being purchased by government because of the restrictive land uses afforded by the classification. To implement these two strategies requires amendments to the MRS to include a Water Catchment Reservation over P1 areas and a Rural-Water Protection Zones over P2 areas, and incorporation of these and the appropriate land use controls into the local town planning schemes.

IMPLEMENTATION OF THE NATIONAL WATER QUALITY MANAGEMENT STRATEGY IN WESTERN AUSTRALIA

Commencing in the early 1990s, the Commonwealth and State Ministerial Councils of Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) and the Australian and New Zealand Environment and Conservation Council (ANZECC), with input from the National Health and Medical Research Council (NHMRC) have simple, complex natural -geological, complex natural -technogenic, very complex natural–technogenic.

- The obtained results allowed the identification of the necessary investigation and remedial measures to stabilize and improve the environment in the research areas.

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17. CARCASS DISPOSAL AND GROUNDWATER PROTECTION: LESSONS LEARNT FROM THE 2001 FOOT & MOUTH EPIDEMIC IN THE UNITED KINGDOM

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Introduction

The 2001 outbreak of Foot and Mouth Disease (FMD) in the UK was first reported by MAFF, now DEFRA (Department for Environment, Food and Rural Affairs) in late February 2001. Over 400 outbreaks were confirmed within four weeks, principally in the western and northern parts of England and Wales. FMD is a highly contagious disease and the particular strain encountered in this epidemic is reported to be particularly virulent. Government policy has been to cull not only affected animals but also all animals that potentially could be affected within a defined zone around each outbreak. By late July 2001 MAFF reported that there had been over 1800 outbreaks with a total of over 3.6M animals culled as a consequence of the epidemic.

Early in the outbreak the Environment Agency determined a hierarchy for disposal based on increasing environmental risk with rendering, incineration and use of licensed landfill at the top of the hierarchy and burning and burial at the bottom. However, the scale of the outbreak and the speed with which carcasses were required to be disposed of, quickly exceeded the capacity available for rendering and incineration. So MAFF requested increasing use of on-farm or mass burial sites and pyres at or close to the source of the outbreak. Ash arising from pyres has then either been buried on-site or taken to alternative disposal sites, such as landfill.

The role of the Environment Agency throughout the outbreak has been to support MAFF in combating the disease and to ensure that an animal health problem did not turn into an environmental problem. This paper considers the some of the problems and issues that have arisen during the FMD epidemic and in particular those that have been faced by the Environment Agency in its role as the environmental regulator responsible for the protection of groundwater in England & Wales.

Nature and scale of the problem

FMD affects cattle, sheep, pigs, goats, deer, horses and other cloven footed animals such as llamas. Based on MAFF figures of the numbers of animals culled as a consequence of the epidemic, it is estimated that, up to the end of July 2001, in the order of 450,000 tonnes of carcasses arising from the epidemic were disposed of, via a variety of routes.

There were in the order of 11 million cattle, 8 million pigs and 43 million sheep in the UK prior to the epidemic. It is estimated by MAFF that the annual natural mortality of cattle, sheep, and pigs combined with the controlled cull of cattle under schemes to control BSE, has given rise to between 420,000 and 700,000 tonnes of carcasses per annum for disposal in the last few years. Thus the tonnage that has had to be disposed of during the epidemic to the end of July 2001 is of the same order as that as the annual cull rate (this is over and above those animals that are slaughtered for food). So why has the epidemic created the problems that it has?

Firstly the epidemic was not spread evenly over the country, but concentrated in hot spots, largely in the west of the UK and particularly in northern Cumbria, Dumfries & Galloway, parts of Wales, the Welsh Borders and Devon. Secondly, the epidemic spread very rapidly and, with the prevailing approach to disease control, there was a need to dispose of a large tonnage of carcasses within a few weeks. Finally, existing alternative facilities for the disposal of carcasses, such as rendering and incineration at commercial incinerators, were not available in the capacities needed for MAFF and the Army. In certain areas, large numbers of slaughtered animals had to be left in the open, awaiting disposal. This presented an environmental risk and several surface water pollution incidents have resulted from the release of body fluids from such carcasses.

Normally, fallen stock would be disposed of in accordance with the Animal By-Products Order, 1992 (Ministry of Agriculture, Fisheries and Food, 2001) and, if buried on a farm site, the burial should be in accordance with a code of good practice (the Water Code - MAFF, 1999). This latter code allows for basic environmental protection measures in the form of set-off distances to water receptors (250 metres to wells and springs and 30m to watercourses), guidance on disposal procedures (must be above the water table etc.), such that, for a low loading of animal carcass waste, typical of usual farming circumstances, there should be little risk to water resources.

In previous epidemics where a cull has taken place, disposal has normally been to ground on the farm or via on-site pyres. In such circumstances this disposal is in accordance with procedures determined by the Animal Health Office, DEFRA.

In the early stages of the epidemic it was envisaged that such established disposal routes would be used again. The Agency's early environmental guidance for disposal to ground reflected a dilute and disperse approach for relatively small disposals, avoiding areas where water resources were vulnerable. In order to achieve safe disposal each site had to be rapidly assessed to determine the risk to groundwater and surface water. Rapid assessment was necessary to reduce the time carcasses were lying dead on the farm following the 24hr and 48hr cull policy. Carcasses on the ground posed an environmental and public health risk, according to the Department of Health.

As sites were put forward by MAFF for consideration, Agency officers gave an initial assessment for such risks, from a desk study of existing data. At the height of the epidemic some Agency offices were considering several tens of sites per day, seven days per week and were required to provide a response within three hours of submission of potential site location. This included consultation with English Nature and Local Authorities or the request for MAFF to undertake such consultation. However, in reality the Agency was often the only environmental consultee.

The rapid escalation of the epidemic and the contiguous slaughter policy during March 2001 meant that other, larger and more centralised burial facilities were necessary in order to rapidly clear farms of slaughtered animals, to minimise environmental and health risks. Therefore, a number of strategic mass burial sites were identified by MAFF. Only a handful of these sites were considered suitable from an environmental perspective by the Environment Agency. These sites were intended to deal with tens or hundreds of thousands of carcasses and they presented unusual environmental challenges, necessitating a different approach to the management of potentially polluting material from the sites.

Public reaction and perception to disposal arrangements has been mixed. Concerns over air emissions have led to widespread adverse reaction to pyres. For the most part, carcass burial has received less attention and adverse reaction from the public generally but, naturally enough, there has been strong local reaction in the vicinity of some sites.

Regulatory control on burials

Small on-farm carcass burial sites have traditionally been regarded as agricultural in nature and have not required planning permission. Due to the emergency nature of the epidemic, the mass disposal sites that have been brought into use have not gone through normal development planning procedures, though in some cases these are now being pursued.

All disposal sites where there is the potential for a discharge to ground (carcass burials, pyres, ash disposal) are subject to the EU Groundwater Directive, which in this case has been implemented by the issue of authorisations under the Groundwater Regulations, 1998 for all carcass burials over 8 tonnes. The Environment Agency is the regulating body for such authorisations and has required a minimum level of prior investigation and assessment before the issue of an authorisation. Some sites have been refused authorisations on the grounds of risk to groundwater or surface water and carcasses or ash deposits have had to be removed from unauthorised burial or pyre sites. All authorisations are subject to environmental conditions that, as a minimum, reflect good practice guidance such as The Water Code. The Agency can require monitoring of groundwater by the authorisation holder, where necessary, to determine whether there is any pollution arising from the disposal.

Risk assessment procedures

The Agency's tiered approach to risk assessment is indicated in Figure 1; this is taken from the joint DETR/Agency/IEH Guidelines for Environmental Risk Assessment and Management (DETR, 2000). The initial desk study noted above is thus an initial risk screening that relies on a combination of desk study data and assumptions regarding burial practices (for example, adherence to codes of practice, with standard set-off distances, as noted earlier). The desk study usually relies on tools such as maps, including Source Protection Zone maps where the mapped information effectively contains an in-built risk assessment of a generic nature. The assessment is entirely dependent on the scale of the mapped data and the assumptions underlying the data represented on the map. Thus, in the case of the FMD epidemic, the risk screening could identify areas where burial according to the Water Code would be acceptable for carcasses up to a certain loading and subject to verification of assumptions on-site, such as location of water supplies.

Once the assumptions underlying an initial risk screening are exceeded or a more precise (site-specific) assessment is necessary to evaluate the risk, tools such as maps become superseded by site-specific data. Time is needed to collect such data and develop the conceptual model of the site that enables a full risk assessment to be conducted. In normal circumstances many weeks or months, depending on the size of the source term, the complexity of the pathways and sensitivity of the receptors, would be needed for a full evaluation of risk. Such timescales were not available at the height of the FMD epidemic.

With the need to rapidly identify strategic mass burial sites, many other factors came into play in addition to the need to protect surface and groundwater resources; site logistics and availability were key issues. Strategic sites were located away from identified major water resources and receptors such as boreholes and springs using risk screening and site inspection, backed up by a limited site investigation. However, in order to make use of some sites, disposal had to proceed without the degree of intensive prior site investigation (characterisation), evaluation and preparation that would be expected for developments of such size, under normal circumstances. Nevertheless, detailed investigations and mitigating measures have proceeded in parallel with site development and operation and DEFRA and the Agency have established on and off-site monitoring respectively at these strategic sites.

The rapid screening of potential burial sites noted above (which was also used for pyre sites) relied heavily on a desk study assessment of existing databases and maps, of varying quality and applicability. On the positive side, England and Wales has, by international standards, generally good geological and hydrogeological databases. The Agency has delineated groundwater source protection zones (SPZs) around major potable supplies and has produced groundwater vulnerability maps for the whole of England & Wales. In addition to published data, the Agency holds records of licensed abstractions, monitoring data and hydrogeological information gained from its activities.

On the negative side, many of the outbreaks were in areas where the readily available geological and hydrogeological data are relatively sparse. Notably the coverage by published geological maps at scales less than 1:50,000 is limited and some areas of Wales and Cumbria have not been mapped in the last century. These restrictions were partly counterbalanced by the setting up of an arrangement with the British Geological Survey for a fast turnaround search of their unpublished records and reliance upon the considerable local knowledge of Agency Regional and Area hydrogeologists.

Many of the affected areas are not on major aquifers or near sources of public water supply, yet in locations where there are many private abstractions for domestic and agricultural use from strata that are considered as minor or non-aquifers. In England & Wales there is no requirement to register many of these private supplies as they are exempt from abstraction licensing. Whilst Local Authorities keep some records of such supplies, the coverage is patchy and unreliable and there is no requirement to inform the Agency, as the regulator charged with the management and protection of water resources, of the location of all private supplies. Without a centralised database it is thus extremely difficult to provide protection for such sources. During the epidemic this caused difficulties as the desk study assessment noted above had to be followed up by a rapid on site search for private supplies before a site could be used.

Every effort was made by those involved to ensure that relevant environmental data were accessed and groundwater resources were protected. The pressures caused by poor access to databases of basic information and very short timescales were substantial and the risks of making a mistake were higher than would be considered acceptable under normal circumstances.

Issues arising from burial of carcasses during the FMD epidemic

Source term data

Existing data on the general rate of decomposition of mammalian carcasses, at the outset of the FMD epidemic was sparse. Little hard evidence existed of the nature of the leachate from carcass burials and the rate of release of such leachate. Therefore, as risk assessments are driven by the nature of the source term, some assumptions had to be made during the risk screening process.

The key factor that has dominated the initial management of burial sites has been the rapid release of body fluids from carcasses. At smaller burial sites the receiving capabilities of the ground can normally accommodate the volume of leachate produced. At the larger and strategic mass burial sites large volumes of leachate were produced in the first couple of weeks following disposal. This resulted in problems with the mechanics of disposal (odour, inability to cover etc.) and encouraged movement away from the burial site by providing an additional head (hydraulic potential). To minimise this, lining systems, the provision of leachate drainage facilities and rapid removal of leachate from the disposal areas has been needed at the larger sites from the outset. Leachate collection, storage, treatment and disposal facilities have proved to be essential major components of site operation and it is assumed that such facilities will be needed for a substantial time period.

Accessibility of risk screening data

In the time available during a major epidemic, rapid risk screening and site selection is possible, but relies on good existing databases if it is to be conducted effectively. In the UK there has been a trend for public funding for basic geoscience and hydrogeological mapping to be reduced and more reliance on the proceeds from the sale of such data, on the basis that industry and commerce should pay more of the real costs. However, most risk screening data in the form of maps and areal databases find their major uses in the predominantly public sector spheres of strategic planning, emergency planning and prioritisation of regulatory activities. The private sector tends to focus on detailed, site-specific data and uses existing mapped data as only a springboard for site-specific investigations and risk assessments tailored to their individual needs.

Whilst many of the bodies involved in the epidemic mobilised substantial resources to cope with the epidemic (the Agency had several hundred people working full time on environmental aspects alone), there is a limit to the capability to compress timescales for the data acquisition needed to facilitate adequate risk assessment and protection of the environment. The FMD epidemic has highlighted that there is a need to improve the quality and accessibility of data that is routinely used in initial risk screening for environmental and planning purposes. These data are a national resource and to ensure that national needs are met they require central funding and direction. For some data, legislative action may be required. For example, supported by appropriate legislation, the provision and maintenance of a single database containing details of private water supplies, that is accessible to local authorities, environmental regulators, emergency planners and emergency services would be of considerable national benefit.

Whilst there has been considerable progress in the transfer of data to digital formats and searchable databases, we are some way off comprehensive storage and retrieval of environmental data in GIS compatible formats in the UK. The ability to examine various combinations of relevant data digitally would have facilitated more rapid initial screening and assessment of disposal sites during the FMD epidemic. Again central co-ordination and ease of access to such data are key issues.

Disposal capacity
The rapid escalation of the epidemic highlighted the need for a variety of disposal routes in accordance with the disposal hierarchy. It was often difficult to predict and match disposal capacity against disposal needs.

Some routes for disposal such as landfill were initially restricted due to concerns from landfill operators and local people regarding the associated long-term liabilities. From the environmental perspective, however, diversion to a licensed landfill is the preferred option to burial elsewhere. Landfills that are licensed for waste streams of this nature have been subject to extensive risk assessment and have been properly engineered to achieve a high standard of environmental protection. This is preferable to disposal in unlined burial facilities or sites that have only been subject to limited risk assessments. We should consider the long-term strategy for the use of such facilities.

The option of using commercial incinerators has been restricted due to limited capacity and the priority allocation of over 5 years cattle to such facilities due to the risks presented by BSE . The development of commercial incineration capacity has been restricted in the UK in recent years due to public concerns regarding air emissions, but a similar argument to that above for landfill can be raised here with respect to pyres.

Meanwhile, whilst burial of carcasses is only one of a number of options, it seems likely to remain as a key element during any future animal disease outbreak.

Prior planning
From the groundwater and surface water protection viewpoint, there is a break point where the capacity of local, environmentally safe, burial facilities to deal with the loading of carcasses is rapidly exceeded. This break point is dependent not only on the volume of source material but also on the geological, hydrological and hydrogeological conditions in the area. It potentially represents a change in scale in the disposal operation and, if mass burial sites are needed, a change in the planning and implementation timescales needed to ensure environmentally safe disposal.

In terms of local (on-site) burial facilities, it is recommended that the incorporation of provisions for emergency burial (including acceptable locations and waste loading) should be an integral part of farm waste management plans. Such plans should be a basic farming requirement, subject to consultation with bodies such as the Environment Agency and would save much time and effort during emergency situations. In particular, sites which are inherently unsuitable for on-site disposal of carcasses could be identified in advance and alternative provisions made.

The provision of facilities for larger scale (mass) burials is more problematic. Facilities of similar scale and complexity to these would normally require a detailed site investigation and quantitative risk assessment prior to commencement of disposal, to ensure their environmental security. Even with substantial resources this takes many weeks or months. Thus, by their very nature, it is difficult for new large strategic sites to be successfully developed in the timescale of an epidemic. However, the provision of stand-by strategic disposal facilities would raise a number of issues such as opposition from local residents, planning blight around the site, long term site management, responsibility for management costs etc. Nevertheless, many of the problems encountered during the FMD epidemic would have been greatly reduced if a number of strategic sites, properly characterised and assessed, had been available at the outset of the epidemic, combined with a disposal strategy for their use. Any future animal disease outbreak must take account of the environmental issues and any means of reducing the peak disposal rate must be considered.

Improvements to risk assessment procedures

At the height of the FMD epidemic large numbers of locations were put forward by MAFF and the Army as potential burial sites and these had to be rapidly assessed by the Agency via risk screening. In the event only a small proportion of the assessed sites were used and it appears that a proportion of the assessment work proved to be wasted. Any efforts to filter out undesirable sites in advance by the provision of risk maps for given types of activity or identify potentially suitable sites for given loadings (for example, via incorporation of emergency carcass disposal into farm waste management plans) would substantially reduce the workload during an emergency situation.

During the epidemic it proved difficult to undertake site-specific generic risk assessments (the second risk assessment tier) due to a lack of reliable source term and site data. Staff could not access farms easily due to the disease risk, so much reliance was based on assessment criteria. The collation of source term data gained from the epidemic and research on selected sites should enable generic assessments to be conducted for likely combinations of loadings and hydrogeological situations. This type of background work and its incorporation into strategic plans will provide some underpinning science that could be relied upon during future emergency situations.

Overall assessment

It is likely that, given the degree of planning and investigation that was feasible during the height of the epidemic, there will be some issues that will arise at burial sites that will necessitate remedial/mitigation measures.

Whilst minor environmental problems have occurred and environmental monitoring continues, there are grounds for optimism in how the environmental risks have been dealt with. The epidemic resulted in substantial logistical and environmental challenges and the resources of the organisations involved in dealing with the consequences of the epidemic have been stretched. The fact that relatively few environmental incidents have occurred to date is a testament to the skills and hard work of all those involved and the precautionary approach that has been adopted during risk screening.

Planned investigations and monitoring at selected sites now provide an opportunity to assemble information that could be of benefit in dealing with any future incidents of this nature. The substantial experience gained over the epidemic must be built upon and some key lessons learnt, particularly in relation to:

- the access to and manipulation of key supporting data;
- means of reducing peak disposal rates;
- prior identification and agreement of disposal routes and provision of disposal capacity to meet the changing demands of an epidemic.

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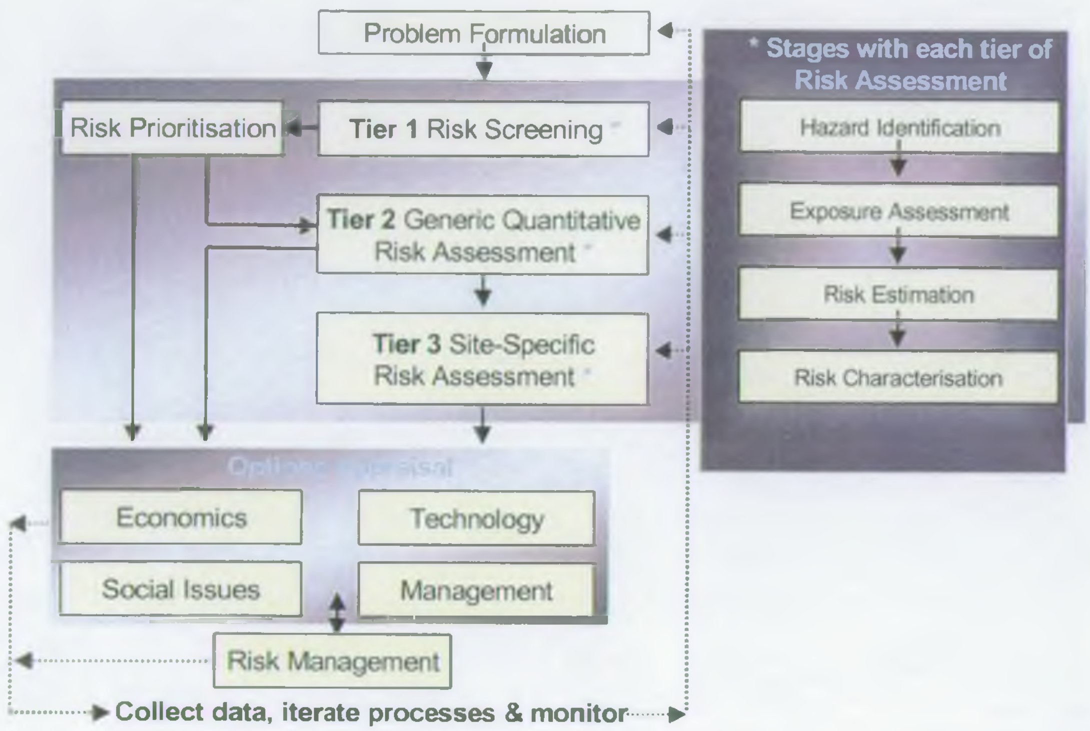

Figure 1: Framework for environmental risk assessment and management

18. THE POTENTIAL OF ARTIFICIAL TRACERS FOR AIDING GROUNDWATER PROTECTION AND RISK ASSESSMENT

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ABSTRACT

Direct evidence of the hazards and risks of contamination in Public Water Supplies can be provided *a posteriori* by actual contamination events, or *a priori* by tracer tests. For obvious reasons, the latter are a better method than the former, but depend upon there being a widespread acceptance of tracer techniques in PWS. The paper considers the acceptability of different tracer categories in terms of their harmlessness, their removability from raw water by treatment, and their occurrence as natural substances. Modern analytical methods in gas chromatography and mass spectrometry are creating new possibilities of using stable isotope signatures as tracers in substances, which are present naturally in raw waters. These possibilities have the potential to make tracer studies much more routinely acceptable than has been the case in recent decades.

INTRODUCTION: THE CASE FOR WIDER USE OF TRACERS

Scientifically based groundwater protection requires knowledge of how potential contaminants are transported into and through aquifers. Source protection requires knowledge of exact pathways, travel times and catchment areas of particular ground water abstractions. Risk assessment of a source's likelihood of contamination is normally based on models, which embody assumed mechanisms of contaminant transport and flow, which are then applied to the situation at the source of interest. Current groundwater protection and risk assessment practice, therefore, is only likely to be as valid as current models are in representing the processes which actually take place in aquifers.

This brief analysis point to two essential tools that are needed for evidence-based, practical implementation of groundwater protection policies and risk assessments. Firstly, contaminant transport models must be realistic for the aquifers concerned, and to ensure this they need to be tested and calibrated with controlled experimental data. Such data can only be acquired through tracer testing. Thus, one potential benefit of greater use of tracers would be to eliminate misleading or erroneous models and identify the simplest, most efficient transport models that will give realistic results for each of our major water-supply aquifers. The second essential tool is a data-base of values of transport parameters for each important aquifer. Such databases have recently been achieved for hydraulic properties, thanks to the routine use of pumping tests and the archiving of results over several decades, but the task of obtaining primary data has hardly been begun for transport.

HATs, RATs AND ANTs: TOWARDS ACCEPTABLE TRACERS IN PUBLIC WATER SUPPLIES.

Only when a large number of measurements have been made of the transport parameters of realistic models can genuine risk assessments using a Bayesian approach be undertaken. Much risk assessment at present is little more than the propagation of uncertainties that are guessed by the assessor. The only way to acquire high quality data on transport parameters such as effective porosity, dispersivity, or double porosity characteristics is by tracer testing under controlled conditions.

Though the desirability of tracer testing is not in doubt in principle, in practice tracer work is hampered by the need to use substances that are acceptable in ground waters which may be used for drinking, and that are also quantitatively recoverable so that they can be used for accurate measurement of transport parameters.

The history of artificial tracers in British hydrogeology was reviewed fairly comprehensively by Atkinson and Smart (1981). The Environment Agency and British Geological Survey collaborated in a more recent review and development of guidelines for tracer use, including a protocol for assessing the impact of a proposed test on abstractions for water supplies (Ward *et al.* 1998). The most widely used tracers in Britain currently are fluorescent dyes and bacteriophage. The most popular and useful dyes are Fluorescein, Rhodamine WT and the optical brightener Photine C. The properties of these dyes were comprehensively reviewed by the Water Research Centre in the 1980s (Ward *et al.* 1998 and references therein), and guideline limits for transient maximum concentrations in raw waters in Public Water Supplies (PWS) were suggested as 10 ppb, 10 ppb and 30 ppb respectively. It was noted however, that the use of Rhodamine WT in drinking water supplies should be avoided whenever possible. The fluorescent dyes have the advantage that they can be measured quantitatively, and so are useful in studies where a mass balance of tracer is required.

The tracers most often used in PWS in Britain are bacteriophages. These are viruses whose only hosts are specific strains of bacteria, and as a result they present no hazard to human or animal health. They are readily identifiable by means of their ability to infect cultures of their host bacteria, and their concentrations in water can be estimated semi-quantitatively. Though highly detectable, they are subject to sorption, degradation and die-off in aquifers, and are not suitable for mass balance studies.

There is thus a need for new tracers, which are acceptable in PWS raw waters and have characteristics that make them potentially useful in characterising solute and particulate transport. Potential tracers may be grouped under three headings:

- *Harmless Artificial Tracers ("HATs")*
- *Removable Artificial Tracers ("RATs")*
- *Added Natural Tracers ("ANTs")*

Some overlap exists between these categories, which are described below.

HATs

These are substances, which are essentially harmless and are acceptable in Public Water Supplies. Bacteriophages are the most widely used. All three fluorescent dyes listed above have been used in tracer tests targetted on PWS, but their acceptability varies depending upon circumstances. Photine C is the most widely acceptable, but has the disadvantage of frequently high natural fluorescence being present in raw groundwater as a background, limiting the concentrations that can be detected. *Lycopodium* spores have been used as particulate tracers in the past, but have the disadvantage that they are slightly denser than water and so tend to sink in laminar groundwater flows. A new possibility is to use polymer microspheres as particulate tracers (Ward *et al.* 1997).

New developments among tracers that could be regarded as HATs include helium and krypton, which are inert gases. These meet the requirements for quantitative tracers, but their gaseous state gives rise to complications in both injection and sampling, and both are still in the experimental stage. Other substances with potential for use as HATs include the widely used chlorofluorocarbons CFC11 and CFC12 which are present in the atmosphere and are still in use as propellants for medicinal inhalers. Such low amounts can be detected in water by gas chromatography that the concentrations of these tracers in groundwater need only be raised to levels a few times higher than are found in surface waters that are in equilibrium with the global atmosphere.

RATs

These are tracer substances, which, although they may be safe at the concentrations used, are for some reason undesirable additives to drinking water. If such a substance can be removed during water treatment, it may be classified as a RAT. Volatile substances can potentially be removed by aeration, while wide ranges of compounds are treated in some PWS by sorption on activated carbon. Where such steps are part of the natural treatment process, there is potential for using RATs.

Volatile substances with potential as RATs include other unreactive halocarbons such as CFC113. Sulphur hexafluoride has also been proposed as a groundwater tracer.

ANTs

An essential feature of both HATs and RATs is that the amount of each tracer occurring naturally in groundwater should be very low or zero. This is needed to ensure that the tracer does not become confused with a naturally occurring background of the same substance. The problem of high background besets what is perhaps the most commonly used tracer, common salt, because chloride concentrations in groundwaters are usually in the range 10-50 ppm, making it necessary to use very large amounts. Results can be ambiguous or difficult to interpret because the test may raise chloride concentrations only 10% or so above their background levels.

This problem can potentially be circumvented by using substances as tracers that are present naturally in groundwater, but distinguishing them from the natural background in some way. The method with the greatest potential is to use an element with a distinctive isotopic composition. The only such tracer that has been widely used to date is deuterated water, in which the hydrogen component of the water molecule is enriched with deuterium. However, a new generation of plasma source mass spectrometers has the potential to make precise isotope measurements on a wide range of elements, following relatively simple preparation from water samples. This raises the possibility of using naturally occurring constituents such as chloride, bromide, strontium or sulphate as tracers. The stable isotopic composition of the tracer must be quite distinct from that of the naturally occurring species in the groundwaters being studied. Once introduced, the tracer may be detected by its perturbation of the isotopic composition in sampled waters, while the total concentration of substance may be measured accurately by isotope dilution. It is thus possible to measure the concentration of tracer against a fluctuating background of natural substance, provided that the isotopic composition of the natural substance remains constant during the experiment.

This method has great potential. Calculations suggest that detectability could be around 10 ppb for tracer strontium, for example, which would make quantitative experiments possible without raising the strontium content of many groundwaters beyond the limits of the natural range. The drawback is likely to be in the expense of obtaining substances with suitably distinctive isotopic composition. The most promising substance in this regard is strontium, which could in principle be extracted from seawater with an isotopic composition sufficiently different from most groundwaters.

DISCUSSION AND CONCLUSION

"HATs", "RATs" and "ANTs" are of course conceptual categories, to some extent conceived for their amusement value as well as their usefulness. However, they have the potential to stimulate thought about the acceptability of different tracer substances by provoking consideration of the circumstances under which they might be used. A tracer, which might be unacceptable in one PWS, might be a RAT in another, provided that previous work with a genuine HAT had demonstrated that maximum concentrations resulting from a certain amount injected would not exceed the capacity of treatment to remove them.

Although acceptability in PWS is an essential criterion for choosing a tracer, it is not the sole one. Suitability for the investigation in hand, and the particular questions that the tracer test is intended to address, are equally important criteria. In the context of PWS, there is often a need to create an assurance that tracer studies will not create problems for the water undertaking or its customers. Very frequently a phased approach can achieve this. In the early stages of such an approach the questions to be answered will be whether a traceable connection exists between the proposed injection point and the PWS, and if it does, what concentrations will be produced in raw water. Once affirmative answers have been obtained to these questions, it becomes possible to plan further tests in the knowledge that doseage of an as-yet unused tracer can be designed to produce a peak concentration in the PWS within acceptable limits.

HATs such as bacteriophage may be the tracer of preference for these early investigations, and can provide a rough guide to concentrations likely to be reached later by other tracers. As bacteriophage are not suitable for precise mass balance work or the derivation of transport parameters, recourse must be made in the later phases of an investigation to another HAT, a RAT, or to a suitable ANT.

Given the narrow range of tracers, which are currently routinely acceptable in PWS, there is a need for serious research to devise new methods with moderate cost. Only when this has been achieved can we expect to find that tracer testing becomes a routine, investigative technique in the same way as pumping tests. Without such routine acceptability, direct evidence-based assessment of *a priori* risks to groundwater supplies will remain a difficult, perhaps impossible task.

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19. BIOSOLIDS TO LAND THAMES WATER'S GIS BASED ASSESSMENT METHODOLOGY

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INTRODUCTION

Terra EcoSystems (TES) is the biosolids recycling division of Thames Water Utilities Ltd (TWUL). Each year about 200 000 tonnes of biosolids are recycled to 15 000 ha of land to be used as a fertiliser and soil conditioner for agriculture; some is also used by gardeners and horticulturists.

Before 1998, when the ban on sea disposal came into effect, TES recycled approximately 40% of the sludge produced with the remaining 60% going to sea disposal. Since 1998, this has increase to about 60% with some 40% incinerated with energy recovery.

TES use a permit system to ensure all the necessary regulatory and environmental conditions are met before recycling sludge to land. This includes consideration of the metals concentrations in the soil, so as to prevent a build up in any area, and proximity to public supply boreholes. The metals content of the soil must be analysed before biosolids treatment and is only allowed if the concentration for each metal in the Sludge (Use in Agricultural) Regulations 1989 is not exceeded.

To ensure that the risk of groundwater and surface water contamination by biosolids is minimal, TES consult TWUL's Water Resources Group on the potential impact on each farm or set of fields involved. It is the task of Water Resources to assess if the biosolids application can be allowed without affecting groundwater quality. Consultations are undertaken by Water Resources, as part of the permit system, on any intended land that lies within a groundwater abstraction source protection zone. Land used outside these zones is not generally referred to Water Resources unless a general consultation for an area is required. On average, about 150 consultations are submitted to Water Resources by TES every year, and it is likely that this number will increase in the future.

The consultation work by Water Resources for TES is coincident with advice available from the Environment Agency (EA) and is based on the results of discussion with, and guidance from, the Agency. When the system was originally established, the EA were directly involved in the procedure with consultations being sent first to Water Resources and then, if considered feasible, to the EA. The EA undertook the assessment, returned it to Water Resources who forwarded the result to TES. This methodology was not very satisfactory, mainly due to the time taken to send information from one team to another and due to delays occurring if either team's staff were unavailable. The assessment time was frequently in excess of two weeks, which caused delays to TES. Consequently, Water Resources has built its own methodology to assess each consultation both within and, increasingly, outside the TWUL operational area with an assessment returned to TES usually within 2 working days. This methodology uses a GIS called ThamesView to facilitate data management using electronic format for all information wherever feasible.

BACKGROUND

Legislation and EA Policy and Practice

The risk of groundwater and surface water contamination is determined by the chemical and microbiological quality of the biosolids, the rate, timing and method of application and the groundwater vulnerability. The soils and the geological strata which cover an aquifer, as well as the actual aquifer material, might give some protection from the contaminants in the biosolids by attenuation. Thus a detailed knowledge of the geological conditions is vital in the assessment. Standard geological data at 1:50 000 scale is used for this but at the moment it is not in digitised format.

The Environmental Protection Act (1990) and the Water Resources Act (1991) are the legislative framework for environmental protection and the management of water resources, while the Waste Management Licensing Regulations (1994) define which categories of wastes are either controlled or exempt. The use of Biosolids on land for agricultural use is exempt from the Waste Management Licensing Regulations (1994) but is controlled by the Sludge (Use in Agricultural) Regulations 1989.

Within this regulatory framework, the EA has the following statement (E.3) in its document *Policy and Practice for the Protection of Groundwater* (Environment Agency 1998):

"The Environment Agency will liaise with sewerage undertakers and recipient farmers over the disposal of sewage sludge to land. It will seek to influence the location, quantity and timing of application in order to prevent pollution of water resources"

This statement has been clarified in Matrix 2 of that EA document such that there should be no application of biosolids to land in Zone I but that within Zones II and III there is a need to evaluate each case. This evaluation should consider the geology, the soil and the nature, timing and loading of the application. Any Nitrate Vulnerable Zones in the area are identified by TES before the consultation is sent to Water Resources and any stockpiling of biosolids for application is notified to the EA directly by TES.

METHODOLOGY

General Considerations

Groundwater is, generally, of good quality requiring little treatment before use. If the aquifer is contaminated, however, remediation can be slow and difficult due to the slow movement of groundwater in the aquifer and the large storage available in many aquifers. Contaminated aquifers, therefore, can be unusable for many decades with remediation being very costly and causing a considerable loss of resource which must be found elsewhere.

The factors which affect the vulnerability of an aquifer to contamination are:

- the nature of the soil
- whether the aquifer is confined and the nature of that confining layer (e.g. clay or gravel)
- the nature of the aquifer (e.g. fissured Chalk or sandstone)

- the thickness of the unsaturated zone where the aquifer is unconfined.

Obviously, where the aquifer is unconfined it is more vulnerable to contamination than where it is confined. A drift cover of Boulder Clay is more effective at reducing downward migration of water that an alluvial sand or gravel. An aquifer with a shallow (i.e. less than 5 m) water table is also more at risk than one where it is tens of meters below ground level.

Where a groundwater source or borehole is at risk, the distance of the source from the contamination is also critical. To evaluate this risk each major or significant licensed groundwater borehole has 3 source protection zones (SPZ) where zone I is the inner, zone II the outer and zone III the total catchment to that borehole.

Zone I delineates a travel time of 50 days from the water table to the borehole and is a minimum of 50 m in radius, zone II defines the 400 day travel time (i.e. about one year) and zone III is the total groundwater catchment area from which all groundwater will eventually flow to the source. The size and form of these zones is determined by the hydrogeological characteristics of the aquifer (e.g. storage and transmissivity), the quantity of natural recharge and the yield of the borehole source. The rationale and definition of these zones is given in detail by the EA (1998) and have been calculated using steady-state groundwater modelling (NRA 1995 and EA 1996) although there have been several revisions since that date.

Outline Methodology

The methodology involves three organizations: the Environment Agency (EA), Terra EcoSystems (TES) and the Water Resources (WR) Group of TWUL. TES liaise with the farmer to find suitable fields for use and after the required evaluation by TES, selected fields are assessed by Water Resources. The WR team evaluate each of the fields using *a hydrogeological risk assessment* methodology and send comments directly back to TES. The work by the Water Resource team, therefore, is thus one stage in the evaluation of suitable areas, as other environmental considerations (e.g. heavy metal loadings or locations of an NVZ) have already been considered by TES before they send it to WR.

The information given in writing by TES to WR is as follows:
- the farm name, NGR and TES farm code number

- the fields to be used and the dates they are to be available for use

- the biosolid material to be used, the method and rate of application

An EXCEL spreadsheet is used to record each consultation as it is received assigning it a unique consecutive number.

Due to the need for a fast decision by TES, the EA are only consulted by WR if there is some uncertainty with the source zone information or if that information is not available on the ThamesView system. The EA is also consulted if there are other factors which are unusual and need confirmation. Where a farm is in a nitrate vulnerable zone (NVZ), TES will notify WR and will reduce the loading accordingly before the consultation is sent. The decision to notify the EA is taken by the WR team when the consultation is received; the urgency of the Consultation by TES is also a vital consideration.

As the quantity of biosolids generated increases, the land area needed also increases and it has, therefore, been necessary for TES to seek farms outside of the TWUL area (i.e. into other EA Regions). At first, all consultations in areas outside the TWUL sewerage area were sent to the Regional EA, as the source zones and site information was not available to WR. However, as most of the data required by the GIS is now available electronically and an increasing number of consultations are now managed by WR, consultations are only sent to the EA when this information is not available or where there is a need for discussion on the consultation.

Use of Flowcharts in the Assessment Methodology

This methodology is shown diagramatically in two flowcharts which details the actions of the three organizations involved in the methodology. These both ensure that the criteria for assessment are both visible and consistent, and that the methodology can be understood by anyone in the WR team working on a consultation. This is useful in demonstrating the methodology to an external organization or individual (e.g. farmer).

Flowchart 1 - First Assessment and Involvement of the EA

The first stage is to determine if the farm or fields involved are within the TWUL area or if the farm details are on the GIS. If they are not, the consultation is sent directly to the EA for their advice and comment. If the EA have any uncertainties these are resolved and the result of the EA's consultation is forwarded to TES when received by the WR team. The methodology allows for an iterative assessment but this is rarely used. This is summarized in the overview Flowchart 1 shown in Figure 1.

If the area of interest is in the TWUL area or details of it are available on the GIS, Flowchart 2, the evaluation by Groundwater Resources, is initiated.

Flowchart 2 - Evaluation by Groundwater Resources

The EXCEL spreadsheet is consulted to determine if there have been any earlier consultations. Thus, if the fields or farm has already been consulted on and, subject to the consultation conditions being unchanged, there is no need to activate the methodology and the consultation can be returned directly to TES.

If there is no zonal information for the area of interest then that must be sought from the EA or advice taken from the EA on how to assess the consultation. Existing older zonal information can be used or an estimate made of the zone but this is unlikely as, increasingly, all the major groundwater sources now have full zonal data. However, if there is any uncertainty, the consultation is sent to the EA.

Where there is source zone information on the GIS for the farm or fields involved in the consultation the methodology assesses each area in turn asking the following questions as shown in Flowchart 2.

Question One - Are fields in Zones I, II or III?

If the field or fields concerned are within zone III then consent to use biosolids on that field is granted and if they are located within zone I, consent is refused. Some fields are large enough to be divided into smaller areas. In the cases where a field straddles a zonal boundary, each sub-field is considered on its location.

Where a field is within zone II, the second question must be asked.

Question Two - What are the geological conditions - unconfined or confined?

If the aquifer conditions are confined or it is assumed that the groundwater is safe from surface contamination, the field can be used. Where there is no confining cover Water Resources would advise that the field is not but allowed during the growing season if there is some alluvial sand or gravel which it is considered will give some limited retardation to any surface contamination during the summer months.

Alternatively, the loading rate or the nature of the biosolid could be changed, to reduce the contaminant loading; as in question 3.

Question Three - What is the time, method and rate of use of biosolids on each land area to be assessed?

This is more a subjective assessment and requires further consideration according to the conditions at the site. However, it is generally considered that a reduction in the rate to be used would best reduce the contaminant loading.

The methodology is designed to be objective, although it is understood that the view in differing EA areas could lead to some confusion or uncertainty. It must be remembered too that a refusal to use biosolids on the land would often result in the farmer using other forms of fertilizer which might also be a risk to groundwater quality.

THAMES WATER'S GIS SYSTEM

ThamesView is a Windows GIS based on the Geodysis system 'StruMap' for use by Thames Water. Data exchange can be in a variety of formats and it will work with a number of other databases. The user can zoom and move around readily which is very useful when looking at the various data sets such as field boundaries. The version used by Water Resources is a limited one and is designed as a 'read only' system. TES managers have a fuller version allowing new fields to be included. The software is located on the hard drive along with the zonal information, while farm data is retrieved from a remote server using the Local Area Network and CDs are used for the OS base map. At the moment geological information is not digitized and so can only be viewed on the standard 1:50 000 base map identified by the NGR.

In 1999 the Source Protection Zones were available electronically from the EA's Groundwater Centre and so by 2000 they were being used in the GIS system based on Thames Water's own system ThamesView.

Stage II of the system will be to investigate the inclusion of digitised geological data as a layer of information, most likely located on an internal TWUL shared drive. This is currently being investigated but is limited by the existing IT which is now being reviewed.

A field and its location can be easily found knowing the farm code and the OS base allows the surface features (including streams) to be identified. The GIS enables the user to view each field that is available for biosolids on an OS 1:50 000 base and shows the exact location of the zonal boundaries on that farm. Its location within zones I, II or III can, therefore, be readily determined and its suitability for biosolid use assessed once the geology is known. The use of the GIS makes the methodology fast and accurate to use and should be even more efficient once geological data is also on the system.

CONCLUSIONS AND RECOMMENDATIONS

The methodology for assessing the suitability of fields or farms for biosolids is detailed and requires a number of data sets, most of which are available electronically on a GIS system known as ThamesView.

The use of GIS enables consultations from TES to be assessed effectively 2 working days, efficiently and accurately by Water Resources. The results of the assessments are, obviously, limited by data availability. In these instances, or when there are other uncertainties, the Environment Agency's regional office is consulted; this, however, can take at least a week and is subject to the workloads at the EA.

The methodology is visible and can be used by different members of Water Resources. The only area of subjectivity in the Water Resource evaluation is where a field is sited on an unconfined within SPZ II. In this case, the understanding of geological data here is crucial and, hence, hydrogeological knowledge is required.

It is recommended that digitized geological data be included in the system as and when the IT is available.

As further suitable farm land for recycling biosolids is sought the data required for assessment can readily be revised or brought into the GIS database.

ACKNOWLEDGMENTS

The author would like to thank the following TWUL colleagues; Dr Michael Jones, Dr Brian Crathorne and Richard Hewison for their comments and advice. The author would also like to thank the Environment Agency for useful comment on the methodology.

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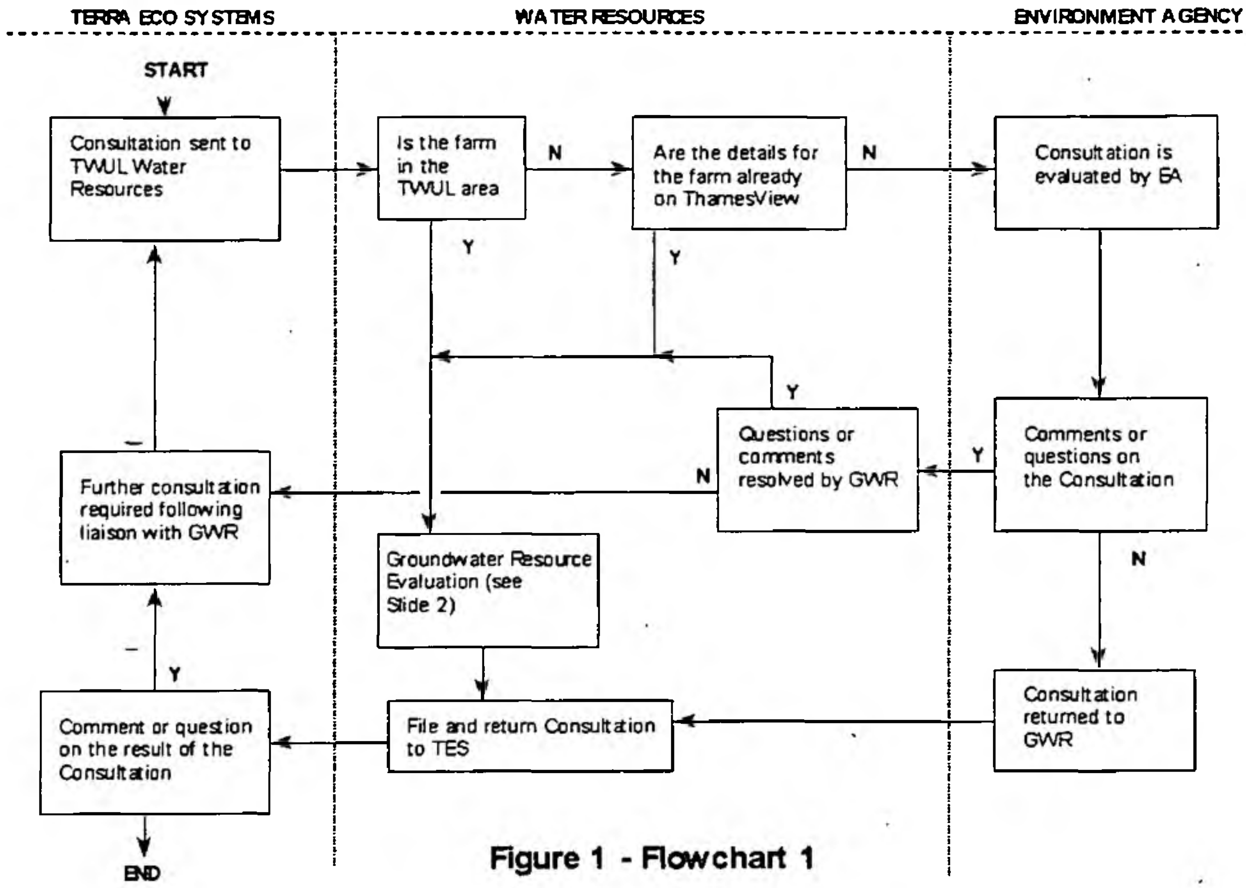

Figure 1 - Flowchart 1

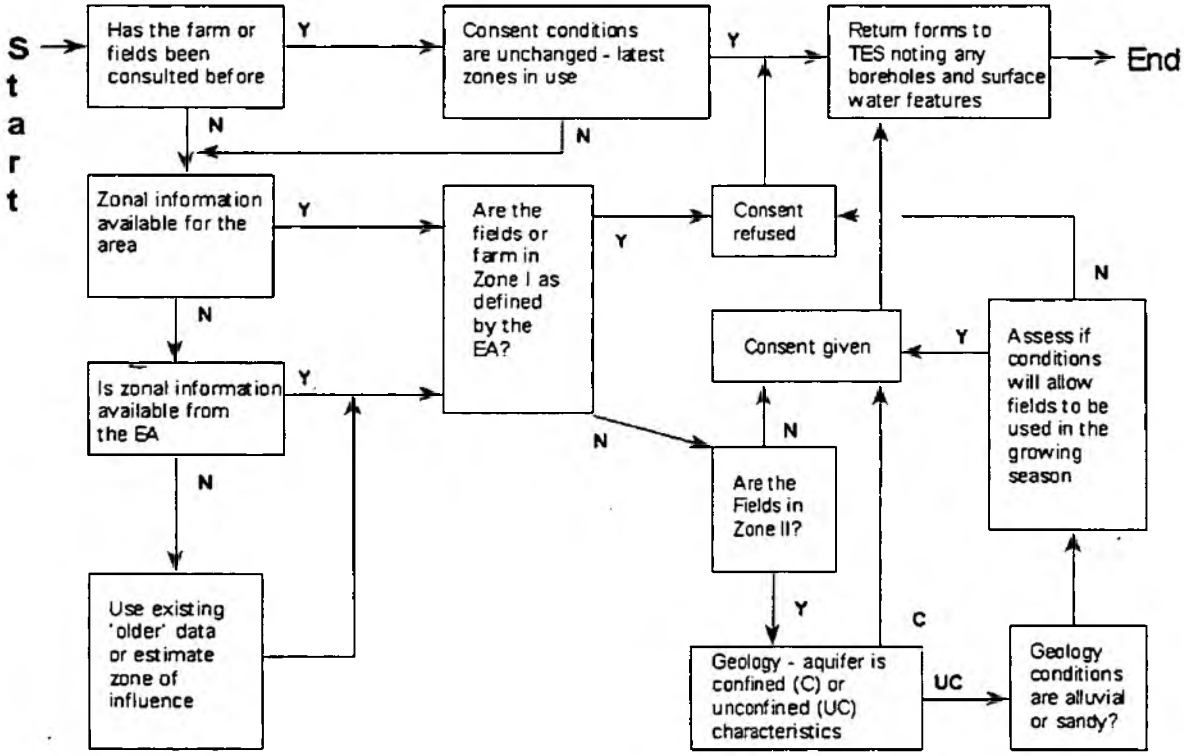

Figure 2 - Flowchart 2

20. GROUNDWATER ABSTRACTION POLLUTION RISK ASSESSMENT METHODOLOGY

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ABSTRACT

A groundwater pollution risk assessment methodology has been developed in order to quantify the vulnerability of groundwater abstraction sources to the risk of pollution. This can be used to rank, justify and implement any required risk management or mitigation procedures. In turn this will facilitate the prioritisation of investment in groundwater assets.

A hierarchical approach was chosen to allow the risk assessment to be successfully carried out with variable quality data and to permit locally detailed knowledge to be incorporated in a robust manner. The risk assessment considers the three components of the pollution model; pollutant source, transport pathway and receptor. For groundwater abstractions, which are the principle concern of water supply companies, these correspond to land use (and associated potential pollutants), aquifer characteristics and the abstraction borehole.

The groundwater abstraction catchment forms the spatial limit of a comprehensive land use audit, which forms the basis for the risk assessment. A land use pollutant risk factor, derived from the risk posed by individual hazards at each land use, has been developed and tested so that reasonable and repeatable scores of risk and uncertainty can be applied to each land use type (potential pollution source) within a catchment. In addition an uncertainty factor is applied to each risk to allow for unknowns in the assessment of the risk scores.

Risk and uncertainty scores are also applied to components of the pollutant pathway and the receptor (abstraction point), which permit direct comparison of the relative risk posed to different abstraction points. While the risk scores relate directly to the perception of risk within a borehole catchment, the uncertainty scores provide a guide to the state of knowledge and the accuracy of the data used to compile the risk assessment. In cases where there are both high risk and high uncertainty scores, the uncertainty score can be reduced by appropriate collection and validation of additional data, allowing refinement of the risk.

The pollution risk assessment at each site should be calibrated by means of the known water quality history of the natural groundwater at the abstraction point. The critical sites are those where there is a high risk or uncertainty score or where there is a mismatch between the risk assessment score and the known water quality history.

INTRODUCTION

Risk Assessment is now a common tool in many business activities. In most cases, the risk considered is purely a financial one, applied to specific business tasks. Because pollution of groundwater has very significant technical and long-term financial implications, it is increasingly necessary to try to quantify the risks of this occurring.

The difficulty in defining robust parameters to describe a hydrogeological situation is well known to groundwater specialists. Every method, however mathematical, is an approximation of the system being studied. Risk assessment adds another layer of uncertainty because it frequently deals with factors, which cannot be or have not been measured.

This paper describes a method of pollution risk assessment for water supplies from groundwater abstractions. The method was conceived under a 1999 R&D programme (GUP, 1999) conducted by Vivendi Water Partnership (VWP). VWP is an UK-based company that provides scientific and engineering services to three Vivendi water supply companies in the UK. The aim has been to focus on the receptor rather than the source of pollution, which is the focus of most pollution risk approaches. The methodology has been trialed in year 2000 on a variety of groundwater abstraction sites to test the validity of the different components of the assessment.

DEFINITIONS

In the context of this paper, since we are only interested in the narrow area of damage to water company assets, we have used specific definitions as follows

Risk Assessment – the methodical process of identification and quantification of threats to the operations of an organisation.

Pollution – an unacceptable water quality constituent resulting from natural or anthropogenic processes.

Groundwater Pollution Risk Assessment (PRA) - the risk to a groundwater abstraction resource of deterioration in raw water quality resulting from pollution.

The risk of supplying contaminated water to a customer is considered to be the subject of a separate risk assessment process, involving the treatment and distribution network, and is not considered further in this paper.

DESCRIPTION OF THE METHODOLOGY

The *source – pathway – receptor* model (LPC 1997) has been adopted as the logical basis for a groundwater PRA and is illustrated in Figure 1. The *source* is the land use from which a known or potential pollutant originates; the *pathway* is the route (within the aquifer) that the pollutant takes between the source and the receptor; and the *receptor* is the point of raw water abstraction (usually a borehole). A similar modification of this model has been adopted by others (Morris *et al.* 2000).

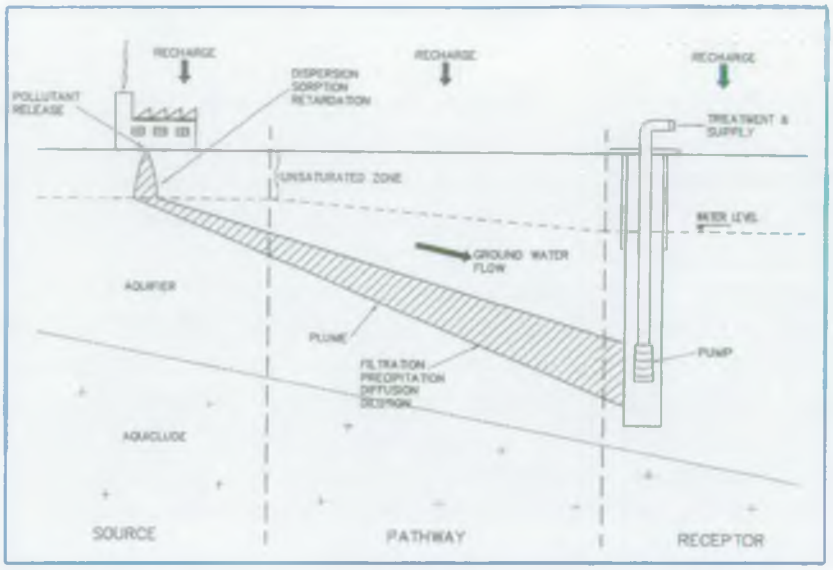

Figure 1 Schematic groundwater pollution transport model

Owing to a lack of data, it is often difficult to maintain consistency between PRA's performed on different parts of the same model or at different sites. To combat this, the PRA methodology has been organised into a multilevel, hierarchical structure, as shown in Figure 2 below.

This hierarchy allows the analysis of factors affecting each component of the PRA model and the allocation of individual risk scores to be conducted separately. The source, pathway and receptor are shown as Landuse, Aquifer and Borehole respectively under level 2 on Figure 2.

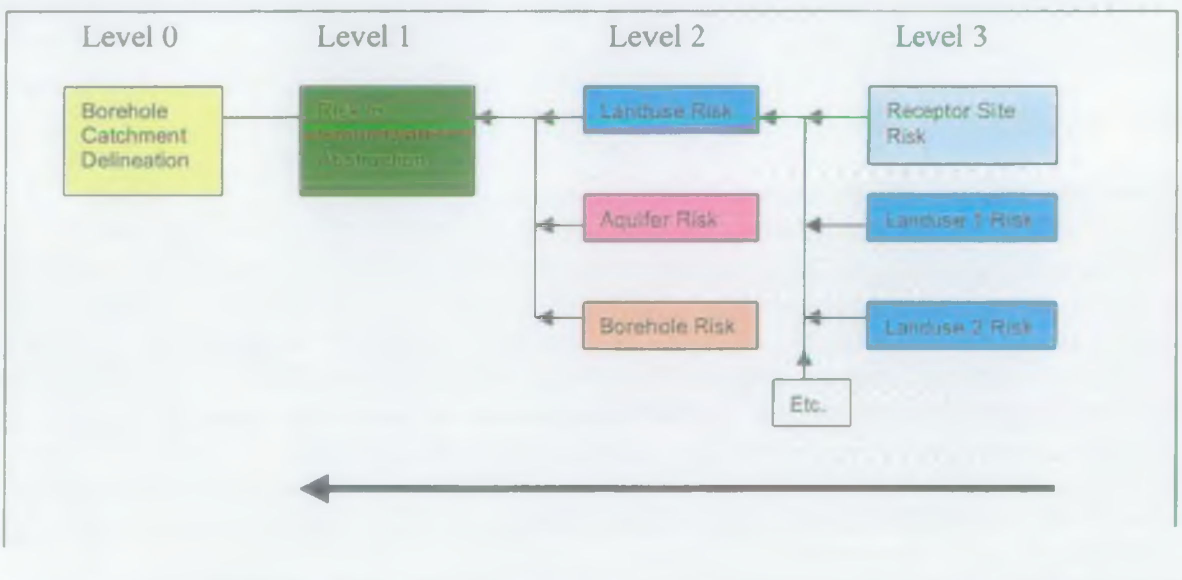

Figure 2 Pollution risk assessment hierarchy

The assessment should be performed from the right to the left, i.e. from the most detailed level (Level 3) first. The score from each level then feeds values into the level above to achieve an overall PRA score for the groundwater abstraction. Standard risk assessment proformas have been prepared for each level of the PRA to ensure that all the appropriate factors are considered.

The groundwater abstraction catchment [Environment Agency 1998] forms the spatial limit of a comprehensive landuse (pollution source) audit and is the prerequisite for a PRA to be carried out. Each of the individual land uses in the catchment, including the receptor land use, may be associated with a selection of potential pollutants. Pollutant types, their toxicity, persistence and transport characteristics, are analysed under Level 3 of the hierarchy. A simplified equation has been used to aggregate these attributes with those of the surrounding environment to provide a pollution risk factor for each potential pollutant at a site. These are then summed to produce an overall score for that site. The individual site land use assessment scores are then carried through to Level 2 to provide the overall Landuse Risk score.

The Aquifer (pathway) Risk in Level 2 incorporates the aquifer type and flow mechanism, as well as specific parameters that may have been derived from pumping test data.

The Borehole (receptor) Risk in Level 2 deals with parameters affecting the integrity of the borehole. These include the date and type of construction, the condition of the headworks, the depth and condition of the borehole casing, the condition of the sanitary seal and specific site characteristics such as vulnerability to flooding.

The risk scores from the individual components of Level 2 are finally carried through to Level 1 to provide the overall risk score for the abstraction site.

DATA COLLECTION

The land use audit and categorisation of potential pollutants is the most data intensive part of the risk assessment. After initial searches have been done using public map data and commercial databases, a ground truth exercise is undertaken comprising a visual catchment survey and headworks inspection. This may then be followed by site-specific questionnaires and/or visits depending upon the results of the preceding data collection.

The data used for the VWP groundwater PRA's came from a variety of sources. These included environmental agencies, local authorities and commercial databases, which were used to identify current, and historic land uses. Information on the pathway characteristics was found in geological texts, such as Aquifer Properties Manuals [BGS 1997] and internal aquifer pumping test reports. These reports also contained information on historic groundwater quality. Receptor data sources for the pilot work conducted by VWP included headworks inspections, downhole inspections, Remote Operated Vehicle (ROV) surveys, pumping station or wellfield operations manuals and local knowledge. It was found that the receptor characteristics were the easiest to define and had the least amount of uncertainty. A selection of source, pathway and receptor data sources are summarised in the table below.

Table 1 PRA data origins and applications

Landuse Risk (Source)	
Data Used	Origin of Data
Catchment Definition	Environment Agency
Potential Pollutants	Visual Catchment Survey
Contaminated Land	Local Authorities
Landfills	Local Authorities, Commercial Databases
Historic Landuse	Commercial Databases
Fuel Stations	Petroleum Licensing Authority
Waste Stations	Environment Agency
Pollution Incidents	Environment Agency
Aquifer Risk (Pathway)	
Data Used	Origin of Data
Regional and Local Geology	Geological Survey
Aquifer Type	Geological Survey
Regional Aquifer Parameters	Geological Survey, Aquifer Properties Manuals
Piezometry	Geological Survey, Groundwater Models, Pumping Test Reports,
Local Aquifer Parameters	Pumping Test Reports, Critical Yield Analyses
Borehole Risk (Receptor)	
Data Used	Origin of Data
Borehole Protection	Headworks Inspection
Casing Integrity	Downhole CCTV Inspection
Borehole Integrity	Downhole CCTV Inspection
Receptor Landuse	Station Manual and Visual Survey
	Geological Survey, Station Manual
Additional Boreholes	Local Knowledge
	ROV Survey
Flood Potential	
Adit Geometry and Condition	

It is recognised that the most important aspect of the PRA is the survey of the borehole itself and potential pollution factors in the immediate vicinity. As a result a borehole headworks inspection procedure has been developed allowing a risk score to be assigned. Figure 3 outlines the major components of a headworks inspection.

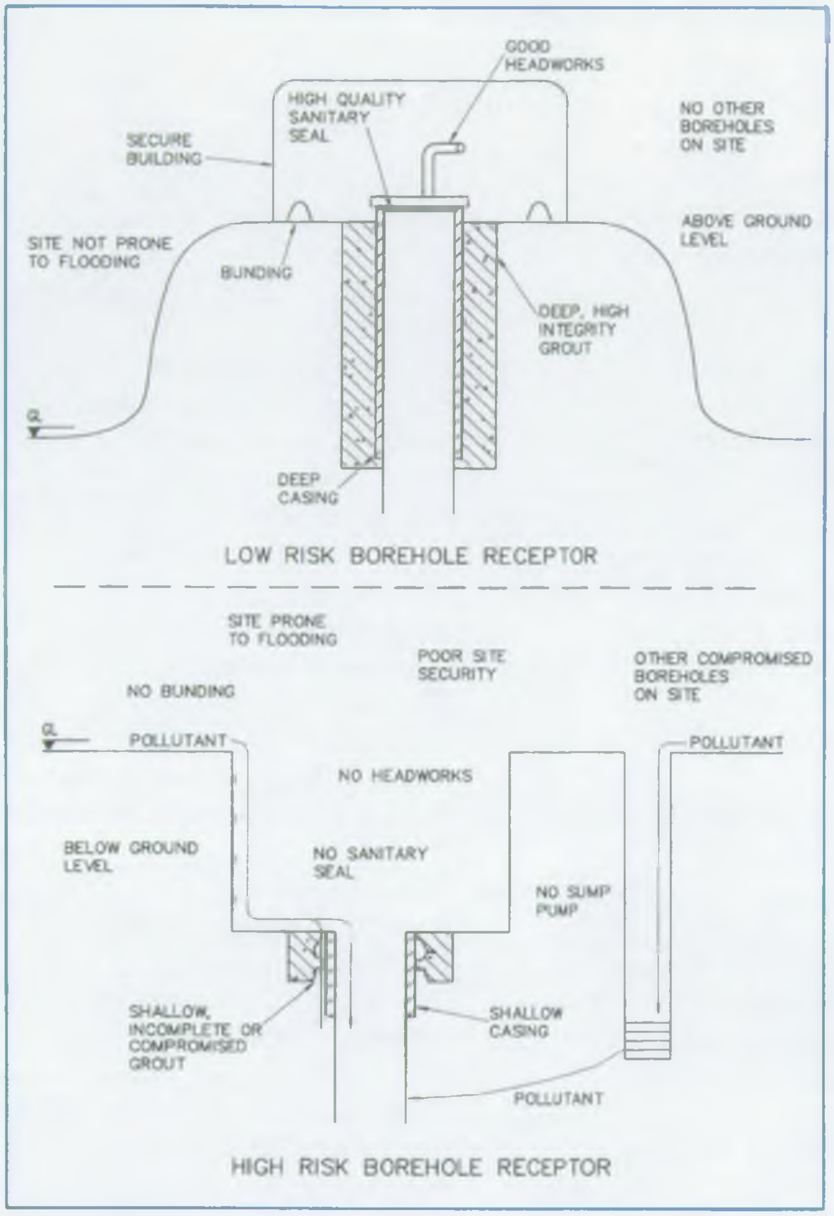

Figure 3 Headworks inspection criteria

DATA ANALYSIS

Geographical Information Systems (GIS) have been employed to display catchment characteristics, individual land uses and other attributes of the datasets. Database and spreadsheet software are being studied to assess the applicability of automatic scoring once a certain number of essential criteria have been met. This will allow the risk assessments to be rapidly updated when new data are introduced.

Current limitations encountered in the use of GIS include the differentiation between point and polygonal datasets and incompatibilities in digital file formatting. GIS has the potential to automatically calculate areas and distances from constituent datasets.

It should be noted that any risk assessment would require periodic review. This is principally to account for changes in landuse but also to progressively reduce levels of uncertainty in the risk assessment analysis. The timing of such reviews will be dependent on the updating of data sources and output from specific studies.

SCORING METHODS

Each factor considered at each level of the risk assessment attracts two types of score, a risk and an uncertainty score.

Risk Scores

The risk scores for each landuse are derived using a pollution risk factor, dependant on the nature and load of each pollutant, the distance from the receptor and the hydrological and near-surface hydrogeological factors pertaining to that site. Existing mitigation measures, such as pollution management procedures at the site are included in the scoring so as to appropriately recognise the beneficial effect such methods would have on containing any pollution event.

Risk scores for the contributing factors to the aquifer are predetermined according to independent and interacting characteristics. Risk scores for the borehole are determined on the basis of the parameters described in the data collection section. In many cases, poor data affect the reliability of the PRA at a particular site. For this reason, an uncertainty score is an integral part of the PRA.

Uncertainty Scores

An Uncertainty Score accompanies every Risk Score and is a reflection of the confidence in the data used to give the risk score. If data, values or descriptions are deemed to be accurate or precise and come from a well-maintained database then a low uncertainty score can be assigned. However if the data originates from uncorroborated or anecdotal evidence then a high uncertainty should be assigned.

Like the Risk Score, the Uncertainty Score is carried through all levels and is treated to the same weighting process so that each groundwater abstraction gets an overall PRA Uncertainty Score as well as a PRA Risk score. The purpose of the Uncertainty Score is to assist in the appropriate evaluation of the Risk Scores and the importance of the relative rank of that score as compared to those for other sites. If the overall PRA reveals a lack of confidence in the risk scoring by having a high uncertainty score then further investigations or improved data capture and archiving will need to be considered in order to reduce the level of uncertainty.

Score Weighting

The PRA for an abstraction combines an analysis of risk from geographically separated sites with a variation in relative contribution. In Level 3, a *de facto* weighting is introduced by considering the pollutant and Landuse attributes alluded to above. In Level 2 the Risk Scores may be weighted according to a predetermined distribution relating to a group of sources but independent of the PRA for a specific site. This mechanism has been established so as to ensure that the most important factors have the greatest bearing on the PRA.

As an example, in VWP companies, operational experience has demonstrated that certain types of quite serious groundwater contamination, if occurring at more than a few hundred metres from the abstraction, do not impact on the quality of the abstracted water. By contrast, severe impacts on quality can be caused by the lack of an adequate sanitary seal around the borehole, even if there is no obvious source of contamination. This experience has led to the greatest weighting being placed on the analysis of risk at the borehole. Fortunately, this is also the area about which the most data are held by the water company and where the company has the greatest power to act.

The land use scoring is difficult to show as it involves several tables for each individual land use within a single catchment. The methodology had been designed so that high scores are indicative of a greater perceived risk. Examples of the risk and uncertainty scores for the pathway and receptor are shown below.

RISK ASSESSMENT AQUIFER PATHWAY SPREADSHEET
SHEET 2.2
ABSTRACTION SITE: Site A

MAP REFERENCE 1234 5678

	DESCRIPTION	REFERENCE	RISK	UNCERTAINTY	WEIGHTING	RISK SCORE	UNCERTAINTY SCORE
Aquifer Type	shallow unconfined	Yield Database	9	0	0.25	[illegible]	0.00
Flow Mechanism	consolidated/fissures	Yield Database	7	2	0.25	1.75	0.50
Effective Porosity (%)	assume median	n/a	5	7	0.25	[illegible]	[illegible]
Hydraulic Conductivity (m/d)	assume median	n/a	5	7	[illegible]	[illegible]	[illegible]
	TOTALS		28	16	1.00	6.50	[illegible]

Figure 4 Pathway Risk and Uncertainty Scoring

RISK ASSESSMNENT BOREHOLE RECEPTOR SPREADSHEET
SHEET 2.3
ABSTRACTION SITE: Site A
Borehole: No. 1 - Production Borehole
Date of Construction:
Date of last reline/rehabilitation
MAP REFERENCE: 1234 5678

	DESCRIPTION	REFERENCE	RISK	UNCERTAINTY	WEIGHTING	RISK SCORE	UNCERTAINTY SCORE
Headworks & Protection	Poor	Inspection	9	9	0.14	1.29	1.29
Sanitary Seal	Poor	Inspection	9	9	0.14	1.29	1.29
Flood Protection	Poor	Inspection	5	1	0.14	0.71	0.14
Depth of Casing (m)	Unknown	CCTV	9	9	0.14	1.29	1.29
Casing & Grout Condition	Unknown	CCTV	7	9	0.14	1.00	1.29
Open Hole & Screen Condition	Unknown	CCTV	9	9	0.14	1.29	1.29
Adits	2 Levels	ROV Survey	9	5	0.14	1.29	0.71
	TOTALS		57	51	1.00	[illegible]	7.29

Figure 5 Receptor Risk and Uncertainty Scoring

Analysis of Scores

By inspecting the risk and uncertainty scores for a number of sites on the same graph, as shown on Figure 6, it is not only possible to quickly identify the sites that carry the highest risk, but also to identify those that would most benefit from the collection of additional data. Where a groundwater abstraction has a high risk but low uncertainty, the risks are well understood and little can be done but to instigate risk management measures. However, at a site where both the risk and the uncertainty score are high a paucity of data is indicated. At such a site, investment in data collection can lead to the reduction in both scores since a greater understanding of the actual risks posed to a site may or may not lead to a reduced risk score for those risks. A comparison of risk and uncertainty scores can be made for single pollutant types in many catchments, for multiple pollutants in a single catchment or for multiple pollutant types in many catchments.

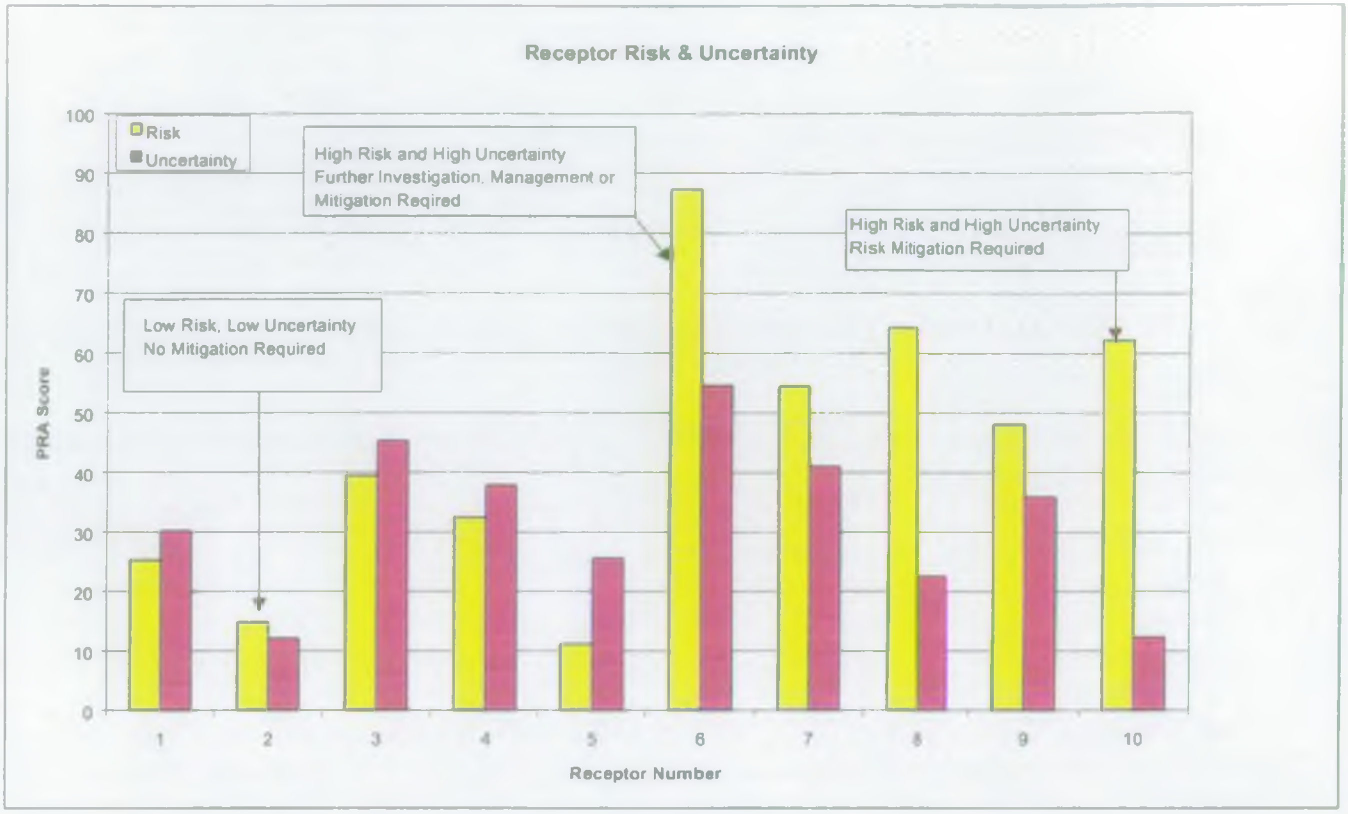

Figure 6 Comparison of Risk and Uncertainty Scores for 10 Receptors

CALIBRATION

In some cases calibration of the methodology has been conducted by comparing the water quality history of a site with the risk and uncertainty scores for that site. Groundwater abstraction catchments in urgent need of a review are those where there is a mismatch between the historic water quality and the risk score, particularly if the uncertainty is high.

CONCLUSIONS

Available risk assessment techniques appear to be focussed on pollutant sources. This methodology focuses on the receptor.

A systematic and auditable approach has been developed to analyse the risk of raw water quality deterioration of groundwater sources. The proposed framework is capable of utilising datasets at varying levels of detail so that sources with varying amounts of data can be ranked simultaneously using a parallel uncertainty scoring system.

Minimum data requirements should be set, principally involving validation of the catchment area. There is a potential to refine the methodology to target risks from specific classes of pollutants in line with available treatment technologies e.g. *Cryptosporidium* and *Giardia*.

The calibration to raw water quality data is proposed to validate existing or establish new risk mitigation measures.

Pilot work to date in United Kingdom has highlighted major difficulties in identifying potential pollutants from many third party land uses, even in a regulated environment. Other problems include the processing and analysis of spatial data. Where datasets have been established, significant progress had been made in the use of GIS tools.

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21. TOOLS TO DELINEATE SOURCE PROTECTION ZONES FOR BOREHOLE AND ADIT SYSTEMS

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ABSTRACT

A significant number of groundwater sources in England have adits, that is horizontal tunnels leading away from one or boreholes and shafts. We have developed a groundwater flow model which is able to simulate correctly the resulting mixture of conventional groundwater flow and pipe flow. The model uses a device called Preissmann's slot to represent the enclosed adit by an equation for open channel flow. This enables a software code called MODBRNCH to be used with very little modification; this code was originally developed for modelling river-groundwater interactions. The availability of a correct numerical model provided a way to test some of the approximate methods which had previously been used to represent adits in conventional groundwater models for the delineation of catchments and time-of-travel zones. These included a zone of high permeability along the adit, and replacement of the adit by a set of individual boreholes. The tests showed that the high permeability zone is an adequate and robust approximation, provided a sufficiently high permeability is used. Hydraulic conductivities of 10^3 - 10^6 m/d are necessary, much higher than had previously been used. The project has provided both an accurate tool for simulating adits, and validated an approximate method for ordinary use.

INTRODUCTION

The Chalk forms the most important aquifer of southern England and in many parts of north-west Europe (Downing *et al.* 1993). Many of chalk groundwater sources in England have adits, which are horizontal tunnels below the groundwater table. The adits are connected to wells from where groundwater is pumped to surface. Most adits are 1.8 m high and 1.2 m wide with arched roofs, and vary in length from 10+ to 7000 m. Their depth varies between 10 and 100 m below ground surface. A wide variety of layouts exist, from simple linear adits to patterns with radial lines, loops and branches. Figure 11 shows the layout at Cottingham near Hull, the case study presented in this paper.

Velocity measurements indicate that Reynolds numbers for flow in adits are often >2300. These values are typically of turbulent flow. Flow in an adit will be pipe flow if it is full, or open channel flow if it is partially dewatered. Flow in the aquifer remains laminar. The flow around an adit may cause a distinct three dimensional pattern of groundwater flow. Ideally, a 3-D numerical model with turbulent adit flow linked to laminar groundwater flow is required.

The current method for delineation of GPZs for adit sources in the United Kingdom is to use a numerical model and either assign a large value of hydraulic conductivity in the adit cells or to distribute the abstraction (i.e. pumping) as several wells to replace the adit (Sarah Evers, Environment Agency, personal communication). The effectiveness of these methods has never been evaluated.

The objectives of this paper are to (1) introduce a new approach for modelling aquifers containing adits, (2) illustrate it's application with a case study, and (3) discussion how adits affect the delineation of source protection zones (SPZs).

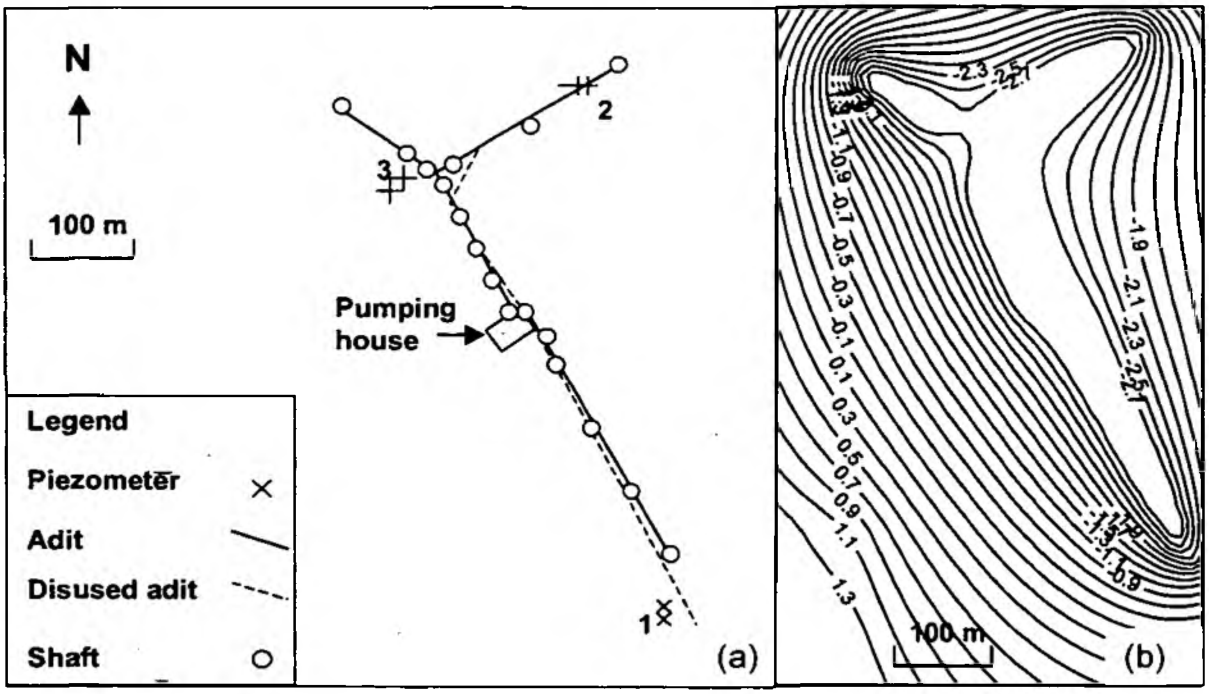


Figure 11 Cottingham adit. (a) Layout, shaft and piezometer locations (b) simulated groundwater heads immediately before pumping test.

THE NUMERICAL MODEL

Preissmann slot approach

The basic requirement for a model of adits in aquifers is that it can couple groundwater with either open channel or pipe flow. The pipe flow case can be made equivalent to open channel flow by introduction of a fictitious, narrow slot above the adit. This is called a Preissmann slot after Preissmann and Cunge (1961). The concept has been used for modelling sewers (e.g. Cunge et al. 1980), but we have not come across any previous uses in coupled groundwater - open channel flow cases.

The slot allows open channel equations to be used for all cases. If the adit is full, the calculated cross-section remains as the true conveyance cross-sectional area, because the slot is very narrow and has negligible cross sectional area. However, the elevation of the water surface in the slot enables the hydraulic head in the pressurised adit to be correctly represented. Figure 12 illustrates the fictitious slot and the model layers for the Willmington case study (Zhang and Lerner, 2000).

The coupled surface-ground water model MODBRNCH

Once the slot had been recognised as a way to simplify the coupling of the adit with the aquifer by replacing it with an open channel system, the need was to find a suitable groundwater - surface water modelling code which could be adapted. BRANCH (Schaffranek *et al.* 1981) is an USGS model widely used to simulate one-dimensional unsteady, non-uniform, multiple-branch open channel flow by solving the non-linear momentum and continuity equations of flow. MODFLOW (McDonald and Harbaugh 1988) is a widely accepted groundwater modelling code, which has a number of user-friendly pre-processors available, including Visual MODFLOW (Waterloo Hydrogeologic Inc) which was used for this study. The MODBRNCH (Swain and Wexler 1996) package incorporates BRANCH into MODFLOW. The coupling of BRANCH with MODFLOW gives a more powerful simulation capability for stream-aquifer interactions, including the routing of surface flows in a network of interconnected open channels while accounting for the effects of stream velocity and discharge. The linkage between BRANCH and MODFLOW by MOD0BRNCH is a water exchange term similar to those in the widely accepted RIVER and STREAM packages. A small modification is needed to handle the Preissmann slot in MODBRNCH. Details of the adaptation, and steady-state testing of the code for adits are given by Zhang and Lerner (2000).

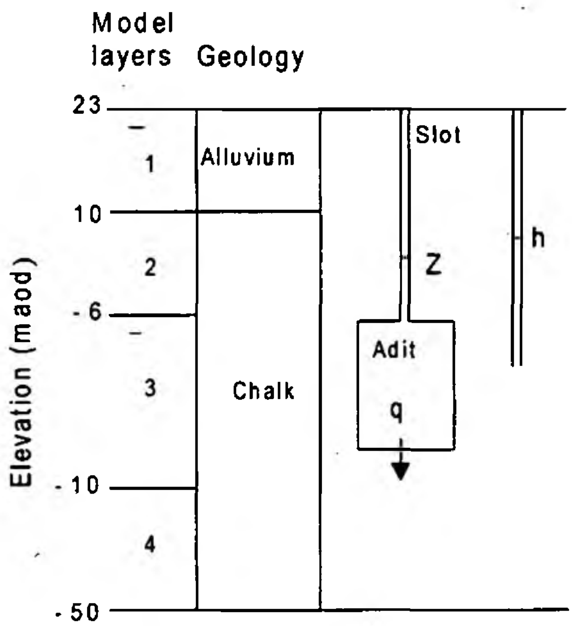


Figure 12 Schematic arrangement of adit, Preissmann slot, and model layers.

COTTINGHAM CASE STUDY

The Cottingham source is constructed in the Chalk aquifer to the north of the Humber Estuary, part of the Yorkshire Chalk (Figure 11). It is one the largest groundwater sources that Yorkshire Water Services has in the Hull area, with a licensed abstraction of 68 182 m^3 d^{-1}, and a mean actual abstraction of 24 000 m^3 d^{-1}. The Cottingham source is complex, comprising two operational pumping shafts, 17 other shafts and about 1000 m of adit in use. There is also a deeper adit which is sealed off. Like most adits in the UK, the Cottingham adit is normally full of water.

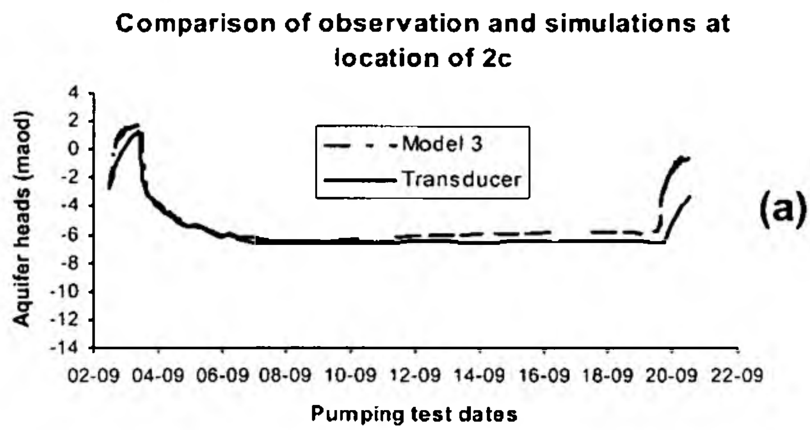
Thirteen piezometers were installed around the Cottingham source prior to a pumping test, which took place in September 1998. One was set within the adit to measure its head, and the other twelve piezometers were set up in three groups around the adit. Each group includes four piezometers located at different levels and installed in two observation boreholes. The locations of the observation boreholes are shown in Figure 11a. They provided a substantial amount of information to calibrate a model against. The pumping test consisted of a 1-day initial recovery, 16-days of constant pumping, and a 1-day final recovery.

The model grid around Cottingham was required to be sufficiently fine and three dimensional in order to specify the exact positions of adit, shafts, piezometers, and the distinct three dimensional pattern of groundwater flow caused by the adits. However the available data are not detailed enough to construct a regional multi-layer model. Telescopic Mesh Refinement (TMR)(Ward et al. 1987) was used to link the regional and local scales. The regional model was a two-dimensional MODFLOW model with an area of 550 km^2, using data from an Environment Agency model (Hodgson and Aldrick, 1996). It has one layer and is discretised as a 60 by 44 grid with a spacing of 500 m. The local model has an area of 2 by 2.5 km and is discretised on a 95 by 70 grid. The grid spacing varies from 50 m around the edge of the model to 20 m at the adit.

Although there have been several regional-scale modelling studies, there has been no previous modelling of Cottingham at a local scale. The local model calibration proved to be very difficult and we had to test several alternative conceptual models to obtain good fits for all steady state and transient head measurements for both aquifer and adit. The models were:

- The pumped water was fully supplied by the adit.
- A constant part of the inflow was contributed by the shafts.
- There was a variable ratio of shaft to adit contributions.

The first model could not match the pre-test steady state conditions. Although the second model fitted the steady state and transient conditions in the aquifer, it could not simulate heads in the adit. The third model gave the best fit (Figure 13), with an initial shaft contribution of 65% of total pumping which decreased to zero by the end of the constant pumping. Conversely, the adit contribution grew from 35% to 100%. A more comprehensive report on this case study is given by Zhang and Lerner (submitted). Overall, the study showed that adits could be successfully modelled in transient conditions, and that such modelling provided insights into the behaviour of the system which could not be obtained without the model.



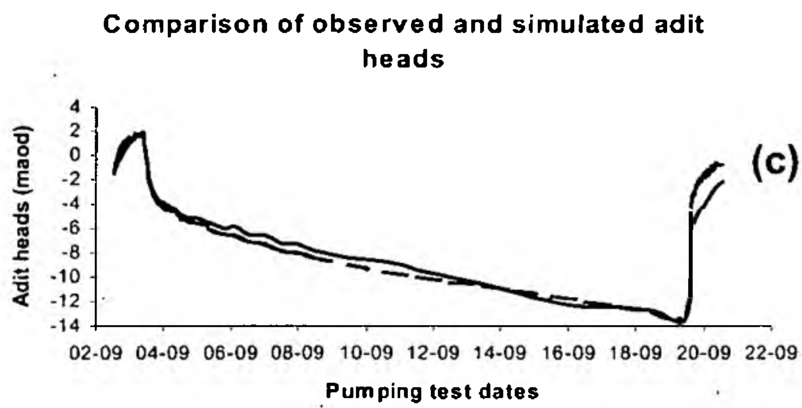


Figure 13 Calibration of the Cottingham adit model (a) typical aquifer piezometer (b) heads inside adit.

SHAPES OF SOURCE PROTECTION ZONES FOR ADITS

Groundwater protection has been focused on delineation of catchment and time-of-travel zones. However Kinzelbach et al. (1992) pointed out that restricting the largest protection zone to the actual catchment area is not sufficient. This is illustrated by the cross-section of a simulation in Figure 14, where there is a region directly above and upstream of the adit that is not in the catchment. The region between the adit and the catchment area should be protected to cover the risks of spills of dense non-aqueous liquids. Therefore the protection zone should comprise the projected flow zone (PFZ) which is defined as the projection on to the ground surface of the subsurface zone through which passes all groundwater flow to the well.

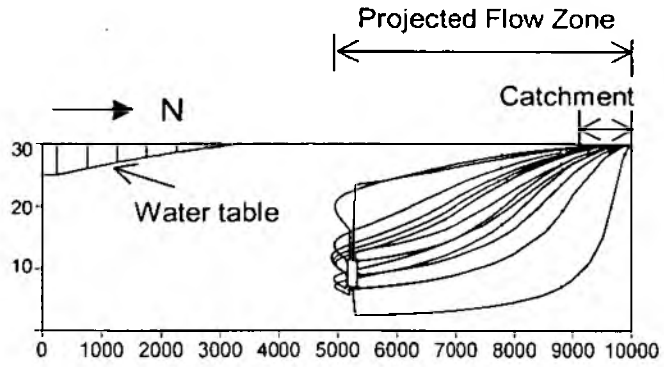


Figure 14 Cross-section showing flow towards an adit. (Adit was 1 km long and 8-10 m deep in centre of a 17x10 km x 30 m thick homogeneous and isotropic aquifer, with impervious boundaries on all sides except for a constant head boundary to the south. Recharge is 200 mm/year, abstraction is 10,000 m^3/d.)

A 17 by 10 km artificial aquifer with a thickness of 30 m has been used to illustrate the shapes of PFZs. A uniform recharge of 200 mm/year and a hydraulic conductivity of 80 m/day were used, which are common values for fissured Chalk in the UK (Zhang and Lerner, submitted). A vertically uniform value of horizontal hydraulic conductivity K_h was used so 2D and 3D models can be compared easily. 10% of K_h was used for vertical conductivity, K_v, as we found that PFZs are not sensitive to K_v. An adit with a length of 7 km was positioned at the centre of the aquifer in plan view, and parallel to its longer sides. The aquifer was discretised on a grid of 94 by 28 with a spacing of 100 m around the adit, and is divided into 4 layers. The top layer represented the Tertiary deposits, and the other 3 layers represented the Chalk aquifer. One layer was above the adit, one layer was below, and Layer 3 had the adit in it, about 20 m below the ground surface. The water was pumped from the centre of the adit.
Four types of aquifer-adit systems were simulated as shown in Figure 15a-d and described below:

a. Three impervious boundaries and a single constant-head boundary parallel to adit.
b. Three impervious boundaries and a single constant-head boundary perpendicular to adit.
c. Two impervious boundaries and two constant-head boundaries parallel to adit.
d. Two impervious boundaries and two constant-head boundaries perpendicular to adit.

In all cases, the combination of areal recharge and one or two constant head boundaries led to a curved water table. In cases (a) and (b) the regional gradient was from one side to the other. In (c) and (d) the regional gradient was away from the centre towards the two equal constant head boundaries. In all cases, gradients were modified by the effect of pumping.
The simulation results for these four systems (Figure 15) demonstrate that the shapes of PFZs for adit sources depend on the boundary conditions and the adit's orientation. For presentation purposes, most pathlines are not shown, with only the outer lines left to mark the PFZs. For the systems shown in Figure 15a-b, the PFZs reach the upstream impervious boundaries. For the bigger abstraction (50,000 m^3/d), PFZs enclose the adits. For the smaller abstraction (30,000 m^3/d), some sections of the adits are not clearly encompassed by the outer pathlines. Figure 15a indicates that the groundwater divide on the downstream side of the adit may coincide with the edge of the adit when the pumping rate is small. In this situation, the water comes from upstream and the two ends of the adit, but little water comes from downstream. Figure 15b indicates that part of the adit does not contribute to the abstraction if the adit is perpendicular to the upstream impervious boundary and the pumping rate is small. Further examples of the shapes of adits are given by Zhang and Lerner (in press).

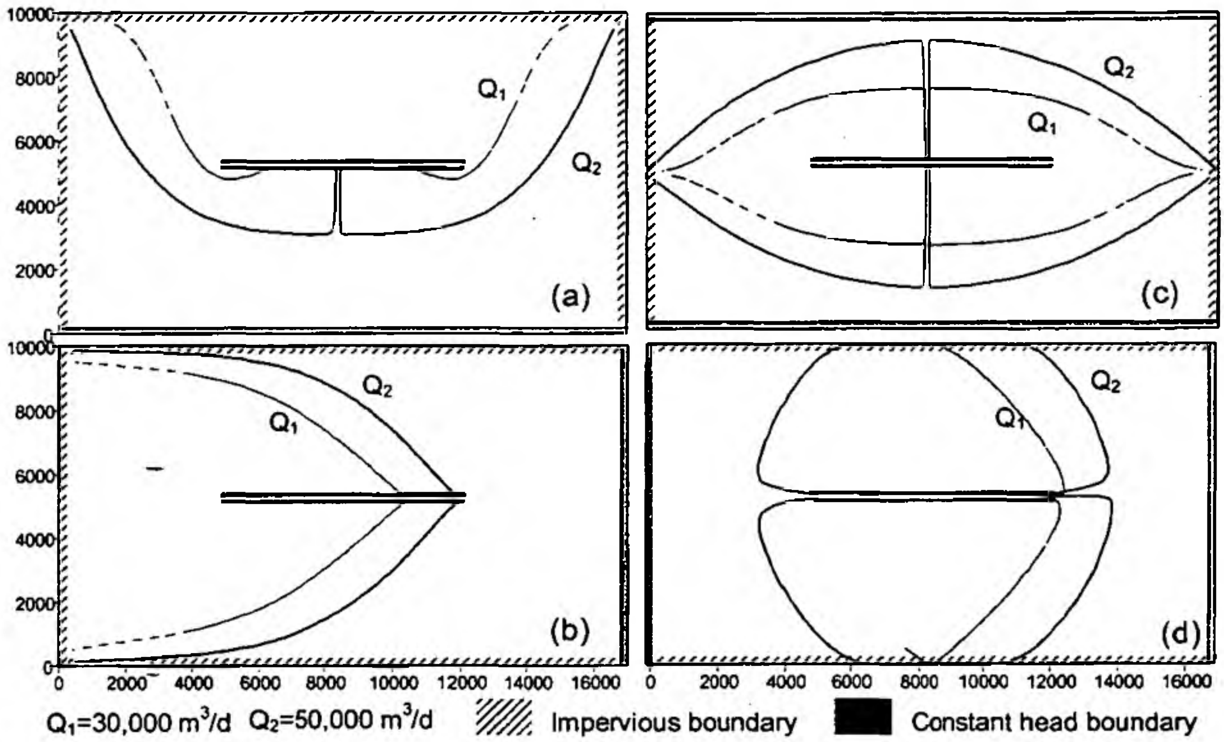


Figure 15 Plan views of PFZs with various boundary conditions, orientations and pumping rates. The distances on the axes are meters.

APPROXIMATE METHODS

The PFZs delineated in the previous sections were computed using the head distribution from MODBRNCH. The results were compared here with two approximate methods based on MODFLOW, (1) using a high value of hydraulic conductivity to simulate the adit, and (2) replacing the adit with multiple boreholes. The tests were carried out with the four systems shown in Figure 15. Almost identical PFZs were obtained using three different methods for the systems of Figure 15c-d in which the PFZs are symmetrical in both directions.

For the boundary conditions shown in Figure 15a-b with impervious upstream boundaries, MODBRNCH and the high K method derive very similar PFZs. However there were discrepancies between the PFZs generated by the multi-borehole method and the other two methods in some cases. The discrepancies depend on pumping rate, recharge, distance to the impervious upstream boundary and adit length, and an empirical criterion has been determined to show when the discrepancies are significant (Zhang and Lerner, in press).

In general, the high K method gave a good approximation to the full MODBRNCH simulation. The K values needed were very high, about 10^3-10^6 m/d. With decreasing adit length, the K value can be reduced. For an adit of 1 km, a K of 10^3 m/d worked fine. For an adit of 7 km, a K value of 10^5-10^6 m/d was needed. The PFZ was affected if the K value was not high enough, but not when the K value was higher than required.

CONCLUSIONS

The combination of the Preissmann slot approach and MODBRNCH can successfully compute the groundwater head distributions and inter-cell velocities for adit sources. The numerical modelling allows one to simulate real boundary conditions, heterogeneity and anisotropy and gain a deeper understanding of the complex hydrogeology around adits in the UK, as shown by the successful interpretation of the Cottingham source.

The shapes of PFZs are controlled by boundary conditions, regional hydraulic gradients and adit orientations. The PFZs are symmetrical about both axes and confined by groundwater divides if the hydraulic gradient is caused by abstraction alone. In contrast, the PFZs reach the upstream boundary if it is impervious. The shapes and sizes of PFZs are also strongly influenced by pumping rate, recharge, distance from adit to boundaries, and adit length. The comparisons of PFZs derived by this model and other methods indicates that assigning a high value of hydraulic conductivity (10^3-10^6 m/d) to the adit within a conventional groundwater model is a good approximation for delineation of PFZs.

ACKNOWLEDGEMENTS

This study was sponsored by the Environment Agency, Yorkshire Water Services, Thames Water Utilities Ltd, General Utilities and Anglian Water Services Ltd (Zhang and Lerner, 2001). Yorkshire Water Services provided the data for Cottingham. Waterloo Hydrogeological Inc. provided Visual MODFLOW. Our thanks go to the project board and sponsors for their financial and intellectual help.

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22. METHODOLOGY FOR WELLHEAD PROTECTION AREAS IMPLEMENTATION. APPLICATION TO URBAN WATER SUPPLY CATCHMENTS IN CARBONATED AND DETRITIC FORMATIONS IN SPAIN

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ABSTRACT

The methodology applied for the delineation of wellhead protection areas for urban water supply wells is intended to safeguard the quality and quantity of groundwater abstracted from wells, respecting socio-economic activities in the surrounding region as much as possible.

Analysis of water supply resources, hydrogeological characteristics of the aquifer, potentially pollutant sources, aquifer vulnerability, risk of contamination and urban soil categories allows the identification of the most accurate criteria to delineate the zones that will make up the protection areas and the methods (analytical, mathematical or hydrogeological) used to delineate them.

The methodology has been applied to several catchments in detritic and carbonated deposits in Spain, combining analytical methods, mathematical models and hydrogeological criteria to illustrate the approach.

Proposed zones around each catchment have been graded from higher to lower importance according to the restrictions of activities that should be incorporated into urban regulations for each village, considering the areas included in the protection areas as "special protection zones".

INTRODUCTION

The wellhead protection areas for urban water supply catchments is a legal requirement in Spanish water laws and is supported by soil laws (BOE 1985, 1986, 1998, 1999). The approval of delineated wellhead protection areas is the responsibility of the Government Board of the Watermanagers Organisation.

Conditions relating to urban, agricultural, cattle raising, industrial and leisure activities that may affect the quality or quantity of groundwater are incorporated into a document that defines the protection area. The conditions do not have to apply equally to the whole protection area. Although Spanish laws do not specify which zones have to be considered, nor what are the criteria to do so, they allow for the division of the protection areas into several zones around the catchment, for which from higher to lower restrictions are applied. Typically the considered zones are (Moreno-Merino *et al.* 1991):

- <u>Absolute restrictions zone</u>: Delimitation criterion is usually a 1-day travel time or an arbitrary fixed area with a relatively small area (100-400 m^2).
- <u>Maximum restrictions zone</u>: Usually defined according to a 50-60 day travel time to protect groundwater against microbiological contamination.

- Moderate restrictions zone: The most accurate criterion for delimitation is to use a travel time of several years, hydrogeological criteria or a combination of both with the objective of protecting catchments from long term persisting pollutants.
- Satellite protection zone: It defines areas far away from the catchment and outside the protection system but with a direct or a preferential hydraulic connection with the catchment. These areas are relevant especially in many karstic and fractured aquifers.
- Quantity protection zone: Its objective is to preserve the volume of water required to supply population needs.

On the basis of information obtained in previous studies (Martínez-Navarrete *et al.* 1997), the optimum criteria (distance, drawdown, time of travel, hydrogeological criteria, natural attenuating power of soils) will be chosen to define the zones in each protection area in the different villages, and which methods (analytical models, mathematical models, hydrogeological criteria) are used to delineate them. Proposed restrictions for the different zones that make up the protection area must be taken to the township urbanistic planning and itemized in the proposal of the wellhead protection area.

Practical application of this previously proposed methodology has been carried out by IGME in the proposed wellhead protection areas, for urban water supply catchments in several villages in Alicante (south-east Spain) located in carbonated formations (Martínez-Navarrete and García-García, 1999 a, b, c, d, 2000). It has also been applied in the delineation of wellhead protection areas in the village of Villacastín, in detritic materials in the River Duero watershed in Central Spain (Martínez-Navarrete and Fernández-Sánchez 2000).

Based on the results obtained from application of the method to these areas, the factors that need to be considered in delineating protection zones and which may be useful for similar locations are illustrated including: selection of criteria and methods, application of selected methods and even the restrictions that are proposed for each zone in the protection areas.

PREVIOUS STUDIES

Essential factors analysed in the previous studies (Moreno-Merino *et al.* 1991) and their applicability in the different phases of delineation of protection areas are:

1. Actual water supply situation: Assessment to include: analysis of water supply locations, pipes, tanks, sewer systems and water purifiers to allow the number of protection areas to be determined; define the pumping volume (water supply locations); plan water pumping tests with the plant available, with no interruption of water supply to population; establish working plans in case of contamination occurring taking into account the affected cathments (pipes and tanks); and evaluate the characteristics of potential pollutant sources (sewer conduits and water purifiers).

2. Water request: Population data and consumed water volumes to define the pumping volume necessary to supply the present and future population and to use these volumes in delineating the protection zones.

3. Economic items: Municipal budget to improve, preserve and maintain water supply infrastructure. It gives preliminary information about the real conservation of the water supply infrastructure and potentially pollutant sources such as sewers or water purifiers.

4. Territorial arrangement: The existing soil categories will be defined (urban soil, industrial usage soil, non-urban or agricultural soil). This analysis is essential to evaluate the socio-economic effects caused by the restrictions that would be implemented in the different zones of the protection area. It will condition the accuracy of the method used, which has to avoid unnecessarily over-protected zones with high economic activities.

5. Geological setting: Characteristics of the geological domain of the study area.

6. Hydrogeology: Characteristics of the hydrogeologic unit to which the urban water supply catchments belong, interconnected aquifers and hydrogeology in the surroundings of the catchments.

   Geological and hydrogeological studies must be a top priority as these are an essential aspect in selecting the most suitable methods and criteria for protection zone delineation and depending on the characteristics of the area provide the data that supports the application of analytical methods and mathematical models.

7. Aquifer vulnerability due to pollution: Analysis of potential pollutant source characteristics, vulnerability of the different formations and aquifer contamination risk.

Knowledge and evaluation of these factors is important in choosing the criteria to delineate the different zones (for example determining the time of travel that should be used), the accuracy that can be expected in the analysis and defining the activities that should be regulated in each zone.

As an example, Table 1 summarises details of livestock which could present a potential pollutant source (Martínez-Navarrete and Fernández-Sánchez 2000).

Table 1 Potentially pollutant sources in the Villacastín municipal area (Martínez-Navarrete and Fernández-Sánchez, 1999, 2000).

Identification Number	Cattle	Farm kind	Number of heads	Manure(t)	DBO_5 (kg/year)	Equivalent population (inhabitants)
1	Sheep	Extensive	600	288	15 000	548
2	Sheep	Extensive	600	288	15 000	548
3	Sheep	Extensive	600	288	15 000	548
4	Horses	Intensive	10-20	96	4000	146
(5)	(Pigs)	(Intensive)	400 reproductive piglets up to 6 kg	3650 m^3 (Project Data)	18 000	658
6	Sheep	Extensive	800	384	20 000	731
7	Calves	Intensive	300-400	2660	128 000	4676
8	Horses	Intensive	30-40 mothers	192	8000	292
9	Slaughter house	Intensive	—	—	—	—
10	Hens	Intensive	60 000 Laying Hens	2400	96 000	3507
(11)	(Pigs)	(Intensive)	3600: 400 piglets 800 re-breeding 2400 bait	6570 m^3 (Project Data)	162 000	5918
(12)	(Pigs)	(Intensive)	140	22 994 m^3	6300	230
17	Calves	Extensive	150	997	48 000	1753

18	Calves	Extensive	150	997	48 000	1753
19	Sheep Calves	Extensive	450	216	11 250	411
			30	199	9600	351
22	Hens	Intensive	10 000	400	16 000	584
25	Milking Cows	Extensive	80	532	25 600	935
26	Sheep	Extensive	300	144	7500	274

WELLHEAD PROTECTION AREAS IN WATER SUPPLY CATCHMENTS LOCATED IN DETRITIC MATERIALS. APPLICATION TO THE MUNICIPALITY OF VILLACASTIN (SEGOVIA, SPAIN).

The township of Villacastín is located in the south-western edge of the River Duero watershed, in a tectonic graben filled up with Cretaceous, Tertiary and Quaternary deposits. Water supply for the population of 1,538 inhabitants is from four wells on the Tertiary and Quaternary aquifer, which lies unconformably over the lower formations, and from three wells in a localised aquifer in granitic deposits to the south of the village.

The detritic Tertiary aquifer comprises a series of lenses of permeable deposits (sands, gravels) with a variable grain size, within a semi-permeable sand-clay-silt matrix, through which the permeable lenses are hydraulically related. This detritic aquifer is partially covered by quaternary materials and both formations are connected hydraulically and behave as a heterogeneous and anisotropic water table aquifer. Hydrogeological analysis (Martínez-Navarrete and Fernández-Sánchez 2000) shows that there is groundwater flow from the granitic deposits to the Tertiary detritic aquifer with groundwater discharge from this aquifer to streams.

The aquifer resource is mainly derived from infiltration of rainwater. Groundwater discharges to the rivers on the Tertiary detritic aquifer. The water resource is used for cattle raising and water supply to the town of Villacastín and isolated houses. The granitic deposits constitute locally important aquifers in the southern zone of the municipal term but have no hydrogeological regional importance.

Quality protection zones

The protection zone for catchments in the detritic Tertiary aquifer is made up of three different zones according to the restrictions absolute, maximum and moderate (Martínez-Navarrete and Fernández-Sánchez 2000). In order to calculate these zones the most suitable method (Martinez, 2000) was Wyssling's method combined and using hydrogeological criteria for the absolute and maximum restriction zones. Delineation of these zones in the granitic aquifer was made using only hydrogeological criteria due to the aquifer characteristics and the degree of knowledge of the hydraulic parameters.

To delineate the moderate restrictions zone in the Tertiary aquifer a mathematical model was used, selecting the computer programs "Processing Modflow" and "Pmpath" (Wen-Hsing and Kinzelbach 1998). Wyssling's method (Wyssling, 1979, in Moreno-Merino *et al.* 1991) calculates the capture zone and travel times for a catchment. It was designed for delineation of protection zones in porous and homogeneous aquifers, so it is suitable for detritic aquifers.
To apply this method it is necessary to know the values of: **Q**: the water volume; **i**: the hydraulic gradient; **k**: the hydraulic conductivity; **b**: the saturated thickness of the aquifer; and $\mathbf{m_e}$: the effective porosity. Using these values then the following can be calculated:

The radius of capture:	$X_o = Q/(2 \cdot \pi \cdot k \cdot b \cdot i)$
The effective velocity:	$V_e = k \cdot i/m_e$
The width of the front of capture:	$B = Q/k \cdot b \cdot i$
And the width close to the catchment:	$B' = B/2$

Travel times selected for analysed catchments are one day for the absolute restrictions zone and 50 days for the maximum restrictions zone. These are appropriate for the potential pollutant sources found and which characterise the municipal area.

The next step was to calculate the parameter l for each time of travel, where $l = V_e \cdot t$. With this parameter the distances in the flow direction (So) and in the opposite direction (Su) for each time of travel can be calculated using the following equations:

$$S_o = \frac{+l+(l\cdot(l+8\cdot X_o))^{1/2}}{2} \qquad S_u = \frac{-l+(l\cdot(l+8\cdot X_o))^{1/2}}{2}$$

Distances upstream and downstream of the catchment abstraction were measured according to the principal flow direction as obtained from the hydraulic heads.

In using analytical methods such as the Wyssling's it is necessary to simplify the hydrogeological regime introducing very strict conditions and so mathematical models which allow changes in the principal hydraulic parameters, aquifer heterogeneities, influence of pumping and other stresses condition to be considered are more accurate and are more appropriate to the delineation of the moderate restrictions zone.

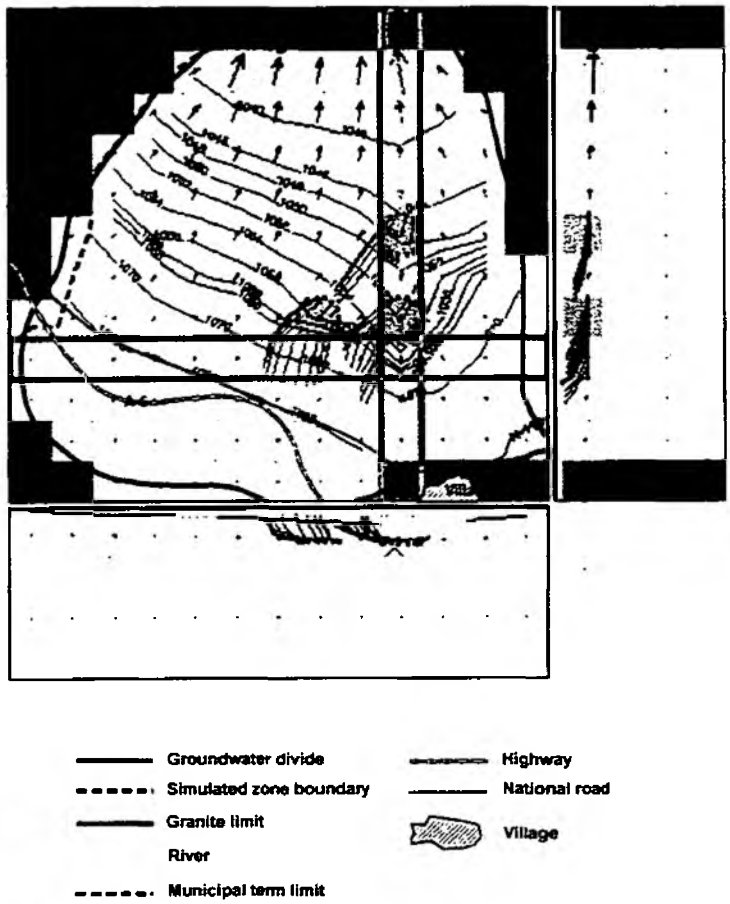
In this study the computer programs "Processing Modflow" and "Pmpath" were used in delineation of the moderate restrictions zone for the wells upon the Tertiary detritic aquifer. These programs allow the simulation of three dimensional groundwater flow and the advective component of solute transport. Consequently these models can be used to define the contaminant capture zone for different travel times.

The boundary conditions for the model are (Martínez-Navarrete and Fernández-Sánchez 2000):

- Impermeable boundary: The contact with the granitic materials (the whole southern part of the modeled area).
- No flow boundary: Groundwater divides, defined on the basis of analysis of the hydraulic heads (eastern and western boundaries of the modeled area).
- Fixed head boundary: The boundary between the model zone and the rest of the tertiary detritic aquifer (this forms the northern boundary).

A simulation in steady state flow was undertaken to define the protection zone for each catchment in the source area. In delineating these zones, particles are placed within the abstraction cell and tracked through the modelled flow path for different travel times. A four-year travel time was used to delineate the moderate restriction area (Figure 1).

Figure 1 Mathematical model simulation to delineate the protection zones in Villacastín.



Moderate restriction zones for the different catchments overlap partially, which made it advisable to define a unique area common to all of them. This area has been defined on the basis of the model calculations and taking account of hydrogeological criteria. The conditions and prohibitions for different activities in the restriction zones are shown in Table 2.

Inside the absolute restriction zone, access to the wellhead must be prevented. This is achieved by a fenced perimeter in which only authorised personnel can enter. Proposed controls in the seven wellhead protection areas for the urban water supply wells are placed in areas with the general "non urban land" category being necessary to treat them with the new category of "zones of special protection", which is justified by the need to protect the public hydraulic domain.

Table 2 Proposed restrictions to activities in each protection zones in the Villacastín water supply catchments (Martínez-Navarrete and Fernández-Sánchez 2000)

	ACTIVITIES DEFINITION	ABSOLUTE RESTRICTIONS ZONE	MAXIMUM RESTRICTIONS ZONE			MODERATE RESTRICTIONS ZONE		
		Forbidden	Forbidden	Conditioned	Allowed	Forbidden	Conditioned	Allowed
AGRICULTURAL AND CATTLE ACTIVITIES	Fertilizers use	●	●				●	
	Weed-killers use	●	●				●	
	Pesticides use	●	●				●	
	Manure storage	●	●				●	
	Animals rests dumps	●	●				●	
	Intensive cattle	●	●				●	
	Extensive cattle	●	●					●
	Storage of fermentable materials for cattle feeding	●	●				●	
	Watering places and cattle refuges	●	●				●	
	Silos	●	●				●	
URBAN ACTIVITIES	Surface dump of urban residual waters	●	●				●	
	Urban residual waters in septic graves, ceespools or pools	●	●			●		
	Urban residual waters in public riverbeds	●	●			●		
	Urban solid waste dump	●	●			●		
	Graveyards	●	●				●	
INDUSTRIAL ACTIVITIES	Industrial settlements	●	●				●	
	Industrial liquid wastes dump	●	●			●		
	Industrial solid wastes dump	●	●			●		
	Hydrocarbons storage	●	●				●	
	Radioactive products deposit	●	●			●		
	Industrial wastes injection in wells and drillings	●	●			●		
	Industrial liquids pipings	●	●			●		
	Hydrocarbons pipings	●	●			●		
	Opening and exploitation of quarries	●	●				●	
	Filling of quarries or excavations	●	●				●	
OTHER	Campings	●	●				●	
	Pedestrians access	●			●			●
	Communication nets transport	●		●			●	

Quantity protection zone

Delineation of a "quantity protection zone" is made with the aim of preserving the resource used for population water supply. For the Villacastín water supply catchments a common quantity protection zone is proposed for the wells on the Tertiary detritic aquifer and wells in the granitic aquifer (Martínez-Navarrete and Fernández-Sánchez 2000). For the four wells on the tertiary detritic aquifer the quantity protection zones were defined using a steady-state model simulation and taking account of hydrogeological criteria. The model simulation showed that the river acts as a line of groundwater discharge and will continue to do so under future abstraction regimes. The limits of the source were defined as the river and by a line

500m to the east of it in order to avoid the effect that pumping could produce on its environs. Delineation of the quantity protection zone for the three water supply wells in the granitic aquifer was made exclusively on the basis of hydrogeological criteria. In this area abstraction will be limited to the wells and springs that were inventoried in the work, prohibiting any new abstraction in the delineated area.

WELLHEAD PROTECTION AREAS FOR URBAN WATER SUPPLY CATCHMENTS IN CARBONATED FORMATIONS. APPLICATION TO SEVERAL MUNICIPALITIES IN THE ALICANTE PROVINCE (SPAIN)

Quality protection areas

The methods used to delineate the zones that will make up the protection areas for the urban water supply catchments in the analysed municipalities of Alicante were based on the characteristics of the deposits, the degree of hydrogeological knowledge on the aquifers and the potentially pollutant sources in the area. The methods used are shown in Table 3.

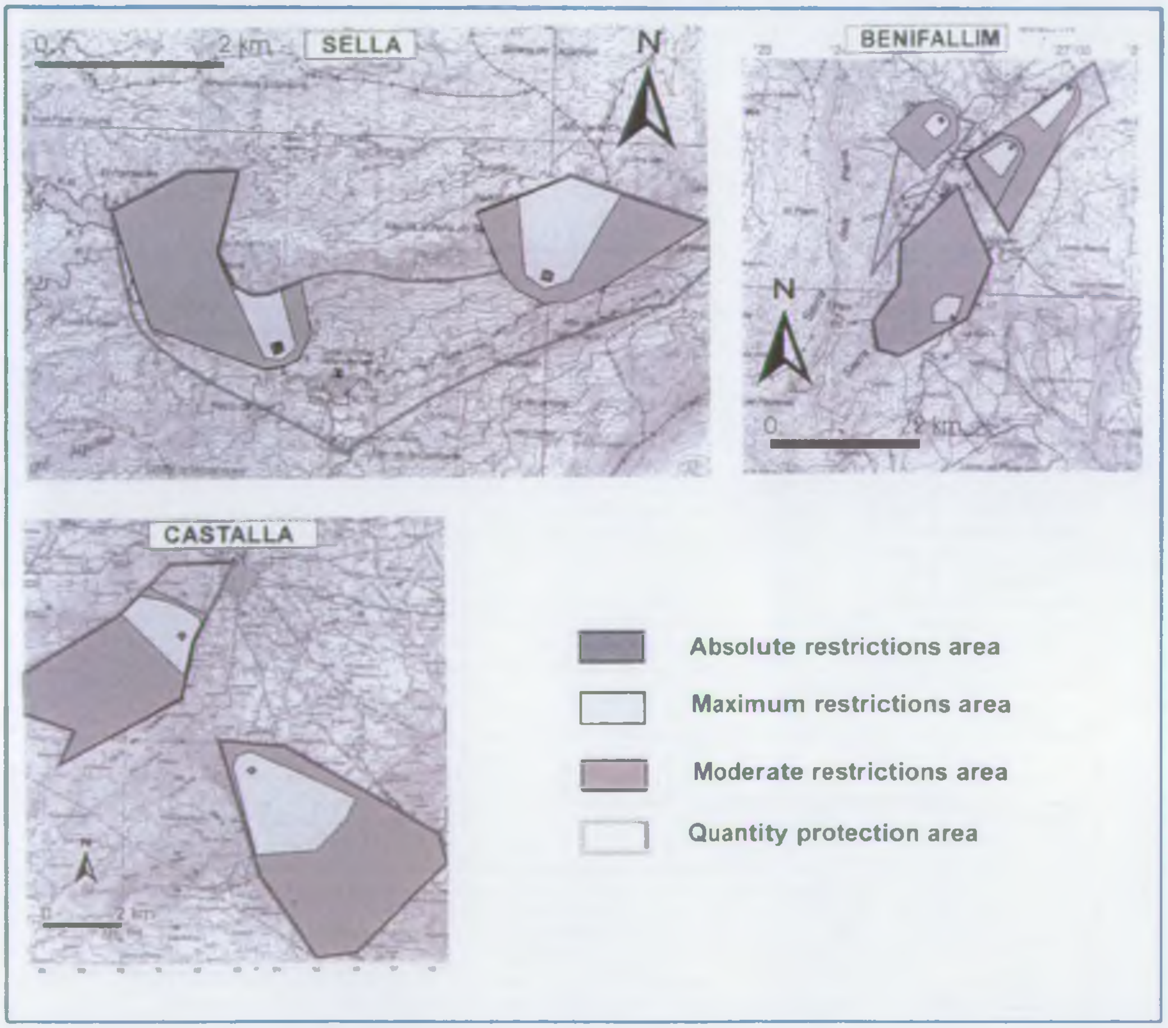
Table 3 Applied methods in wellhead protection areas delineation for the different restrictions zones in the province of Alicante

	METHOD			
Catchment	Restriction zones	Wyssling	HYdrogeolÓgicAL (aquifer limits)	OtHER hYdrogeolÓgicAL CRITERIA
Font Major (Sella)	Absolute (1 day)	♦		
	Maximum (50 days)	♦		♦
	Moderate			♦
"Aitana" well (Sella)	Absolute (1 day)	♦		
	Maximum (50 days)	♦	♦	
	Moderate		♦	
Racó de la Balsa (Benifallim)	Absolute (1 day)	♦		
	Maximum (60 days)	♦		
	Moderate (1 year)	♦		
"El Morral" well (Benifallim)	Absolute (1 day)	♦		
	Maximum (60 days)	♦		♦
	Moderate (1 year)	♦		♦
"El Rentonar" well (Benifallim)	Absolute		♦	
	Maximum		♦	
	Moderate		♦	
"Bco. del Tormo" well (Benifallim)	Absolute (1 day)	♦		
	Maximum (60 days)	♦		♦
	Moderate (1 year)	♦		♦
"El Llosar" well (Tibi)	Absolute			♦
	Maximum		♦	
	Moderate		♦	
"Barranco de la Escalera" well (Onil)	Absolute (1 day)	♦		
	Maximum			♦
	Moderate		♦	♦
"Voltes" well (Castalla)	Absolute (1 day)	♦		
	Maximum (60 days)	♦	♦	
	Moderate		♦	
"La Espartosa" well (Castalla)	Absolute (1 day)	♦		
	Maximum (60 days)	♦		♦
	Moderate		♦T	

Even though Wyssling´s method was designed to calculate protection zones in porous and homogeneous aquifers, it was found that it was suitable for several aquifers to which it was applied, specially in the cases of the calculation of the distances corresponding to the time of travel along the central axis, but it was necessary to combine it with hydrogeological criteria in the delineation of the maximum and moderate restrictions zones. Application of Wyssling´s method was made by following the same steps detailed above for the detritic aquifer.

Hydrogeological methods have been used in some of the catchments where it was not possible to apply analytical methods and used in other catchment to support other hydrogeological criteria (Table 3). In the Sella catchments both hydraulic heads and the existence of an unsaturated zone were taken into account in drawing the protection zones. The protection zones in the Benifallim catchments were defined based on the presence of impermeable marls at the surface and the fragmentation of the aquifer by several faults. In the water supply catchment in Tibi the whole area of the aquifer was used because of its small dimensions and because existing activities had no apparent affect on water resources. For the Onil catchment Wyssling´s method was initially used to define the moderate and maximum restrictions zones but these sources were then modified to include the whole catchment. In Castalla the protection zones were defined using the results of application of Wyssling´s method and taking into account the limits of the aquifer.

Figure 2 Delineated protection zones in carbonated aquifers in the province of Alicante.



Polygonal lines that will define the three zones of the quality protection area were established for each catchment in order to apply the restrictions in an easier way after taking them into the urban regulations as shown on Figure 2. These activities and restrictions are detailed in a specific table similar to that illustrated in Table 2.

Quantity protection areas

In order to delineate the quantity protection zones, a hydrogeological balance of the aquifer was undertaken. Analysis of this balance provided a check on whether the aquifer is able to maintain a human water supply both currently and in the near future. The results from the balance were complemented with data, such as the analysis of hydraulic heads evolution in different sectors of the aquifer.

These hydrogeological studies should be supported by other methods that show, in a more accurate way, the area in which the impacts could happen and to quantify them. If the assessment of the aquifer behaviour shows: local behaviour, homogeneous properties, simple abstraction and/or drainage, simple geometry with no complications, then analytical models (integration of the flow differential equations plus the images theory) may give an adequate approximation. These methods allow zones to be defined in which hydraulic effects will be minimal (influence of radius calculation), or to define areas with a drawdown lower than a specific value.

If on the contrary, the aquifer has a regional behaviour, heterogeneous properties, complex abstraction and/or drainage, complex geometry and limits, then mathematical models are more useful to support the hydrogeological studies. Through the use of mathematical flow models several water abstraction scenarios can be simulated obtaining the effects over the whole aquifer. This allows the evaluation of the relationships between the different abstractions and the influence of bringing into service new abstractions, defining on that basis, the protection zone areas and the restrictions in each case.

To be able to develop a mathematical model it is essential to have a conceptual model of the aquifer in which the boundaries and processes are clearly defined. It is also necessary to have enough data for the aquifer hydraulic parameters.

In defining the quantity protection zones for water supply catchments in the municipalities of Alicante, hydrogeological methods only were used taking into account the characteristics of the aquifers and the impracticality of obtaining the hydraulic parameters necessary for a mathematical model (Martínez-Navarrete and García-García, 1999 and 2000).

Delineation of the quantity protection zones for the urban water supply catchments in the town of Sella was made by using hydrogeological criteria combined with the results obtained from a mathematical model. The results were extrapolated to determine the useful water resources for several other aquifers used for public supply in Alicante (ITGE and Diputación Provincial de Alicante 1999).

CONCLUSIONS

Application of the methodology by IGME, to delineate wellhead protection areas for urban water supply catchments in the detritic and carbonated formations in Spain, in the villages of Sella, Benifallim, Tibi, Onil and Castalla (Alicante) and Villacastín (Segovia), has provided an accurate understanding of the water supply situation, supply needs, urban arrangement, hydrogeological characteristics of the aquifers, aquifer vulnerability, potential pollutant sources and the risk of contamination in each catchment. These data are essential in order to choose the most accurate criteria to define the zones that will make up the protection areas and the basis for the method (analytical, mathematical, and hydrogeological) used to delineate them.

Analysis of the data obtained in previous studies shows that time-of travel (Wyssling's method) and hydrogeological criteria were the most accurate approach for defining protection zones for carbonated aquifers taking account of the specific characteristics of these catchments. Delineation of the different zones of the protection areas for dedritic deposits was made by combining the results from analytical methods, mathematical models and hydrogeological criteria. Wyssling´s analytic method was used to delineate the absolute and maximum restrictions zones, and a mathematical model, selecting the computer programs "Processing Modflow" and "Pmpath", was used to delineate the moderate restrictions zone complementing both methods with hydrogeological criteria.

Using mathematical models allows changes in the principal hydraulic parameters, aquifer heterogeneities, influence of pumping and other stresses conditions to be taken into account so that they provide a more accurate method of defining the moderate restrictions zone. The use of these models allows the simulation of three dimensional groundwater flow and the advective component of solute transport and therefore allows the contaminant capture zones for different times of travel to be calculated.

Quantity protection area delineation is made with the aim of preserving the resources used for population water supply. Delineation of the quantity protection zone can be made on the basis of hydrogeological criteria and using mathematical models if information is sufficient to calibrate them.

Activities to be regulated and the restrictions to apply are detailed in a specific table for each catchment and these must be taken into an urban arrangement classifying them as "specially protected zones" and supported by means of protecting the public hydraulic domain. Results from the application of this methodology are considered to be satisfactory and applicable to other areas with similar characteristics.

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23. GROUND WATER PROTECTION BASED ON INTEGRATED, DYNAMIC FLOW AND PARTICLE TRACKING

H.R. Sørensen and A. Refsgaard [18]

ABSTRACT

The extensive program of groundwater vulnerability mapping is currently in progress in Denmark. The accurate, determination of capture zones and infiltration areas of wells and well fields is an important aspect of this task, for which groundwater flow models are often used. However, groundwater models are often based on recharge and leakage estimates determined from simple analyses. Furthermore, capture zones are often based on steady-state flow fields. Both of which lead to unreliable delineation of wellhead protection areas.

Applying transient integrated surface water/groundwater models to describe the flow conditions often leads to significantly different recharge and groundwater flux estimates when compared to more traditional methods. When these models are combined with particle-tracking analysis to describe the interaction between surface water and groundwater, reliable estimates of recharge areas and capture zones can be determined. When the model results are further combined with information on water chemistry and geochemistry, as well as the results of geologic modelling, accurate vulnerability maps can be made.

Such an integrated approach to vulnerability mapping is the subject of this paper. Following the description of the method, is an example application where the method has been used to develop a groundwater protection strategy. This strategy has been used to prioritise protection efforts and to determine the impact of different land-use scenarios on future groundwater quality.

INTRODUCTION

Water resources and water supply are fundamental to the continued economic development in the western world, and indeed to human survival in much of the under developed world. The increasing, and competing, demands for domestic, agricultural, industrial and recreational water has made water a scarce natural resource in almost all regions of the world. Compounding the increasing demand is the problem of groundwater and surface water pollution, global warming and the need for the preservation and restoration of aquatic ecology.

The efficient management of water resources today requires input from a wide range of professionals, including ecologists, economists, engineers and planners. This interdisciplinary co-operation involves, among other things, information about all aspects of the land-based hydrologic cycle. Furthermore, it is increasingly being seen that there is a need to manage water resources on a watershed or even river basin scale. It is in this context that distributed, hydrological models should be seen as necessary tools in this process.

It is essential to protect water resources for various future uses, including the assurance of acceptable groundwater – and surface water – quality in the future. The effective protection should result in:

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land-use regulations to protect existing groundwater resources, e.g. limiting the use of fertilisers and pesticides in defined areas; remedial action plans for exploited aquifer systems, e.g. in areas contaminated with chlorinated hydrocarbons; and exploitation plans for new aquifers the risks of contamination are lower.

It is impossible to protect all areas equally, which means that some kind of prioritising must take place. One way to do this is to map the vulnerability of the groundwater resources and protect selected areas based on such mapping. In this paper, an area can be characterised as vulnerable if solute species that are transported with the recharging water have a negative impact on water quality in existing water supply wells. In principle groundwater vulnerability depends on the species under consideration. In this sense, an aquifer can be vulnerable with respect to one species but not vulnerable to another species.

Since the vulnerability of an aquifer depends on both "natural" (geology, hydrology, hydrochemistry, geochemistry. etc.) and anthropogenic (land use, groundwater pumping, etc.) conditions, it is essential to address both. Vulnerability due to natural conditions could be denoted hydrogeologic vulnerability, while the latter could be denoted anthropogenic vulnerability. Thus, for example, vulnerability mapping could be used by decision-makers to prioritise efforts to reduce nitrate contamination of groundwater abstracted for drinking water purposes.

The US EPA developed one of the first, simple methods for vulnerability mapping. The DRASTIC method (Aller *et al.*, 1987) was designed to determine groundwater "hydrogeologic" vulnerability on large scale. The method utilises seven hydrogeological parameters to determine the DRASTIC index as a weighted sum of the parameters. The parameters are:

Depth to water table
Recharge
Aquifer media
Soil media
Topography
Impact of the vadose zone media, and
Conductivity.

Mapping is done on a grid, where the DRASTIC index is determined in each cell based on an evaluation of the value of each parameter. This method has been applied in a number of projects and been the subject of various evaluations comparing DRASTIC vulnerabilities to actual incidences of pollution. However, these parameters are primarily indirect measures of vulnerability and they are more or less correlated, making a summation of the indexes questionable.

In this paper, we propose to include more "direct" parameters in our vulnerability mapping. For instance, we propose to determine the travel time in the soil, instead of using the soil media as a parameter. Groundwater models are often used for this task. However, such models are often based on recharge and leakage estimates determined from simple analyses. Furthermore, capture zones are often based on steady-state flow fields. (Foster and Skinner, 1995). Both of these simplifications can lead to unreliable delineation of wellhead protection areas.

Applying transient integrated surface water/groundwater models to describe the flow conditions often leads to significantly different recharge and groundwater flux estimates when compared to more traditional methods. When these models are combined with particle-tracking analysis to describe the interaction between surface water and groundwater, reliable estimates of recharge areas and capture zones can be determined. When the model results are further combined with information on water chemistry and geochemistry, as well as the results of geologic modelling, accurate vulnerability maps can be made.

AN INTEGRATED APPROACH TO VULNERABILITY MAPPING

In the schematic shown in Figure 16, the highest priority for protection is in the area above the "window" to the aquifer. In this area, groundwater recharge is high and a solute species will quickly penetrate to the aquifer. The transport time to the abstraction well is small and there is a high risk that abstracted water will be contaminated. However, if the species were easily biodegradable then the risk might not be as high.

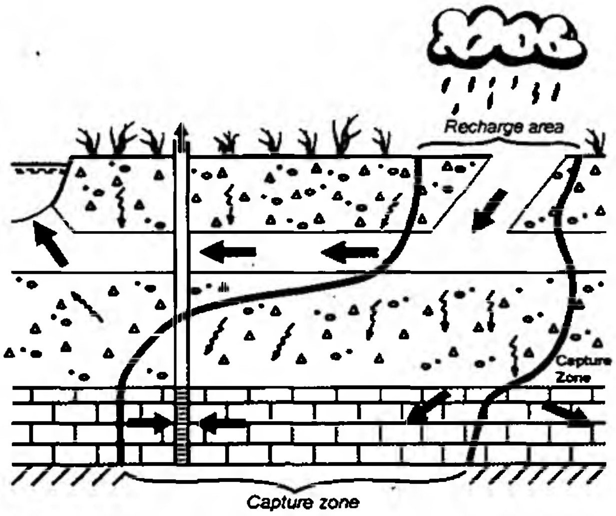

Figure 16 Cross-section in a typical Danish Chalk aquifer covered with inhomogeneous till.

This simple example shows that the vulnerability of a groundwater aquifer depends on a large number of conditions (e.g. the physical and chemical characteristics of the overburden and the aquifer media, plus the spatial and temporal distribution of recharge, land use, and groundwater exploitation, etc.). To get a complete picture of the aquifer vulnerability it is necessary to address all the conditions both individually and in together.

Table 1 lists the "parameters" that have to be considered, keeping in mind that many of them are not independent but to a large extent correlated. Thus, it is meaningless to determine a vulnerability index for each parameter and add them to determine a relative measure for the vulnerability. Instead we developed a GIS tool that can present each of the parameters as maps and evaluate the (species dependent) vulnerability for each parameter. The following five vulnerability classes can be defined and each parameter map could be divided into these classes:

extremely vulnerable,
fairly vulnerable,
slightly vulnerable,

not vulnerable, and
vulnerability cannot be determined due to sparse data.

Combining the information from the various maps we can determine differences in the vulnerability patterns and add the associated uncertainties to obtain species-dependent vulnerability maps (see Figure 17). Several administrative themes are also useful, such as roads, railways, buildings, etc. It is of special interest to determine discrepancies in the information derived from the interpreted maps, since this will indicate more or less directly the uncertainty of the final vulnerability. For example, differences in the water age determined from the groundwater model should be compared to the water age determined from direct water samples; differences in the patterns of groundwater recharge determined by the integrated hydrological modelling and maps of clay cover thickness may indicate errors in the hydraulic parameters of the clay and/or misinterpretation of the geological model; unexpected "water types" compared to the aquifer media may indicate that the geological model is misinterpreted or the water originates from different source, for example, due to erroneous specification of the well screening.

Table 1 "Parameters" that could be included in the vulnerability mapping process

1.1.1.1.1 Parameter	1.1.1.1.2 Data source	1.1.1.1.3 Comments
Recharge	**Hydrologic model or simple water balance assessment**	**E.g. mean summer or winter recharge**
Thickness/type of overburden	**Geologic interpretation model**	
Infiltration time to the aquifer	**Hydrologic model or simpler assessment**	**To evaluate the potential for degradation and adsorption**
Recharge and discharge areas	**Hydrologic or groundwater model**	**E.g. Particle tracking analysis**
Capture zones for wells	**Groundwater model**	**E.g. Particle tracking analysis**
Age of abstracted water	**Groundwater model or measurements of CFC gases**	**Particle tracking analysis is useful; mark and follow precipitation/recharge**
Water "type" in aquifer	**Measurements and analysis of water quality parameters**	**E.g. Water can be characterised as oxidised, reduced or strongly reduced based on only a few water quality criteria**
Aquifer media	**Geologic interpretation model**	**Limestone, sand, gravel etc.**
Gradients in the aquifer and other geologic units	**Groundwater model combined with measurements**	**To determine flow directions**
Geochemical conditions in and above the aquifer	**Geologic interpretation model based on measurements of geochemical parameters**	**To determine conditions for degradation of various species**

Water chemistry	**Water samples from wells**	
Land use and other maps	**Various**	**To combine vulnerability with knowledge of potentially contaminating land uses**

Such comparisons can easily be carried out in a GIS by comparing the vulnerability classes for the different themes or by comparing the themes directly (e.g. the system is prepared to answer questions like: find areas where the water type indicates "old" groundwater and the groundwater model simulates "young" groundwater).

Different parameters have different importance when discussing various species. For instance, the travel time from source to abstraction well combined with the redox environment is of outmost importance when addressing vulnerability towards diffusive nitrate contamination whereas the redox environment has minor or no influence on the vulnerability towards chlorinated compounds from point sources.

"Adding" the vulnerability classes results in what can be denoted as a vulnerability "density" map. Extremely vulnerable areas towards the species under consideration will appear as high density areas, whereas areas with little vulnerability are areas where none of the parameters indicate vulnerability. Areas with sparse data and can also be indicated and may be helpful during the development of an optimal monitoring programme for early warning of water quality in groundwater production wells.

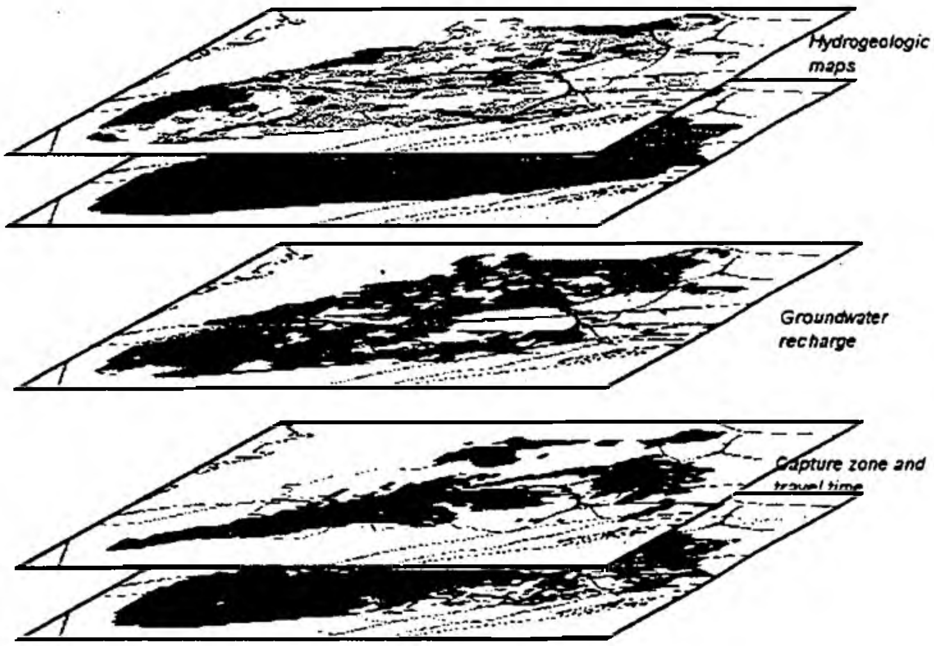

Figure 17 Maps of various parameters interpreted in common.

Since the spatial and temporal groundwater recharge distribution is essential in the vulnerability mapping process, this should be given special attention. Thus far, we have argued that the use of a numerical model will enable one to derive several parameters to be used in the mapping process. Groundwater models, however, are not geared to simulate groundwater recharge since recharge is often used as a calibration parameter during the development and calibration of the model. Furthermore, groundwater models are often steady state or they are only run for selected stress periods. Neither of these provide the complete picture of the flow situation.

Instead of a strict groundwater model, an integrated, hydrological model, such as MIKE SHE, can determine the recharge based on the soil characteristics, precipitation, potential evaporation, land use and other external and internal parameters and variables. The next section is a short description of the MIKE SHE modelling system, with special emphasis on its applicability to vulnerability mapping.

THE MIKE SHE HYDROLOGIC MODELLING SYSTEM

It was more than twenty-five years ago that the development of the Système Hydrologique Européen, SHE, was initiated (Abbott *et al.*, 1986). MIKE SHE – an extension of the original SHE code – is today one of the very few commercially available codes that can be described as a physically based and fully distributed hydrological modelling code. Over this period, MIKE SHE has been successfully applied in hundreds of applications on both research and consultancy projects.

MIKE SHE was developed as an alternative to the more traditional lumped conceptual rainfall-runoff models such as the NAM model. The international collaboration during the initial development of the SHE code necessitated a modular process-based structure to the code. Each module describes one of the major hydrological processes in the hydrological cycle and, together, they provide a complete integrated description of the land-phase of the hydrological cycle (Figure 18). Additionally, each component can be run separately or coupled to one or more of the other components.

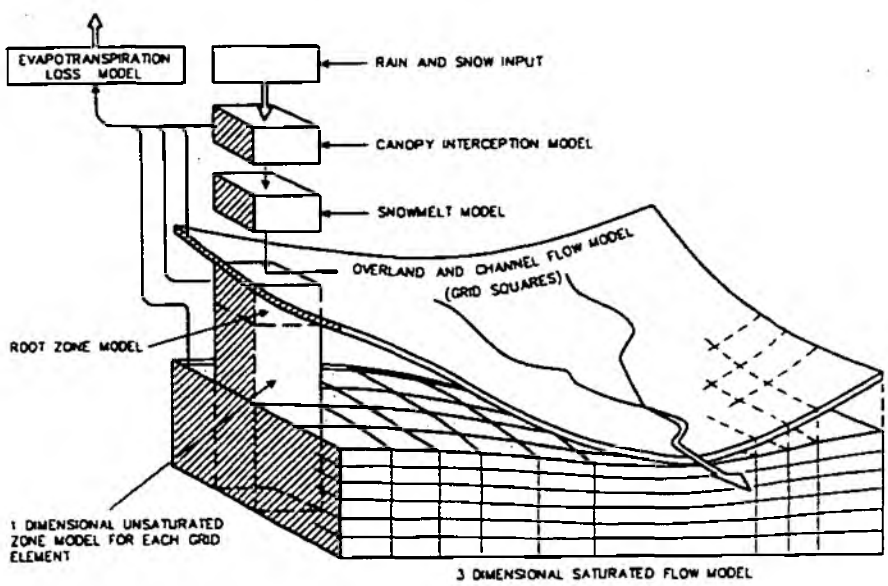

Figure 18 Schematic representation of the components in MIKE SHE (Storm and Refsgaard, 1996).

MIKE SHE was originally developed with the view that the level of detail should be sufficient to justify the claim of a physically based system. The equations used are, with few-exceptions, non-empirical and well known to represent the physical processes in the different parts of the hydrological cycle. The parameters in these equations can be obtained from measurements and used in the model, so long as they are compatible with the scale of the model. The flow processes represented in MIKE SHE include: snow melt, rainfall interception and evapotranspiration, overland flow and channel flow, vertical flow in the unsaturated zone, and groundwater flow. In MIKE SHE, each of these processes operates spatially and at time steps consistent with their own spatial and temporal scales. For example, daily rainfall may be distributed, due to topographic relief, into a few zones across a watershed. Infiltration and evapotranspiration will vary with vegetation, surface cover, slope, soil properties, etc. and is calculated directly by the model based on the distribution of the these conditions.

Overland flow and rainfall-runoff hydrographs may peak within hours after a heavy rainfall necessitating short time steps for overland and channel flow calculations. And, finally groundwater, which is typically the slowest process, may only require monthly time steps. In areas with a shallow groundwater table, direct contact between a river and the aquifer a fully integrated dynamic description with daily time steps (or less) may be required to describe the conditions with adequate precision.

One of the primary components used in vulnerability mapping is the particle-tracking module. It can be used to delineate capture zones and transport times for the well fields and single wells. Typically, ten particles are introduced into each cell at the start of the simulation. Subsequently, the movement of each individual particle in the flow field is traced by giving each particle a birth date, a birth location and successively tracking its position. The transport is assumed to be conservative (i.e. adsorption or chemical reactions are not accounted for).

MIKE SHE's flow and particle tracking components take both saturated and unsaturated conditions into account. If a particle is above the free groundwater table it will move vertically downwards with the current velocity until the groundwater zone is reached. Thereafter, horizontal movement can also occur depending on the flow field. The vertical velocity is determined by linear interpolation between the vertical velocity at the top and bottom of the layer. In the lowest layer the velocity at the bottom is zero representing the impermeable bed.

Particles are removed from the model by different sinks – abstraction wells, rivers, drains, model boundaries and exchange between the unsaturated and saturated zones. When a particle reaches a cell containing one or more of these sinks it can be removed, or it can continue if the sink is "weak" compared to the groundwater flow. The number of particles removed by a sink in a cell is determined by the water volume removed divided by the volume removed plus the water volume in the cell. The fractions are added over every time step until the sum is higher than one – and then a particle is removed. This has the effect that not every particle reaching a well is removed by the well.

Keeping track of the original location of particles removed by a well delineates the capture zones. The transport time from the original location to the well is also noted for each particle. The calculations are performed for a number years and afterwards the capture zones are mapped. The particle-tracking calculations can be based on stationary and transient flow fields or reuse of periodical flow calculations.

APPLICATION OF THE MODEL FOR MANAGEMENT PURPOSES

The capital of Slovenia, Ljubljana, faces serious problems with their water supply, which is solely from untreated groundwater. Groundwater is extracted via a number of well fields located close to the city. Various point sources, as well as diffuse pollution from agriculture and a leaking sewer system, are major threats to the groundwater quality.

The main source of water is the Ljubljasko Polje aquifer, from which 90% of the required drinking water is extracted. It consists of unconsolidated sedimentary deposits and is unconfined. Hydraulic conductivities up to 10e-2 m/s are observed in the aquifer. The groundwater table fluctuates by as much as ten meters between winter and summer, which results in dramatic seasonal variations in the flow field. It is highly connected to the nearby river Sava, which recharges the aquifer in some sections and acts as a drain in other sections. The aquifer is located below the agricultural areas supplying the city market with vegetables and is, in places, beneath the urban areas of the city. The groundwater quality is seriously threatened in several ways including, the excessive use of fertilisers and pesticides, leakage from the sewer system, road accidents, industrial zones, urban sprawl, illegal waste deposits, and gravel excavation. Furthermore, accidental surface water contamination in the upstream reaches of the river Sava could also compromise drinking water quality due to the high rates of recharge from the river.

Although it is well known that the Ljubljansko Polje aquifer is well connected to the river Sava, neither surface water recharge rates, nor groundwater recharge through precipitation, are known in detail. In general, the water balance in the area is known but not in enough detail. The water balance in the neighbouring Ljubljansko Barje aquifer system is even less understood due to its connection to extensive karst formations.

One of the key issues in this study was to determine the origin of the drinking water being extracted from the well fields. For example, the degree of mixing between precipitation recharge and river infiltration was unknown. Thus, the model that was required for this study had to include groundwater and surface water flow and transport, as well as precipitation, evaporation and recharge. The consequences of changing river management practices from, for example, additional flow control structures, as well as the impact on groundwater quality from spills in the river also had to be addressed by the model. Furthermore, the model had to be able to describe the three-dimensional behaviour of groundwater flow both in the Ljubljansko Polje and the neighbouring Ljubljansko Barje aquifer system. The model was also required to include non-point and point sources to simulate contamination from agricultural practices, waste disposal sites and sewer system leakage.

To satisfy these extensive requirements, the model was developed using the fully integrated catchment modelling system, MIKE SHE, and river modelling system MIKE 11 (DHI, 1999; DHI, 2000). These two codes were combined with a simple rainfall-runoff model (NAM) and the advanced crop growth and nitrogen consumption model, DAISY (Hansen et al., 1990).

Model results - capture zones and travel times

A large number of scenarios were simulated with the integrated model to determine the risks of contamination from agriculture practices, sewer leakage, waste disposal and infiltration from the river Sava.

MIKE SHE's particle-tracking module was used to determine the capture zones for the large well fields located in the Ljubljansko Polje aquifer. Several particles were initially placed in every grid cell and then moved based on the velocity field. By tracing their change in position a map was created showing the origin of the particles that were collected in the water supply wells. Such a map is shown in Figure 19, and shows both where water is infiltrated and if existing contamination in the aquifer is likely to reach the water supply wells. Travel times for the particles from surface to wells is also important in the sense of vulnerability mapping, as a fast travel time means that no remedial actions could be introduced if an accident were to occur.

Figure 19 shows examples of capture zones and transport times to the Ljubljansko Polje well fields. The figure shows that the well fields "fight" for water resulting in a very complex flow pattern and that that the groundwater that is extracted is from both recharge and river infiltration. Furthermore, the river does not act as a hydraulic divide since some of the water pumped from the wells comes from the opposite side of the river. Most of the pumped groundwater is less than 2 years old, which leaves little time for remedial action.

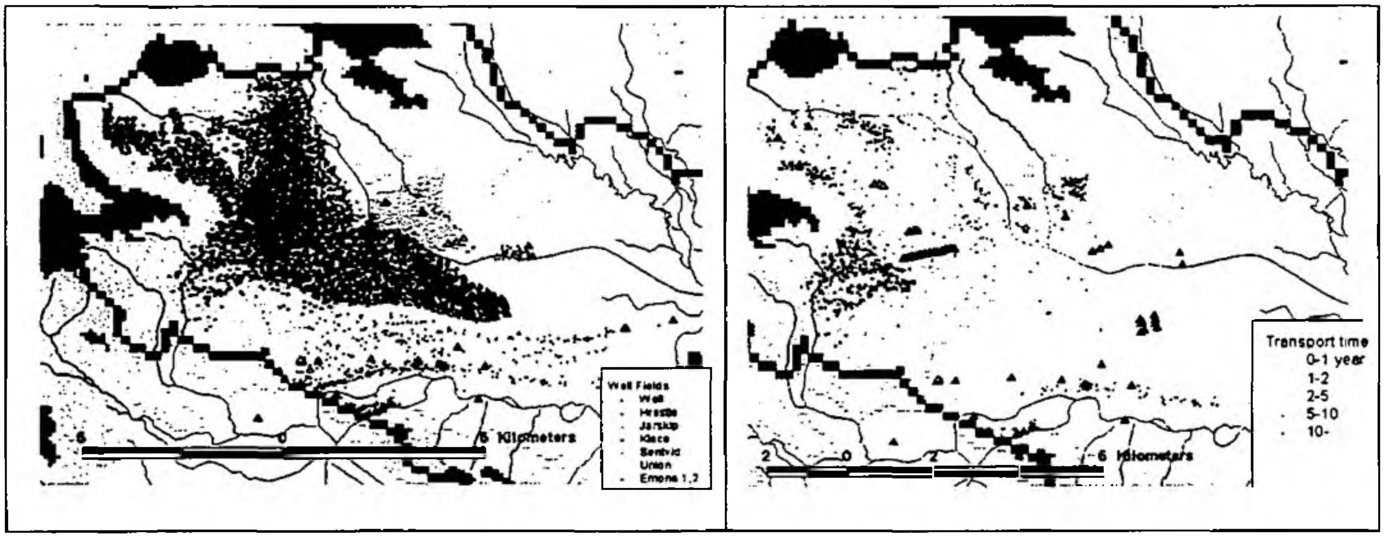

Figure 19 Capture zone and travel times for the major well fields exploiting the Ljubljansko Polje aquifer

Similar maps were created for the various flow conditions, since there is a large variation in flow patterns in the area. These maps, together with maps of the simulated groundwater recharge distribution served as a basis for developing a generalised groundwater vulnerability map and a prioritised groundwater protection map.

LIMITATIONS IN INTEGRATED, DISTRIBUTED MODELLING

The modelling and vulnerability concepts described in this paper are, in principle, ideal for contributing to the vulnerability mapping process. However, a number of limitations exist in the use of this integrated, distributed approach.

In most catchment studies, it is not possible to use a spatial resolution sufficiently detailed to claim that the developed models are physically based. This is not the same as claiming that the code is physically based. However, this is a familiar problem faced by the traditional groundwater modeller who uses pumping test data to determine hydraulic conductivity distributions. Thus, even though groundwater models are gross simplifications of real aquifers the model results have been useful. Likewise integrated models can provide numerous benefits even if there is considerable lumping of the parameter values.

There are also a number of scale problems that should be carefully considered when developing an integrated model, including:
The flow exchange between groundwater and the river system is defined by Darcy's Law and the difference between the river stage and the next adjacent groundwater node. Thus the flow rates and resultant head changes depend on the model discretisation, which can be important, for ex-ample, when simulating the hydrograph recessions correctly.

If a drainage network finer than the model grid exists, then it is not possible to model the entire network. In such cases, sub grid variations in topography need to be accounted for to simulate the hydrograph response in the main streams correctly.

The hydraulic parameters used for the unsaturated zone are typically measure on small, undisturbed samples in a laboratory. Such samples are rarely representative of the conditions in a grid square, which may be 10s or 100s of metres in size. Thus, effective parameters must be used in the model, and the simulated soil moisture results can rarely be validated directly from field measurements.

This last point is important because in most catchment models the use of Richard's equation becomes conceptual rather than physical and a simpler method could be used. However, the Richard's equation provides a good routing description and can simulate capillary rise under shallow water table conditions (e.g. in wetlands).

Finally, it is often argued that fully integrated, fully distributed models are too data intensive and they are likely to be over-parameterised. This risk is certainly there, but it also exists in any typical groundwater model. Generally it is not worthwhile and is too time consuming to modify a large number of parameter values, for example, to make a hydrograph fit better, if the data are not there to support the modifications.

CONCLUSIONS

A concept for vulnerability mapping, which leads to a prioritised groundwater protection strategy has been described. This concept has been implemented in a geographical information system (GIS) and includes a number of distributed hydrogeologic and anthropogenic parameters, including geologic and numerical modelling. The integrated groundwater and surface water modelling system, MIKE SHE with MIKE 11, was used with particle-tracking analysis to demonstrate this method of evaluating groundwater vulnerability. The GIS was used to display and analyse all parameters both individually and together.

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24. PROBABILITY-BASED PROTECTION ZONES IN FRACTURED AQUIFERS – IMPLICATIONS FOR LAND-USE PLANNERS

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ABSTRACT

Source protection zones (SPZs) are defined as part of the Environment Agency's policy for the protection of groundwater. The Agency have delineated SPZs for boreholes and springs on the basis of horizontal flow time and distance from the source, giving four divisions of the capture zone: the operational courtyard, the inner and the outer protection zones, and the total capture zone. These zones are usually determined through reverse particle tracking for the required time using 'porous media' numerical models. However, most Major and Minor Aquifers of England and Wales are fractured to some degree.

Drawing on the outcome of an R&D project for the Environment Agency and continued research at UCL, a prototype methodology is being developed for delineating protection zones in fractured rock. This approach considers fractured aquifers explicitly, and gives a more rigorous treatment of the uncertainties associated with fractured aquifers, resulting in probability-based inner and outer protection zones and total capture zones. Case studies highlight the difference between the porous-media model derived protection zones and ones from the probability based fracture methodology. The practicalities of using probability-based protection zones by land-use planners is explored, together with the possible use of statutory probability-based zones under the Water Framework Directive.

INTRODUCTION

Groundwater protection zones (GPZs) in England and Wales have been developed for some 2,000 sources. These zones have been delineated using the models Flowpath (Franz and Guiguer (1989)) and MODFLOW (McDonald and Harbaugh (1988)), assuming flow through a porous medium. However, the majority of sources in England and Wales are within the fractured Major and Minor aquifers, and for many cases the porous-medium assumption[19] has been shown to be of dubious validity.

Therefore an improved methodology is required for delineating protection zones in fractured aquifers. However, any new methodology must be compatible with and enhance the present methodology since much expense and time has already been expended in creating the existing zones. Also few data exist for each groundwater source, especially in relation to fracture characterization, and hence any methodology must not have onerous data requirements, but can rely on the existing data and data that can be extrapolated from nearby. Due to the extreme heterogeneity of fractured systems, each fracture or aquifer parameter can take on a wide range of values. At present this parameter variability is dealt with using a deterministic uncertainty analysis outlined below. Any new methodology should incorporate a much more rigorous uncertainty analysis, preferably using a risk-based approach to produce probabilistic zones

[19] The 'porous medium assumption' takes the rock to be a continuum, so that flow could occur from any point to any other point and (continuum) properties (e.g. permeability and porosity) can be defined at every point.

(Robinson and Barker, 2000). In terms of land-use planning these probabilistic zones must be straightforward to apply and easily understood. Finally, and most importantly, the new methodology must be scientifically defensible, as economic decisions regarding land-use will be made as a result of the location and type of the protection zone in the area.

DEVELOPING A NEW METHODOLOGY

The existing Agency methodology

The delineation of protection zones under the present methodology relies on porous-media based numerical models to determine zones of advective travel time and total capture. These porous media models assume that the fractured subsurface can be represented by an equivalent porous medium (EPM) at the scale of the numerical model grid cell size. However, it is frequently inappropriate to use the EPM assumption in fractured rock situations. The existing methodology does, however, allow the aquifer parameters to be varied to obtain the deterministic uncertainty zones: the zone of confidence, best estimate zone, and zone of uncertainty. A confidence index is then attached to the modelled zones overall, given as the ratio of the area of the zone of confidence to the area of the zone of uncertainty, but the individual deterministic uncertainty zones do not have any confidence level attached to them.

The proposed methodology

Any robust methodology for fractured rock aquifer protection zones will rely on having the appropriate quality and quantity of data for the modelling method chosen. If numerical models are used that require large quantities of data that cannot be obtained from the field, theoretical arguments or from extrapolation across areas, then the zones produced will not be defensible. The method should also be as scientifically advanced as possible given the amount of data available, in order that the methodology is robust.

Stochastic models provide a tool by which this new, more robust methodology can be developed to produce protection zones in a risk-based environment. Stochastic models also allow uncertainty in all parameters to be simulated, thus being far more rigorous than the deterministic uncertainty analysis performed in the present methodology. In order to produce risk-based or probabilistic protection zones the stochastic model would require distributions of parameters. In general stochastic fracture models require the following as a minimum:

- Density or spacing of each fracture set and their distributions;
- Orientations of each fracture set and their distributions;
- Trace lengths of each fracture set and their distributions;
- Apertures of each fracture set and their distributions.

Let us first examine whether we have sufficient, or can gather sufficient, data for such a stochastic model. Data that exist, in general, for a groundwater source comprise:

- Pumping test data giving transmissivity and storativity data, as well as cone of depression information;
- Geology map of the area;
- Borehole logs for the site.

Occasionally there may be other sources of data such as:

- Geophysical logs;

- Packer testing data;
- Tracer testing data.

It can therefore be seen that, unless extremely good geophysical logs and tracer testing has taken place at the site, many of the parameters and distributions required for the stochastic model will not be available. Can any of the data required be obtained from alternative sources? Fracture outcrop analysis is straightforward and takes little time to perform and allows distributions of fracture density, fracture orientation and fracture lengths to be obtained for each particular fracture set. However, there are other methods of obtaining fracture data. From extensive literature review it is considered that it is possible to extrapolate data across regions of the same structural provenance and also to infer data from theoretical relationships. For example:

- **Fracture Density or Spacing**
  - Structural relationships show that for many sedimentary rocks, as are many of the Major Aquifers of England and Wales, there is a linear relationship between bed thickness and fracture spacing (Ladeira and Price, 1981). Since the bed thickness is often known from geological logs then an estimate of fracture spacing can be obtained.
  - Rock Quality Designation data are often available for many sites since the parameter is assessed in geotechnical investigations for rock mass quality and behaviour. Priest and Hudson (1976) relate this data to fracture spacing data for a given spacing distribution.
  - Percolation theory relationships presented by Robinson (1984) and Charlaix *et al.* (1984) indicate the connection between fracture density and fracture length. Therefore if one parameter is known, an estimate of the other can be made.
- **Orientation**
  - The orientation at which fractures develop depends on the stress regime at the time of formation. In general the orogenic and tectonic history of England and Wales is well understood, with the stress regimes at different times being known. Hence, from structural considerations, it should be possible to predict the types of fracture patterns seen from the stress history and local knowledge of that particular region.
- **Fracture Lengths**
  - As discussed in determining fracture density, percolation theory relationships presented by Robinson (1984) and Charlaix *et al.* (1984) indicate the connection between fracture density and fracture length.
  - Hatton *et al.* (1994) showed that there is a universal scaling law relationship between fracture length and fracture width or aperture. Therefore if one of the parameters is known, an estimate can be made of the other.
- **Apertures**
  - As discussed above, the relationship presented by Hatton *et al.* (1994) allows an estimate of aperture if fracture length is known.

From extensive literature review it has also become apparent that for each of the fracture parameters there is a statistical distribution that parameter is most likely to adopt. For example, trace lengths, aperture and density are likely to follow a log normal distribution, and orientation tends to follow an elliptical distribution.

Therefore, it is considered possible to obtain sufficient fracture data from site data and alternative sources for a stochastic fracture model, involving only moderate effort. The use of a stochastic fracture model to delineate protection zones therefore seems feasible. However, from a practical point of view, the size of domain that can be modelled using a stochastic fracture model, even on a relatively powerful PC does not approach source catchment scale. The inner protection zone could be modelled using the stochastic fracture model alone, but not the outer zone or the catchment of the source. One of the main requirements of the new methodology is consistency, therefore a method of incorporating the fracture model within a model that has the capability simulating a catchment-scale domain is required, so that all zones are developed using the same technique.

The new technique must still simulate the heterogeneity of the fracture flow patterns, but be within the framework of a porous media model to permit catchment-scale stochastic modelling, leading to probability contours. The modelling technique should be 3-D to simulate the connectivity and heterogeneity of the fracture systems with confidence. This can be achieved by combining a stochastic 3-D fracture flow model, such as Fracman, and a 3-D porous media model, such as Modflow.

The proposed methodology consists of four principal stages:

1. Data collection and collation. Fracture parameters and distributions are obtained from existing data, any new data collected from the field, as well as data extrapolation and theoretical considerations.
2. Fracture flow modelling. Firstly the fracture system must be set up and calibrated with available data. Then flow across a fracture block must be simulated to obtain the effective permeabilities and porosities in all directions across the fracture block. The size of the fracture block used in the simulations is varied in order to find a size above which the permeability and porosity tensors stabilise. The block size at which the permeability and porosity tensors stabilise represents the representative elementary volume (REV) of the rock.
3. The directional porosity and permeability distributions are fed into a stochastic porous media model such as Modflow with a grid cell size that is the same size or bigger than the REV determined in stage two. The boundaries and features of the area to be modelled are set up, such as rivers, drains and recharge. The model is then calibrated using parameters not used in calibration in the fracture model, for example, recharge. Reverse particle tracking is then performed for multiple realizations of the model.
4. The particle tracks are then analysed to produce the probability contours for the 50-day, 400-day and total capture zones.

Testing the Proposed Methodology

Three of the four principal stages of the methodology have been tested and are described here. The first two stages of the methodology have been considered in relation to a site in the Old Red Sandstone of Ross-on-Wye, near Gloucester. Groundwater flow within this unit is considered to be primarily by fracture flow with negligible intergranular flow (Mott MacDonald, 1996), with the flow primarily occurring in the upper 30 - 50 m. Groundwater flow is thought to be towards the NNW with a gradient of between 0.01 and 0.04.

During April 1998 three new monitoring boreholes were drilled on the Alton Court site, Ross-on-Wye. The boreholes were cored, packer tested and geophysically logged. Radially converging tracer testing was then performed in conjunction with a pumping test. This relatively new set of data has been used in conjunction with the existing data to build up a conceptual model of the site. The fracture statistics were then input into Fracman and the model calibrated so that good agreement was obtained between the model fracture network and the measured fracture parameters. The parameters used in calibration were fracture density within a borehole, fracture density of individual fracture sets, storativity of the overall system, transmissivity of a borehole, aperture sizes and also numbers of fractures intersecting a borehole.

Initial simulations were performed to obtain agreement with the first set of parameters on creating a fracture network, but without any flow modelling. With this set of parameters flow modelling was conducted to obtain calibration with the pumping test data. The pump test data were the most important data with which to achieve calibration, and therefore it is this second set of parameters that are used in further modelling. These parameters are summarised in Table 1.

Table 1 Fracture parameters for Alton Court after calibration

Parameter	**Fracture Set Number**		
	Set 1	**Set 2**	**Set 3**
Strike (degrees)	144.0	320.0	31.5
Dip (degrees)	24.6	67.5	8.3
Distribution	Fisher	Fisher	Fisher
Distribution coefficient – dispersion[1]	10	10	10
Size (m)	10	10	10
Size Distribution	Log normal	Log normal	Log normal
Standard Deviation	5	5	5
Direction of Elongation (degrees)	0	0	0
Aspect Ratio	1	1	1
Termination %	0	0	0
Intensity (m^{-1})	0.505	0.376	0.157
Intensity Distribution	Gamma	Gamma	Gamma
Distribution coefficient[1]	0.05	0.01	0.001
Transmissivity (T) correlation[1]	With size	With size	With size
T Correlation exponent[1]	0.3	0.3	0.3
T Correlation factor[1]	2.57×10^{-6}	2.57×10^{-6}	2.57×10^{-6}
T Deviation factor[1]	1	1	1
Storativity (S)correlation[1]	With size	With size	With size
S Correlation exponent[1]	0.3	0.3	0.3
S Correlation factor[1]	5×10^{-6}	5×10^{-6}	5×10^{-6}
S Deviation factor[1]	1	1	1
Fracture thickness correlation[1]	Uncorrelated	Uncorrelated	Uncorrelated
Fracture thickness (m)	10^{-4}	10^{-4}	10^{-4}

Note: [1]Parameters as defined in the Fracman model (Dershowitz *et al.*, 1998)

These parameters were then taken and used to create multiple realizations of the calibrated fracture system. A hydraulic gradient was then applied across each of the blocks in different directions and the flow in and out of the block calculated. An effective permeability of the block could then be obtained using Darcy's Law for each different direction. Additional realizations were performed until the distribution of the permeabilities in each direction stabilised. The size of the fracture block used in the simulations was then varied to ensure that the size of block used was a representative elementary volume. Particle tracking was also performed at the same time across each of the block realizations to determine the distribution of times for the particles to cross the block. The distribution of effective velocities could then be obtained since the path length is known. The effective permeability in that direction is also known from the flow across the block and hence an effective porosity in that direction can be derived.

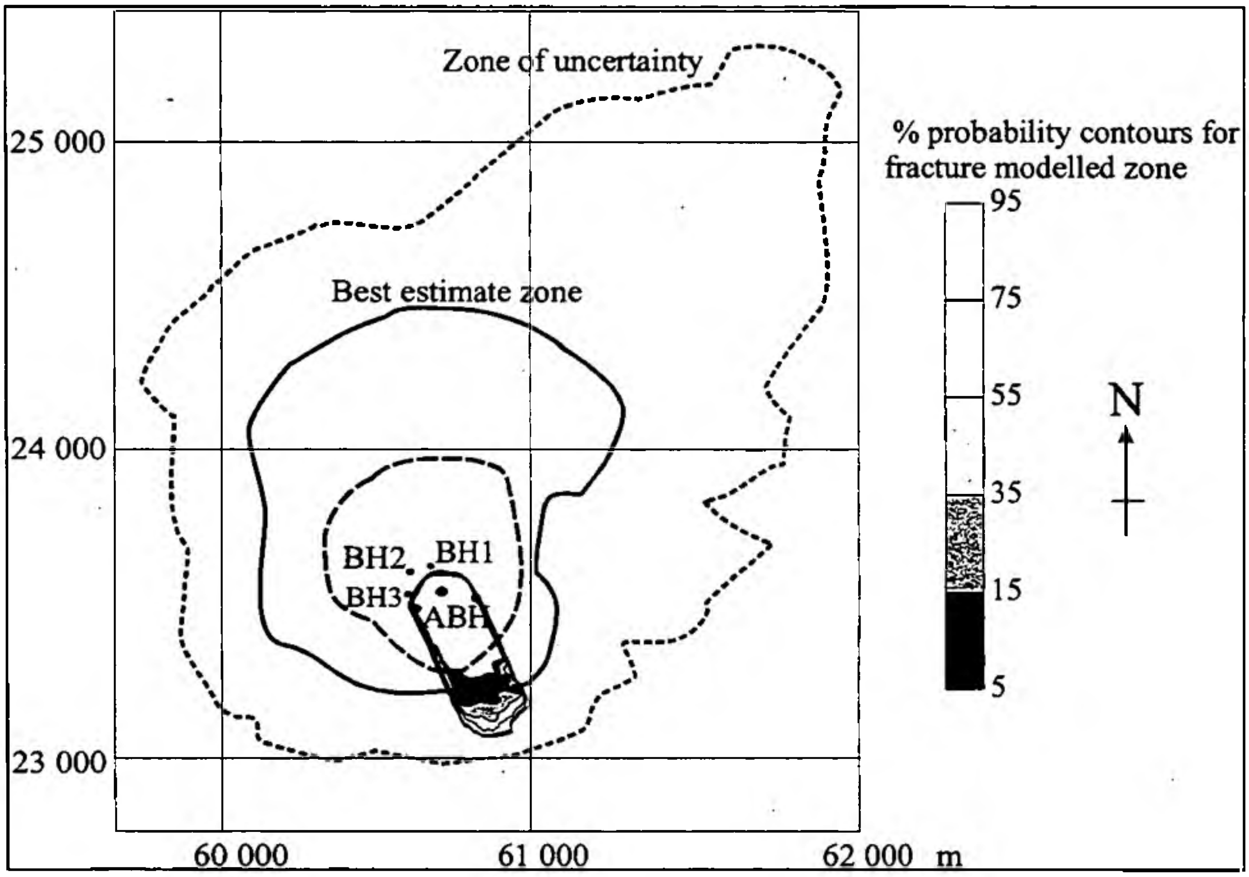

Figure 1. Comparison of 50-day probability based protection zone contours and the original 50-day protection zones at Alton Court.[20]

The fourth principal stage of the methodology has also been successfully tested. A code has been developed to take the ensemble of particle tracks and derive the probability contours from them. This has been done for the Alton Court site. In order to test the code for creating the probability contours, the site was initially modelled using the 2-D particle-tracking stochastic fracture model, SDF. This SDF model and new code were used to create the probability contours for the 50-day travel-time zone, and these contours are shown in Figure 1. An interesting aspect of the probability-based protection zone contours is they have been

[20] To some degree the comparison here is considered to be anomalous because a) the fractured media zones in this case are much smaller than the porous media zones (possibly because of the small effective porosity used in the porous-media model) and b) the unpumped groundwater flow direction is towards the north in the Alton Court area, but the regional groundwater model from which the porous-media model zones are derived suggests that unpumped groundwater flow directions are towards the south, suggesting a poorly calibrated porous-media model.

partially validated using forced-gradient tracer testing from BH1, BH2 and BH3 to the abstraction well (Figure 1). The tracer testing showed that the injection boreholes were on the edge of the capture zone of the well, as indicated by the fracture modelling. The porous media protection zones do not show good agreement with either the tracer testing at the site or the fracture modelled zones. However, it must be noted that the probability contours presented here are from a modelling exercise in 2-D[21], rather than in 3-D as advocated in the proposed methodology. Therefore, the good agreement of the fractured media zones with the tracer testing are fortuitous, rather than by design in using the correct 3-D conceptual model for the site.

In summary, therefore, implementation of the methodology has shown to be successful. However, as with the porous media derived protection zones, a method must be found to validate the zones. The validation is concerning the uncertainty in our knowledge of the fractured system, or in other words to what extent the system is unknown, rather than assessing the uncertainty in the aquifer parameters. Validation of probability-based protection zones will be more complex than deterministic protection zones, but as seen with the case study at Alton Court, tracer testing offers an important tool to aid in their validation.

INTERPRETATION OF PROBABILITY CONTOURS

In order to be able to interpret the probability contours created using the proposed methodology an understanding of how the contours are developed is important. The method for creating the probability contours relies on using a stochastic model that is capable of particle tracking, such as stochastic Modflow with Modpath. There are two different techniques for creating the probability contours; one for delineating the 50-day and 400-day contours and another one for delineating the total capture zone contours.

Both techniques rely on combining reverse tracked pathlines for multiple scenarios and multiple realisations within each scenario. The particles are reverse tracked for many years, as in the existing methodology, so that the total capture zone of the groundwater source can be determined. A horizontal two-dimensional grid is superimposed on the area covered by the reverse tracked particles: this surface essentially represents the water table.

For the 50-days and 400-day contour technique, the times at which particles pass through each element of the grid (e.g. a grid square) are noted. Many particles will pass through most grid elements, because of the multiple scenarios and multiple realisations within each scenario that have been reverse tracked, so a distribution of travel times for each element can be determined. For the chosen travel time, i.e. 50 days or 400 days, the probability of particles taking longer than that time to reach the well is determined from examining the distribution. The probability is then contoured across the model domain to obtain the full set of probability contours for each travel time. This technique is illustrated in Figure 2, although this represents is a 2-D rather than 3-D version of the procedure.

The technique for calculating the total capture zone probability contours is slightly different to the other protection zones. For each model realization, a flag is set for each grid element to indicate whether any particle passes through it. This is repeated for all scenarios and multiple realizations within each scenario. The probability of a grid element lying inside the capture

[21] In fact, 2D modelling was not successful in that it proved necessary to increase the model fracture lengths by a factor of 50 from the trace lengths obtained through percolation theory relations, in order for the network to percolate in 2D.

zone is calculated as the proportion of realizations for which no particle has entered. The probabilities are then contoured in the same way as with the other protection zones. Thus, higher probabilities occur at greater distances from the well and indicate increasing certainty that the (probability) zones encompass the capture zone.

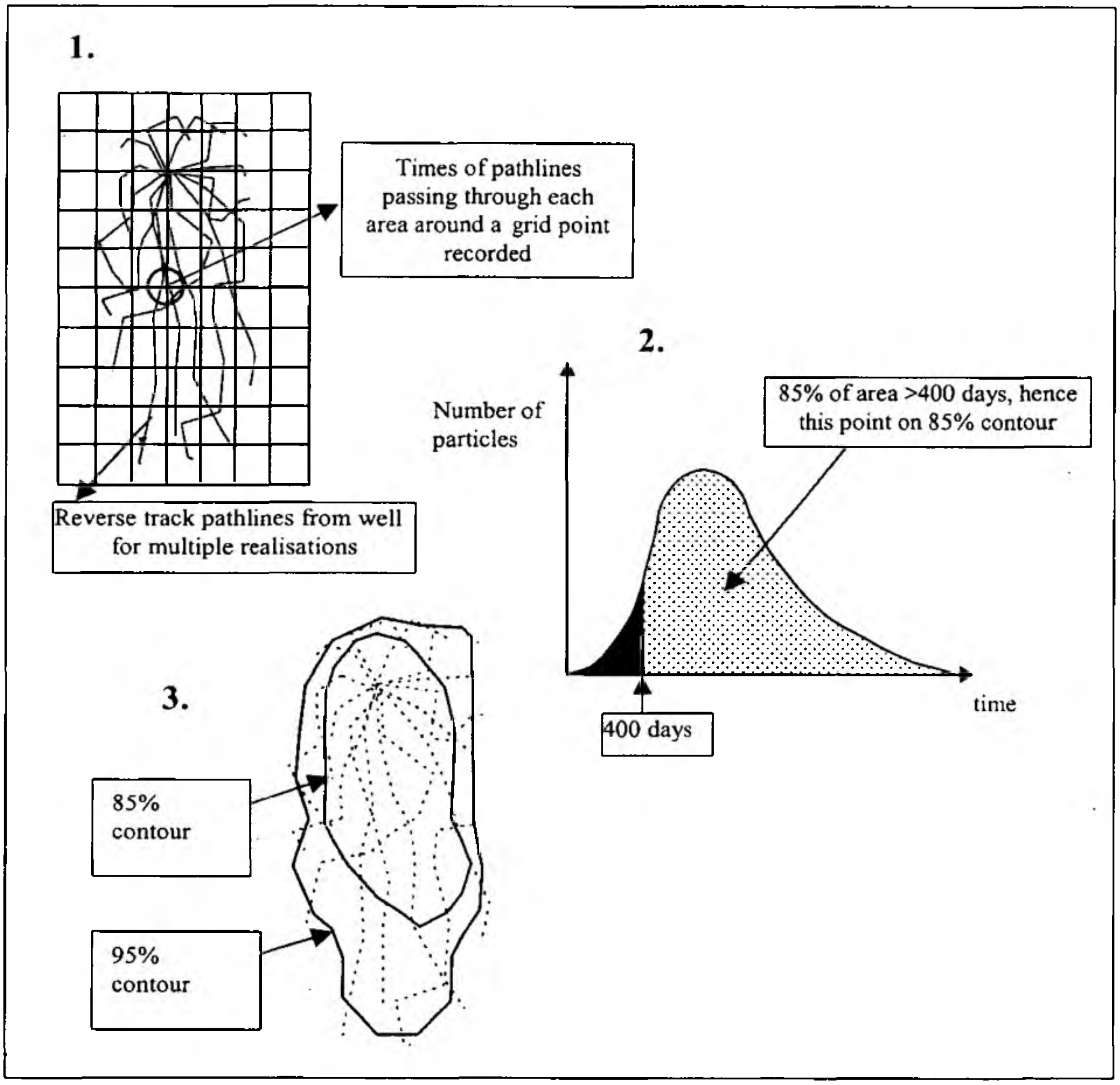

Figure 2. Technique for creating probability contours for 50-day and 400-day protection zones.

The probability contours aim to show the confidence in modelling the system. The definition of the probability contours is based on the proportion of ensemble realisations for which particles released at a point reach the well in more than a given time e.g. 50 days or 400 days. Therefore the 10% probability contour will be closer to the abstraction well than the 90% probability contour. Therefore the higher the probability, the higher the confidence that the actual protection zone for the well lies within the area. The width of the travel-time distributions at the individual points around the well also give an indication of the overall uncertainty in travel-times for the fracture network over that length of time and distance from the well. If the width of the probability contours (say between 10 % and 90 %) is large then the uncertainty in travel-times in that fracture network is large. Also vice versa, if the distance between the probability contours is small then there is a smaller amount of uncertainty associated with the system.

Interpretation by the Regulator and Land-Use Planner

Having developed a methodology whereby protection zones can be described in a risk-based framework, consideration must be given to the following issues if they are to be used by the land-use planner and the regulator:

a. Which probability contour should be used for making land-use decisions;
b. What decisions should be made if the new probability-based contours are excessively large?[22]
c. How the probability-based zones should be represented in map format;
d. If the protection zones change dramatically in size and shape, some landowners may find their land, which has previously been in a protection zone, no longer being located within a zone.

If we consider the first issue, in order to protect the groundwater source to a high degree, ideally the high probability contours should be used, for example the 90% or 95% contour, since these contours would encompass the larger area around the groundwater source. However, in practice this may mean that the probability-based protection zone becomes extremely large, especially in areas of sparsely fractured rock, and therefore unworkable. In this instance, can the 50% probability contour be used, for example? If this is done, then all zones would have to be set at the 50% contour for consistency. The regulator would have to decide which probability would represent the protection zone, and it is more than possible that this decision could not be made until many case studies had been completed to obtain the full range of protection zone sizes and shapes.

One alternative to this would be to have different probabilities applying to different land uses. For example, activities such as sheep dipping and the new location of petrol stations that put groundwater at a higher risk of contamination should not be permitted within, for example, the 90% contour. Consideration of the probability contours in this context would require the set of policy statements that support the protection zones to be revised.

In considering the third issue, the most practical option would be to illustrate the 50-day, 400-day and capture zones on separate maps for clarity. It is possible that in some instances the low probability contours of the 400-day zone could overlap with the high probability contours of the 50-day zone. Therefore, to avoid misinterpretation the different sets of probability contours should be illustrated separately.

If a landowner does find that his land has moved from being within a restricted area to being outside, and that land-use restrictions have been applied in the past but are then lifted, does this entitle them to compensation? It must remembered that dramatic changes in the extent and shape of the zones will not be well received by those whose land alters in the restrictions applied. However, it should be remembered that when working with probabilities, a point outside a zone may be within the 'true' protection zone, and therefore from a technical point of view it is unlikely that compensation could be claimed.

[22] We have yet to complete the development of a set of codes to implement the methodology, but we strongly suspect that the zones they give will be large, both because of the geometrical heterogeneity and because travel times are very sensitive to apertures, which cannot be well constrained.

Implications For Statutory Probability-Based Protection Zones

Under the new Water Framework Directive there is a possibility that protection zones could become statutory when interpreted by the UK regulator. The Water Framework Directive (2000) states under Article 7 "Member States shall ensure the necessary protection for the bodies of water identified with the aim of avoiding deterioration in their quality in order to reduce the level of purification treatment required in the production of drinking water. Member States may establish safeguard zones for these bodies of water."

If protection zones become statutory under this Article, then it becomes extremely important that the zones are defensible. With probability-based protection zones the defensibility becomes easier to justify since the probability zones themselves accept that there is a limit to our knowledge and understanding of the system, giving quantification to this uncertainty.

The Water Framework Directive also states that all "Protected Areas shall be kept under review and up to date". If the proposed methodology were to be adopted then this task would certainly be achieved, as scientifically more rigorous and up to date zones would be produced, as well as keeping the existing zones under review.

SUMMARY

It has been shown that the production of probability based protection zones can be achieved, giving results in terms of a risk-based framework. This risk-based approach is consistent with other Environment Agency approved modelling approaches to groundwater quality assessment, with the use of models such as LandSim and ConSim. The proposed methodology would also meet the requirements of the Water Framework Directive to keep the protection zones under review and up to date. If the proposed methodology is to be adopted then this must be in the full understanding that fractured rock protection zones are expected to be larger than at present, and may also cover new areas. Also, if the proposed approach is to be taken up then careful consideration must be given to the policy changes required.

However, despite the extra effort that may be required with regard to the policy statement changes, the zones produced will ultimately be more defensible than the existing ones; the uncertainty analysis is far more rigorous with quantification of uncertainty in the probabilistic zones, and the fractured rock characteristics are taken into account.

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25. MICROBIAL AND CHEMICAL TRACER MOVEMENT THROUGH CONTRASTING SOILS

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ABSTRACT

Land treatment of effluent can result in chemical and microbial contamination of shallow groundwater. We investigated the fate of two microbial tracers and a non-reactive chemical (Br^-) tracer when applied to large undisturbed lysimeter soil cores. The soils included a poorly drained Gley Soil and well-drained Pumice, Allophanic and Recent Soils. Resulting leachates, collected continuously over at least one pore volume, were analysed for the microbial and bromide tracers. Bromide moved uniformly through the Pumice and Allophanic Soils with peak concentrations at about one pore volume, while the microbial tracers were detected only at low levels or not at all. In contrast, both bromide and microbial tracers moved rapidly through Gley and Recent Soils, appearing early in the leachate and then tailing off. Such flow patterns in the Gley and Recent Soils are indicative of bypass flow. Coarse soil structure in the Gley Soil and finger-flow due to water repellency in the sandy Recent Soil were considered responsible for the observed bypass flow. Allophanic and Pumice soils have finer, more porous soil structure leading to a predominance of matrix flow over bypass flow. This study suggests vertical movement of microbes varies significantly with soil type.

INTRODUCTION

Land application of sewage waste may contaminate receiving groundwater by mobilising entrained microbes through soils with percolating waters (Burge and Enkiri 1978). Although a number of soil-microbe interaction studies have established relationships between soil material and microbial movement, many are limited by the use of repacked soil cores (Isensee and Sadeghi 1999), soil suspensions (Moore *et al.* 1981) or are topsoil studies only (Gagliardi and Karns 2000). In such studies, where deeper layers of the soil profile and effect of bypass flow have not been included, movement of applied microbial loads to the soil have not been adequately examined for practical purposes.

Geologically New Zealand is tectonically active, with numerous volcanoes, resulting in a diverse landscape with a wide range of contrasting soil types occurring over short distances. There is a paucity of data on the fate of the microbial loads applied to New Zealand soils. Wells (1973) rated the properties of New Zealand soils in relation to effluent disposal and concluded that fine-grained soils from young (2000 to 7000 years age) tephra had the ideal combination of soil properties for effluent disposal.

However, there were no supporting experimental data. A study of coliforms in leachates from soil cores irrigated with secondary treated municipal effluent (Childs *et al.* 1977) is difficult to interpret as issues of edge-flow, inadequate core diameter (150 mm) and the use of some repacked cores were not addressed.

Given the paucity of information on the transport of microbes through different soils in New Zealand, we examined the fate of a bacteriophage, faecal coliforms and Br^- tracer applied to large, undisturbed lysimeter soil cores from typical North Island soil types commonly used for effluent treatment. Tracer solution was applied as a pulse followed immediately by rainfall applied via an overhead rainfall simulator.

MATERIALS AND METHODS

SOILS

The four soils used in the study cover a wide range of chemical, physical and mineralogical properties (Table 1). The clayey Netherton soil (Typic Endoaquept [Soil Survey Staff 1996], Gley Soil [Hewitt 1992]) is developed in estuarine alluvium and has coarse prismatic subsoil structures with low porosity within the prisms; organic matter often lines structural cracks. Topsoils have medium or coarse polyhedral structure. The soil has mixed clay mineralogy.

The Atiamuri soil (Typic Udivitrand [Soil Survey Staff 1996], Pumice Soil [Hewitt 1992]) is developed in sandy rhyolitic tephra grading into massive but porous, welded pumice flow tephra at about 40 cm depth, which is inimical to root development but allows the movement of water.

The Waihou soil (Typic Hapludand [Soil Survey Staff 1996], Allophanic Soil [Hewitt 1992]) is developed in rhyolitic tephra and has allophanic clay mineralogy with variable charge. It is likely to have some positive surface charge at typical field pH.

The young Waiterere soil (Typic Udipsamment [Soil Survey Staff 1996], Recent Soil [Hewitt 1992]) is developed in dune sand and has minor pedological development with single grain structure throughout, except for some weak aggregation in the topsoil.

Soil Lysimeters

Three replicate, undisturbed lysimeter cores (500 mm diameter × 700 mm high) from each soil were used in this study. Soil lysimeters from farm paddocks were hand carved *in situ* and the lysimeter casing progressively pressed down over the soil monolith. The lysimeters had a 10-mm internal annulus filled with petroleum jelly to prevent water preferentially flowing at the soil-casing interface (Cameron *et al.* 1992). A sampling port was installed in the centre of the base of the lysimeter to allow collection of leachate. The pore volume (PV) for each set of lysimeter cores (Table 1) was established from the same sites by extracting replicate undisturbed soil cores (55 mm dia. × 30 mm high) from each soil horizon and determining total porosity (Gradwell 1972).

TRACER EXPERIMENTS

The tracer studies were conducted as two separate experiments on the same soil lysimeters. Firstly, a combined bacteriophage and bromide tracer was applied and its transport examined. Secondly, transport of faecal coliforms applied via dairy shed effluent (DSE) was examined. Lysimeters were irrigated with tap water for 2 days to bring the cores to field saturation with leachate emanating from the sampling port, then allowed to drain for 7 days before application of the tracer solutions. Seven days is similar to the return period commonly used at effluent irrigation sites.

The tracer solution containing bacteriophage (10^9 PFU/mL) and Br^- (2000 ppm) was irrigated onto each lysimeter at 5 mm/h (30 mm depth of application). The lysimeters were then irrigated continuously with water at a rate of 5 mm/h using a drip-type rainfall simulator with drippers spaced on a 20-mm triangular grid approximately 170 mm above the soil surface as shown in Figure 1. Background levels of host-specific *Salmonella* bacteriophage and bromide in leachate were determined from samples taken at the end of the wetting-up period. Determination of any ponding during application and subsequent irrigation was by visual observation.

Table 1 Summary of soil properties of the four soils studied

Soil property		**Netherton soil**	**Atiamuri soil**	**Waihou soil**	**Waitarere soil**
Classification[1]		Gley Soil	Pumice Soil	Allophanic Soil	Recent Soil
Origin		Estuarine alluvium	Proximal airfall pumiceous tephra	Distal airfall tephra	Dune sand
Drainage Class		Poorly drained	Well drained	Well drained	Well drained
Texture		Clayey	Coarse sand, some gravel	Silty	Sandy
Morphology		Coarse soil structure	Fine to single grain soil structure. Welded pumice below about 400 mm	Fine soil structure	Single grain soil structure
Topsoil thickness (mm)		14	10	18	12
K_{sat} (mm/h)[5]	Topsoil	50	60	120	100
	Subsoil	30	30	110	200
K_{-40}[2] **(mm/h)**[6]	Topsoil	12[3]	15	60	40[4]
	Subsoil	1[3]	20	35	40[4]
Carbon (%)[7]	Topsoil	5.4	8.1	6.8	6.0
	Subsoil	0.8	0.4	1.7	0.6
pH[7]	Topsoil	6.1	5.5	5.1	5.0
	Subsoil	5.1	6.2	6.5	5.7
CEC (me./100 g)[7]	Topsoil	32	21	28	19
	Subsoil	27	6	12	3
Sand (%)	Topsoil	10	37	24	87
	Subsoil	0	42	19	94

Silt (%)	Topsoil	38	60	50	7
	Subsoil	31	57	47	4
Clay (%)	Topsoil	52	3	26	6
	Subsoil	69	1	34	2
Lysimeter pore volume (L)		72.1	77.9	79.79	56.2

[1] (Hewitt 1992) [3] Joe (1984) [5] Klute and Dirksen (1986) [7] Blakemore *et al.* (1987)
[2] Nearby site. [4] Magesan *et al.* (1999b) [6] Cook *et al.* (1993)

Lysimeter leachate samples were collected in volumes ranging from 250 mL to 2 L, depending on where the peak in the breakthrough curve (BTC) was anticipated. In general, the early part of the Netherton BTC was sampled each 250 mL (based upon initial experiments, data not presented) while the other soils were sampled over 2-L intervals until close to the anticipated peak at 1 PV, when the leachate was sampled at 1-L intervals. Soil leachate was collected into sterile bottles and subsampled. Subsamples for microbial assays were stored on ice and analysed as described below within 24 h of collection. Bromide concentration in the leachate samples was measured using an ion selective electrode (Metrohm 6.0502.100 Switzerland) within 1 week of collection. Leachate volumes are expressed in percent of pore volume. One pore volume is the amount of space in the soil core occupied by soil pores or cracks. This was typically about 45–65% of the total soil volume. Results of bromide and microbial assays were transformed to C/Co values (where Co = applied tracer concentration, C = tracer concentration in lysimeter leachate). These values were plotted for each individual lysimeter replicate on a linear scale for each soil type. Recovery percentages of tracers were calculated by integrating all sample values over the total volume collected.

Figure 1 Diagram of the lysimeter, irrigation, and leachate collection system.

The bacteriophage *Salmonella typhimurium* 28B (Lilleengen 1948) (size about 50 nm) was used as a tracer in this study. The phage, grown overnight on its host strain *S. typhimurium* Type 5 in Tryptic Soy Broth (TSB) (Difco) at 37°C, was isolated by chloroform lysis of the bacterial host then passed through a 0.45-µm mixed cellulose ester-based membrane filter to remove cell debris. To obtain a clean virus preparation free of organic material, the filtrate was centrifuged at 25,000 × g (Sorval T21) for 2 h at 4°C, the supernatant was poured off, and the phage resuspended in 1-2 mL of phage storage buffer (Sambrook *et al.* 1989) and stored at 4°C until required. Phage stocks were enumerated using the soft agar overlay method that resulted in plaque-forming units per mL (PFU/mL). Leachate samples (1 mL), diluted in phosphate buffer (pH 7.0) as required, were mixed with 0.5 mL of a 4 h host-strain culture in 8 mL molten soft-agar and poured onto nutrient agar plates (Difco). After 18–24 h incubation at 37°C, well-formed, clear plaques were counted and reported as PFU/mL. Each reported phage concentration is the average of three replicate soft-agar enumerations.

For leaching experiments with DSE, all lysimeters, except for the Waitarere soil, were irrigated (25 mm depth of application) with DSE at 50 mm/h. The lysimeters were then irrigated continuously with water and leachates collected as above. Before beginning the study, lysimeter ports and tubing were disinfected with sodium hypochlorite at 3 ppm for 15 min and the insides scrubbed and rinsed with tap water before reattaching and starting experiments. Faecal coliforms (FC) in DSE and soil leachates were enumerated using membrane filtration (American Public Health Association 1998). Samples were diluted in phosphate-buffered water (pH 7.0) as required, then filtered through cellulose-ester membrane filters (0.45 m pore size, Sartorius) according to standard procedures. The filters were placed on mFC agar (Difco). Duplicate plates were prepared for each dilution. Blue colonies were counted after 24 h at 44.5 ± 0.2 °C.

RESULTS

Samples of lysimeter leachate before bacteriophage application showed no phages capable of forming plaques on *S. typhimurium* Type 5 host strain. Lysimeter leachates before DSE application did not contain culturable faecal coliforms. The levels of faecal coliforms in DSE applied to lysimeters ranged from 1.4×10^6 to 1.2×10^7 /mL depending on time of sampling. Table 2 summarises the data obtained from the BTC and shows the peak concentrations of both microbial and chemical tracers and the pore volume at which the peaks occurred, plus the percentage of the tracer recovered.

Table 2 Summary of breakthrough curve results for the four soils

		Netherton soil	Atiamuri Soil	Waihou Soil	Waitarere soil
Bromide	Peak conc. (ppm)	119–409	383–473	140–154	555–810
	PV[1] of peak	0.02–0.11	0.59–0.68	1.17–1.31	0.19–0.23
	Recovery (%)	46–72 at 1.1 PV	87–91 at 1.0 PV	78–95 at 1.8 PV	89–107 at 1.4 PV
Bacteriophage	Peak conc. (PFU/mL)[2]	3.5×10^7–3×10^8	3–47	Not detected	1.5–5.6×10^7
	PV of peak	0.03–0.28	0.37–0.90		0.27–0.37
	Recovery (%)	6–38 at 1.1 PV	<0.15 at 1 PV		2–9 at 1.4 PV
Faecal coliforms	Peak conc. (/100 mL)	4.2–8.3×10^5	Not detected	1.32–3.13×10^2	Not applied
	PV of peak	0.0017–0.023		0.43	
	Recovery (%)	15 at 0.069PV		<0.5 at 1 PV	

[1] **PV Pore volume**
[2] PFU Plaque-forming units

Netherton Lysimeters

In this well-structured, clayey soil both the chemical and microbial tracers were present in the leachate at high levels early on in the BTC (Figure 2a), peaked early and had a long tail typical of soils that are dominated by bypass flow (Casey *et al.* 1998). One of the Netherton lysimeter replicates drained significantly more slowly than the other two and had surface ponding within hours of the start of irrigation. For the two lysimeters without surface ponding, the bromide peaked at about 20% of the application concentration by about 0.1 PV, whereas the bacteriophage tracer peaked at about 80% of the applied concentration. Recoveries of bacteriophage were 12% and 38% for non-ponded lysimeters, and 6% for the ponded lysimeter.

Maximum numbers of FC were collected at about 0.002 to 0.02 PV at approximately 30–60% of the application concentration. Faecal coliform numbers remained above background levels for the duration of the experiment and were still detected at slightly under 0.2% of the application concentration after about 1 PV of leachate had been collected. Up to 15% of the total FCs applied in DSE were collected in the first 5 L of leachate (about 0.07 PV).

Atiamuri Lysimeters

The bromide tracer peaked in a range between about 0.6 to 0.7 PV, but had a relatively symmetric BTC, suggesting matrix flow is the dominant flow regime (Magesan *et al.* 1999a) (Figure 2b). Bacteriophage tracer was present at very low levels in all of the replicates= leachates but the pattern was irregular, with some samples containing only a few virions, followed by other samples where the tracer was not detected. The peak bacteriophage C/Co ratio detected in the leachate was 9.4×10^{-12} at 0.9 PV. Less than 0.15% of the bacteriophage tracer was recovered from each lysimeter.

Faecal coliforms were not detected in 100-mL volumes of leachates up to 1 PV (*c.* 80 L) after the application of DSE and irrigation.

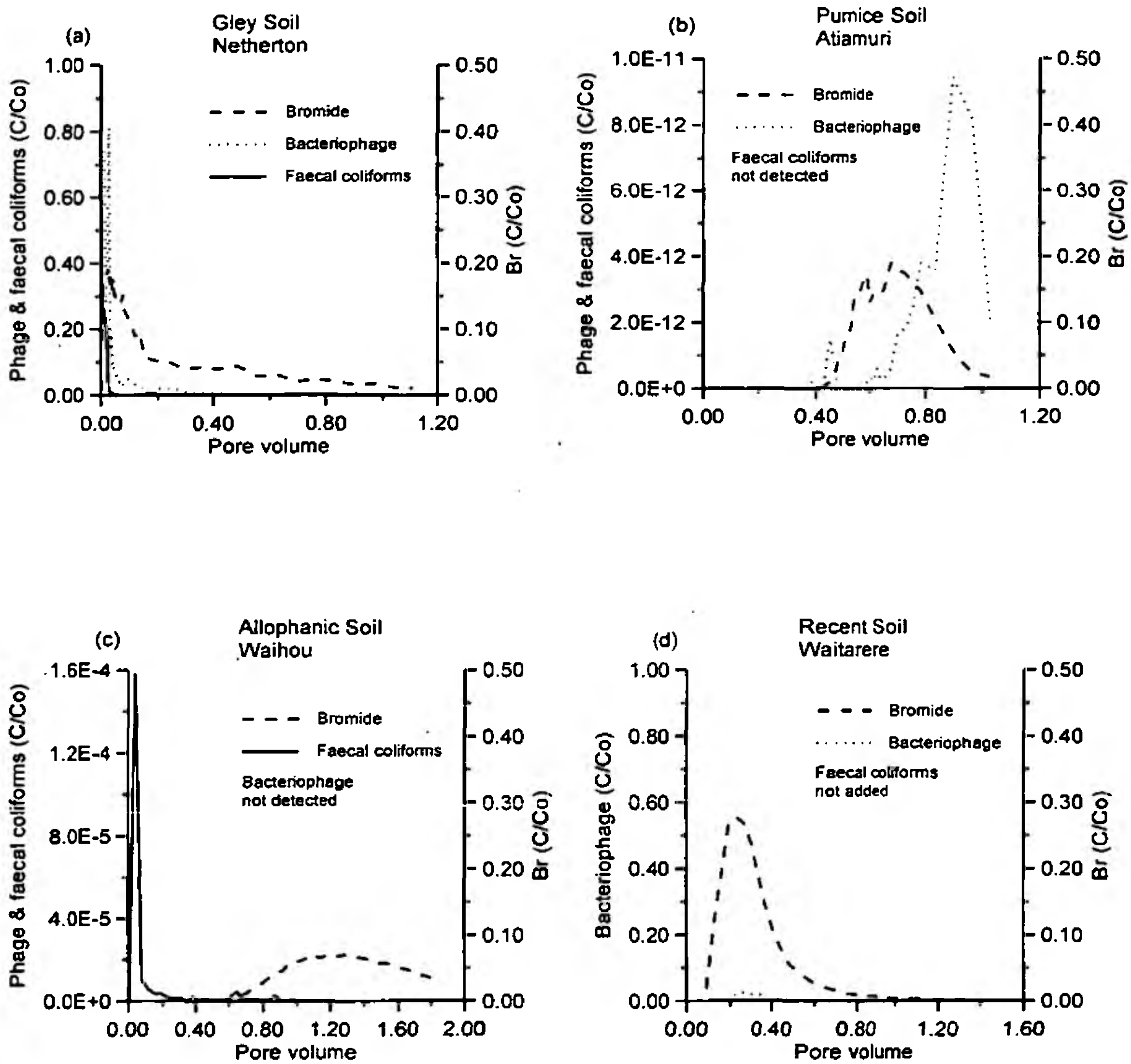

Figure 2 Typical examples of breakthrough curves for undisturbed lysimeters of Gley Soil (A), Pumice Soil (B), Allophanic Soil (C) and Recent Soil (D) showing leachate concentration ratios of bromide, bacteriophage and faecal coliform tracers following tracer application and simulated rainfall at 5mm/h. Note different scales.

Waihou Lysimeters

The bromide BTC was relatively symmetrical, indicating a predominance of matrix flow over bypass flow (Figure 2c). All bromide BTC peaked at about 1.3 PV, suggesting some retardation of the bromide tracer. The bacteriophage tracer was not detected in leachate samples collected to about 1.8 PV for Waihou lysimeters.

Low levels of faecal coliforms were detected in leachates from the Waihou soil. Maximum numbers of viable bacteria detected in the leachate occurred at 0.043 PV at about 0.04% of the application concentration. Faecal coliforms were still detectable in leachates at 1 PV, although levels were very low at about 2.3×10^{-3} % of the application concentration or 20 FC /100 mL. On the basis of averaging numbers of bacteria present in all leachates collected, we estimated that less than 0.5% of the total number of FCs, applied to the soil were collected in 1 PV of leachate from Waihou soil lysimeters.

Waitarere Lysimeters

In the sandy Waitarere soil, the bromide tracer was present in the leachate at maximum levels of about 30–40% of application concentration early on in the BTC, at about 0.2 PV (Figure 2d). As in the Netherton soil, this early high peak and long tail is typical of conditions where bypass flow is significant. The bacteriophage tracer showed similar flow characteristics to the bromide tracer. Bacteriophage peaked early at about 0.3–0.4 PV with peak concentrations of approximately 4% of the application concentration. Phage tracer values then progressively decreased to about 0.001% of the application concentration when sampling was discontinued. Recovery of the bacteriophage tracer ranged between 2% and 9%.

Dairy shed effluent was not applied to the Waitarere lysimeters, consequently assays of FC were not made.

DISCUSSION

Microbial and chemical tracers moved rapidly through the clayey Netherton (Figure 2a) and sandy Waitarere soils (Figure 2d). Bacteriophage tracer was not detected in leachate from the allophanic Waihou soil (Figure 2c) whereas faecal coliforms were detected at low levels. Conversely, low numbers of bacteriophage and no faecal coliforms leached from the pumiceous Atiamuri soil (Figure 2b). In contrast, the chemical tracer moved uniformly through both the Atiamuri and Waihou soils (Figures 2b, 2c) and had high percentage recovery. This illustrates the limitation of using chemical tracers to indicate movement of microorganisms through soils.

The early peak and long tail to the BTCs of microbes and bromide on the Netherton and Waitarere lysimeters (Figures 2a, 2d) are indicative of bypass flow, although actual flow mechanisms are likely to be different. The large difference between K_{sat} and K_{-40}, and the slow K_{-40} value in the Netherton subsoil (Table 1) indicates preferential flow is likely (Magesan *et al.* 1999a). The clayey Netherton soil has large structural cracks lined with organic matter and clay cutans, as well as large bio-pores (worm holes and root channels). Large macropores such as these can rapidly transmit microbes to depth (Natusch *et al.* 1996). Gerba and Bitton (1984) indicate it is generally agreed that fine-grained soils retain viruses more efficiently than sandy soils since the clay mineral fraction has a greater surface area and ion-exchange capacity. However, this must be tempered by the physical soil structure and the ability of percolating waters to hydrodynamically interact with the soil particles. In the case of the Netherton soil, large soil cracks rapidly transmit percolating waters minimising interaction with much of the fine-grained soil matrix. In contrast to the clayey Netherton soil, it is common for young dune sand soils such as the Waitarere soil to be water repellent (Wallis *et al.* 1991), and consequently develop finger-flow pathways through the soil (Bauters *et al.* 1998) with bromide transport velocities up to three times faster than estimated piston flow velocities (Ritsema and Dekker 1996). However, even with strong bypass flow characteristics, after 1 PV both Netherton and Waitarere soils continued to shed large numbers of the bacteriophage tracer.

Results from the allophanic Waihou soil, where no bacteriophage was detected, were not unexpected (Figure 2c). The soil has a fine polyhedral structure throughout, and McLeod *et al.* (1998) demonstrated only minor bypass flow of pyranine dye tracer on similar allophanic soils under slow overhead irrigation rates. The small difference between K_{sat} and K_{40} values indicates this soil has a uniform pore-size distribution and bypass flow is less likely (Magesan *et al.* 1999a). The Waihou soil contains up to 21% of allophane that tends to retain the bacteriophage because, at typical field pH, allophanic clays in the Waihou soil and the bacteriophage possess opposite net surface charge thus adsorption should be facilitated. As well, allophane has a very large surface area (700B900 m^2/g), which enhances virus sorption (Moore *et al.* 1982). These mechanisms may provide an explanation for the high virus sorption (low leaching) apparent in the Waihou soils. The low levels of FC detected in leachates of the Waihou soil following DSE application may be related in some part to the faster initial application rate of 50 mm/h for the DSE compared to 5 mm/h for the bacteriophage tracer.

The early arrival of the relatively symmetrical bromide peak in the pumiceous Atiamuri soil was unexpected (Figure 2b). The irrigation rate of 5 mm/h is relatively slow compared with the saturated hydraulic conductivity of the slowest-conducting soil layer in the profile of about 30 mm/h. This, combined with the close K_{sat}:K_{40} ratio and fine polyhedral soil structure, suggests bypass flow would not be dominant (Magesan *et al.* 1999a). Given the lack of weathering and particularly the welded nature of the flow tephra in the subsoil, we hypothesise that not all the pore volume was contacted by the leachate, with some of the pumice fragments having non-accessible internal porosity. We suggest this physical exclusion is more likely than anion exclusion. The uppermost Atiamuri subsoil layer showed a weak reactive-aluminium test reaction (Fieldes and Perrott 1966). This indicated the presence of minor amounts of reactive hydroxy-aluminium groups, which occur, for example, in allophane, and affect virus sorption as described above. The absence of FC in the leachate may be attributed to filtration. The soil is relatively young with soil development confined to the upper layers. Structural cracks and clay- or organic-lined flow paths have not developed throughout the soil and flow takes place through weakly altered soil parent material with consequent filtration. Virus particles, being significantly smaller, would not be filtered as efficiently.

This study demonstrates that some soils are less efficient in retaining microbes than others. Movement of microbes through soil is restricted by adsorption and filtration processes. These processes are important for protecting groundwater against faecal pollution particularly as cell death is not so effective. Faecal microbes can survive long periods in the environment and even multiply (Gagliardi and Karns 2000). While adsorption and/or filtration processes significantly minimized movement of microbial indicators in Waihou and Atiamuri soils, microbial contamination of shallow ground waters could result from spray irrigation of effluent onto clayey Netherton and sandy Waitarere soils at currently used application rates. The numbers of bacterial indicators in most leachates analysed from Netherton soil exceeded the ANZEEC (1992) guidelines for drinking water for livestock.

From the tracer recovery data we predict it is likely that the soils we investigated will continue to shed microbial tracers for some time. With increasing pressure for land application for the disposal of effluent, we anticipate increased application onto less suitable land in the future, with consequent declines in leachate quality. This poses risks for biological and chemical contamination of associated groundwater resources. We are currently developing a GIS approach, based on transport enhanced by the bypass flow associated with strongly structured soils and minimised by matrix flow and/or allophanic soil mineralogy, to show risk of contamination of shallow groundwater throughout New Zealand. We concur with Wells (1973) that young, fine-grained tephric soils have good characteristics for effluent disposal. We would also include Pumice Soils that have similar properties to those we examined. Wells (1973) determined that Gley Soils were unsuitable for effluent disposal because of anaerobic conditions. While we concur with this general conclusion, we attribute the poor performance in our study to significant bypass flow.

CONCLUSIONS

High levels of microbial tracers rapidly reached the subsoil of a well-structured clayey Gley Soil, and a sandy Recent Soil, because of bypass flow mechanisms, whereas only minor amounts were detected in leachates from a Pumice Soil and an Allophanic Soil. In contrast, the bromide tracer moved uniformly through the Pumice and Allophanic Soils suggesting chemical tracers are not always good indicators of microorganism movement through soils.

There were minor differences in the BTC of the bacteriophage and FCs but the overall influence of bypass flow was much more important in determining the shape of the BTC.

Results of this study have useful implications when sites for land disposal or treatment of effluent, including municipal and dairy shed wastes, are being considered. Breakthrough curve studies on large intact cores are useful as one of the procedures for defining suitability criteria of a particular soil for land disposal of effluent.

Regionalisation of this type of data is currently being accomplished throughout New Zealand using pedotransfer functions.

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26. KARST GROUNDWATER PROTECTION IN ENGLAND AND WALES – AN UPDATE

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INTRODUCTION

Karst aquifers represent valuable groundwater resources that support both strategically important abstractions and baseflow to adjacent river systems. Karst aquifers are particularly vulnerable to both diffuse and point source pollution. This vulnerability is frequently characterised by thin soils and groundwater flow within fissures and enlarged conduits, which offer little protection to the quality of karst groundwater water.

The most effective method of protecting this valuable resource is effective landuse planning. Vulnerability mapping methods have been developed, throughout Europe and the United States, that attempt to identify the spatially variability of risks to groundwater in karst terrains in order to aid the planning process.

The Environment Agency, in partnership with Trinity College Dublin, is currently researching available karst vulnerability mapping methods. This research is leading to the identification of a karst Vulnerability Mapping method to augment current groundwater protection tools employed by the Environment Agency, this will ensure improved protection to this valuable groundwater resource.

Karst aquifers can be described as being characterised by;

- The absence of permanent surface flow and the presence of closed surface depressions.
- The occurrence of enlarged fractures and fissures as a result of carbonate dissolution.
- The existence of significant springs, often located at the lowest elevation of the carbonate rock outcrop.

Karst aquifers represent a major water resource which is not only used extensively for public, private and commercial supply, but also supports surface water and wetland features with essential baseflow that ensures their ecological "well being". Those aquifers within England and Wales that may be considered as displaying karst characteristics range from; Carboniferous and Jurassic Limestones to parts of the Cretaceous Chalk. Karst characters vary significantly from aquifer to aquifer, as a result of the chemical, physical and structural characteristics of the host carbonate rock and its structural and geomorphological history.

Groundwater quality within karst aquifers can be put at significant risk from surface activities. The nature of karst promotes concentrated and rapid movement of recharge, through the unsaturated zone to the "water table". This form of recharge often provides little opportunity for the attenuation of surface derived contaminants prior to reaching the "water table". Besides some notable exceptions, the impermeable matrix of carbonate rocks result in little water rock interaction. The impermeable nature of the matrix significantly reduces the opportunity for attenuation process involving the host rock.

Groundwater flow within the saturated zone can range from diffuse, relatively slow movement along individual joints and bedding planes, to concentrated and rapid movement along solutionally enhanced conduits. As a result of both the degree of flow concentration and groundwater velocities below the "water table", water quality impacts arising from pollution incidents at aquifer discharge points range from rapid, concentrated events lasting several hours to protracted, "diluted" events lasting days/weeks.

From the collective experience of countries engaged in the protection of karst groundwater, it would seem that the most effective method of protecting these often highly vulnerable aquifers is by employing effective landuse planning. In order to assist planning authorities in this task a number of tools need to be developed, perhaps the most significant being karst vulnerability mapping (KVM).

Groundwater protection within England and Wales is defined within the Environment Agency's "Policy and Practice for the Protection of Groundwater" (GPP). This document describes the hierarchical approach the Agency takes toward groundwater protection. The Agency has adopted the concept of Groundwater Vulnerability Mapping and has produced Vulnerability Maps for England and Wales, at a scale of 1:100,000. These maps are used as high level-planning tools and can assist both Planning Authorities and developers in making those more strategic decisions that have the potential to impact groundwater quality.

The GPP also describes how the Agency has adopted the concept of Source Protection, for groundwater abstractions. Three groundwater Source Protection Zones are recognised;

- Inner Source Protection Zone – defined by a 50 day travel time, from any point below the water table to the source, of a minimum of 50 metres radius from the source.
- Outer Source Protection Zone – defined by a 400 day travel time, from any point below the water table to the source.
- Total Source Catchment – defined as an area within which all groundwater will eventually discharge at the source.

Hierarchical groundwater policy statements are made for each zone in order to identify to both planners and developers the Agency's policy objectives with respect to differing threats to groundwater resources and how the Agency is likely to respond to specific proposals. Source Protection Zones have been defined around large numbers of public groundwater abstractions.

To date, the Agency has no specific tools to assist in the protection of groundwater within karst aquifers. In order to focus efforts in protecting valuable karst groundwater resources, the Environment Agency has instigated a Research and Development Project. This project aims to identify a KVM technique for use in karst aquifers within England and Wales. This project, which is collaborative with Trinity College Dublin, is running in parallel with the European Unions' COST Action 620, which is seeking to co-ordinate the development of a consistent European approach to the assessment of karst vulnerability.

The production of an Agency KVM technique will complement the existing concepts of Groundwater Vulnerability and Source Protection Zones, adding to the Agency's groundwater protection "tools". It should be noted that KVM will be carried out at much larger scales than the Agency's existing Groundwater Vulnerability Mapping method. The technique will be capable of being used as a detailed assessment technique on a site-specific scale, subject to data availability. It is possible that certain elements of the "new" technique maybe scaleable, allowing more general/smaller scale karst vulnerability maps to be produced, however this is an area where more research is required.

The delineation of Total Catchment Zone for a karst source is carried out using a number of recognised hydrogeological techniques that remain valid in karst aquifers. These techniques include tracer tests, studies of piezometric data and the estimation of catchment size from water balance calculations. The use of KVM will allow the zonation of the Total Catchment Zone. These zones will reflect the location of those features, that can be identified, which influence the way recharge is infiltrated.

Currently, groundwater protection practice restricts new developments within the Total Catchment Zones of karst sources, in similar ways to that required within Inner Protection Zones of non-karst sources. The Inner Protection Zone, as detailed within the Agency's GPP, is defined as the area around a source that is either within 50 days travel time or 50 metres radius, whichever is the larger. The use of Inner Protection Zone policy's for Total Catchment Zones around karst sources may distort the the Agency's approach to new developments within these zones. A new KVM technique should ensure that new protection policies can be employed within karst areas in a consistent, robust and defensible manner.

The use of groundwater vulnerability mapping, with focused groundwater protection policy statements, as a means to protect valuable karst groundwater is widespread across Europe. Various approaches have been adopted, ranging from methods that assess groundwater vulnerability in both non-karst and karst aquifers such as the German and Irish methods, to those that have been developed explicitly for use in karst aquifers such as the Swiss EPIK method. Various means of assessment are used in these methods to establish spatial changes in vulnerability, ranging from parametric rating and weighting to matrix overlay assessment systems.. All of these methods lend themselves to analysis using a Geographical Information System.

Each method considers the spatial distribution of specific parameters. Examples of these include; depth of soil, thickness of unsaturated zone, presence and development of epikarst, extent and nature of protective cover. Each method uniquely combines sets of parameters that are perceived/thought to reflect the conditions prevalent in the country for which the method was developed.

The Environment Agency's own Research Project has established an inventory of available KVM techniques. The project has then proceeded to trial three of these techniques; DRASTIC, EPIK and the Irish Vulnerability Mapping Methodology, in four karst areas; Cotswolds (Jurassic Limestones) and the Mendips, Vale of Glamorgan and Yorkshire Dales (Carboniferous Limestone). Whilst the trial areas are small, they were chosen to be representative of various karst settings.

The results of these small trials are now being assessed in order to establish their likely effectiveness against intuitive hydrogeological experience of those areas. Once this exercise is complete, work will begin to develop a "new" method that best reflects both geological and hydrogeological conditions in the karst aquifers in England and Wales. Any new method developed for use by the Environment Agency must be mindful of the current availability of data for geological and hydrogeological parameters within those aquifers for which the method is intended.

Significant amounts of work remain before an Environment Agency method is available for in the assessment of vulnerability in karst aquifers. A number of challenges remain, one of the more difficult is likely to be the development of robust, protective, but defendable policy statements to support the assessment procedure produced by the "new" method. These policy statements will need to take account of protection requirements in both resource and source protection areas within karst aquifers. They will also provide clear guidance on those activities, within specific vulnerability classes, to which the Agency may object.

As part of its Research and Development project, the Agency has considered novel techniques for the rapid collection of data that will assist in karst vulnerability mapping. The Agency has begun to utilise its own remote sensing capabilities which include the use of airborne methods such as LIDAR, CASSI and Infra Red photography, in an attempt to establish whether they can be used to collect surrogate data for any particular parameter. Whilst this work is in its infancy, early results suggest that the development of highly detailed terrain models using LIDAR data, will accurately focus areas where ground truthing is required. The other techniques, may after further investigation, identify areas of vegetation stress, which may then be used to determine/infer soil thickness.

Whilst in Wales, the volumes of abstracted surface water far outweigh those from groundwater, karst sources dominate the land area covered by total protection zones. Of the 69 defined source protection zones, with a total area of approximately 365 square kilometres, 17 are karst sources (25%), with a total protection area of 55%. The protection of karst groundwater is a significant issue for Environment Agency Wales. Karst groundwater sources exist in a number of different landuse settings, ranging from both high and lowland agricultural areas, to heavily industrialised catchments where surface waters are in intimate contact with groundwater abstractions from karst aquifers. The development of KVM as a "tool" to assist in the protection of these vulnerable yet valuable resources, will be a welcome step forward in resolving the complexities of karst groundwater protection.

The opinions expressed in this paper are those of the author and may not necessarily reflect the current policy of the Environment Agency.

27. DEFINING GROUNDWATER PROTECTION ZONES IN ENGLAND AND WALES

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ABSTRACT

This paper describes how a GIS was used to identify areas of England and Wales vulnerable to diffuse source groundwater pollution. The methodology is demonstrated using groundwater nitrate pollution as a case study.

Geographical variations in vulnerability were examined by overlaying details of leaching characteristics, soil types, low permeability drift, and aquifers. Three main models of nitrate vulnerability (intrinsic, specific and risk) were generated, each with several variants based on different weightings of the components (e.g. a greater emphasis on the leaching layer relative to the other elements). Details of 3714 boreholes were then matched to the vulnerability maps and statistical techniques were used to assess the ability of the models to distinguish sites with different groundwater nitrate levels. The results revealed that a specific vulnerability model was the best predictor.

Potential protection zones were defined as areas with the greatest specific vulnerability scores and the highest interpolated probabilities of groundwater nitrate concentrations ≥ 50 mg/l. These boundaries were then simplified using epsilon band techniques to reflect uncertainties in the input data layers. This exercise produced a 'precautionary' set of zones where land use may need to be controlled in England and Wales.

INTRODUCTION

Groundwater provides over 30 % of the drinking water in England and Wales and is an important source for many rivers. Pollution of groundwater from diffuse sources, such as agriculture, may therefore pose risks to human health and the environment. In order to combat this threat, groundwater sources are currently protected from surface contamination by a series of zones within which land use is controlled. One example is Nitrate Vulnerable Zones (NVZs) where agricultural practices are controlled and farmers must ensure that nitrate applications do not exceed the crop requirements. There are also restrictions on the times of the year that fertilisers can be applied, rules on how they should be spread, and regulations on the storage of farm slurry (DETR & MAFF 1998). All these measures are designed to minimise nitrate migration to groundwater and by their nature also protect surface water.

At present NVZs are based on the modelling of capture zones around public water supply boreholes (Environment Agency, 1998). One limitation of such an approach, however, is that it only protects groundwater destined for public water supply. The research described in this paper sought to develop a generic methodology that could be used to identify all areas of England and Wales vulnerable to diffuse source groundwater pollution and where restrictions on land use might be necessary. Vulnerability to groundwater nitrate pollution was selected as a case study and the research made extensive use of GIS techniques.

MODELLING GROUNDWATER VULNERABILITY

The vulnerability of groundwater to diffuse pollution sources was modelled as being influenced by four main factors:

(i) Surface leaching - the quantity and quality of water leaving the root zone of a piece of land.
(ii) Soil characteristics - which may attenuate the pollution or lead to horizontal water movement.
(iii) Drift cover - low permeability material that may impede the movement of water to the underlying aquifer
(iv) Aquifer type - distinguishing between highly permeable and/or fractured aquifers, and those that have a negligible permeability

Similar variables have been used in a number of previous groundwater vulnerability studies (e.g. Robins *et al.* 1994, Merchant 1994, Hiscock *et al.* 1995). The research did not consider groundwater flow because it was not practical to incorporate such information in a national scale assessment.

Three contrasting models of nitrate vulnerability were produced. Each contained identical information on soil, drift material and aquifer type, but differing definitions of the leaching layer. These models are described below:

(i) The *risk* model incorporated land use data and a model of nitrate leaching to estimate the concentration of nitrate leaving the root zone.
(ii) The *specific vulnerability* model removed the land use component from the nitrate-leaching model and assumed a uniform loading of nitrate across England and Wales.
(iii) The *intrinsic vulnerability* model replaced the nitrate-leaching model with an estimate of the volume of water leaving the root zone.

Given the incorporation of data on land use and a nitrate-leaching model, it was anticipated that the *risk* model would be the best predictor of groundwater nitrate concentrations. Other models were examined to assess the extent to which a simpler approach could be effective, particularly to determine whether information on current land use was a prerequisite for identifying areas vulnerable to groundwater pollution.

DATA SOURCES

Surface Leaching

Data on leaching characteristics were obtained from the Modelling Agricultural Pollution and Interactions with the Environment (MAGPIE) Decision Support System (Lord and Anthony 2000). This software uses information on land use, farming practices, climate and soil characteristics to produce estimates of nitrate concentrations leaving the soil zone on a 1 km^2 resolution grid. The three leaching layers generated from MAGPIE were as follows:

(i) *Leach1* was used in the *risk* model and represented the mean nitrate-nitrogen concentrations in land drainage (mg/l NO_3) under long-term mean climate conditions and land use/land cover correct for the 1994/1995 cropping year.

(ii) *Leach2* simulated variations in nitrate leaching risk due simply to climatic and soil characteristics and was used in the *specific* model.

(iii) *Leach3* estimated the mean annual soil drainage (mm) and was used in the *intrinsic* model.

Aquifer, Drift Cover and Soil Characteristics

Digital vector map layers were extracted from the Environment Agency's groundwater vulnerability maps (GVMs) (Robins *et al.* 1994, National Rivers Authority 1995) to represent aquifer type (e.g. major, minor or non-aquifer), the presence of low permeability drift cover, and soil classes. The full soil classification (*Soil1*, see Robins *et al.* 1994 for details) was also simplified into a new layer (*Soil2*) that just distinguished high and intermediate leaching potential soils from those with low potential.

CREATING VULNERABILITY CLASSIFICATIONS

In order to combine the four data layers, it was first necessary to convert the leaching details from a raster grid format to a vector structure consistent with the other information. Overlay procedures were then implemented within a GIS to produce the vulnerability models shown in Table 1. The *risk* and *specific* vulnerability models included the simplified *Soil2* variable to avoid double counting of soil characteristics already incorporated in their more sophisticated leaching estimates. During the overlay process it was also found that some coastal areas lacked leaching estimates and these polygons were assigned values from the nearest grid cell within 1 km. Areas outside this distance were excluded from the analysis, as were those with only leaching data.

Having completed the overlays, the next step was to convert the different combinations of attributes into a vulnerability rating. Using a similar approach to other vulnerability assessments (e.g. DRASTIC, Merchant 1994), input layer attributes were ranked with low numbers representing the greatest groundwater vulnerability and high ones the least. Table 2 shows the classification scheme for the leaching layers, high nitrate concentrations in *Leach2* and *Leach3* constituting greater vulnerability, as does low soil drainage in *Leach1* (any nitrate will be less diluted). It should also be noted that the classes are not based on even increments. (e.g. small changes in soil drainage are more important when the overall amount of drainage is limited).

The ranking of aquifer and soil attributes in Table 3 was based on information provided in the Environment Agency GVMs. Incorporation of drift cover was more problematic due to very limited information on thickness or attenuation properties. A conservative approach was therefore adopted where the rankings gave priority to aquifer permeability rather than the absence of drift (see Table 3).

The final stage in the classification procedure was to combine the leaching ranking with that for the soil/drift/aquifer characteristics. There was, however, little published evidence to indicate the relative importance of these factors and so three variants of each model were produced based on different weightings. Variant 1 assumed the leaching layer to be half as important as the soil/drift/aquifer characteristics. Variant 2 weighted the two layers equally, while Variant 3 assumed the leaching data to be twice as important as the other attributes. Adopting such an approach also allowed the influence of changes in layer weightings to be examined, meeting the criticism directed at some previous studies by Merchant (1994).

VERIFICATION AND FINAL MODEL SELECTION

An assessment of the different vulnerability models and variants was made by examining their ability to distinguish boreholes with contrasting groundwater nitrate levels. This analysis utilised a georeferenced database of 3714 borehole nitrate concentrations compiled by the Environment Agency. Amongst the attributes recorded for each borehole was a predicted nitrate concentration (mg/l) in 2017 based on recent trends in nitrate levels at the site. These 2017 estimates were used for the verification exercise so that the results would indicate the model best able to predict future areas at risk from nitrate pollution.

The geo-referenced boreholes were matched to the vulnerability model using point-in-polygon procedures within a GIS (Burrough and McDonnell 1998). To examine trends in nitrate concentrations the vulnerability scores were then grouped into classes. Many of the boreholes were concentrated in areas of relatively high vulnerability, so the class intervals were uneven and covered increasing proportions of England and Wales aquifer area down the vulnerability scale. Table 4 shows the class ranges along with mean nitrate concentrations for the three variants of the *risk* and *specific* vulnerability models. The trends in this table indicate a general decline in nitrate levels with reduced vulnerability, but further statistical assessment was undertaken by examining four characteristics:

(i) Is highest mean nitrate value in Class 1? Ideally a model should have the highest mean value in Class 1 and then decreasing levels through the remaining classes.
(ii) Range of mean nitrate values. Preferably the range should be as large as possible because it reflects the ability of the model to differentiate nitrate values.
(iii) Spearman rank correlation. This indicates the association between vulnerability class codes and mean nitrate values. A correlation of -1.0 signifies a perfect trend of declining nitrate values through the classes.
(iv) Analysis of Variance (ANOVA) F statistic. The larger this measure, the less overlap there is between the nitrate values in different vulnerability classes. Formally, the F statistic is the ratio of between to within sample variances (Bryman and Cramer 1997).

Table 5 summarises the results obtained and suggests that all the model variants performed fairly well at differentiating boreholes with contrasting groundwater nitrate concentrations. In general, the *intrinsic* vulnerability model performed least well, while the *specific* and *risk* models did better. This implies that a nitrate-leaching model is a crucial element in vulnerability classification. However, the *risk* and *specific* models produced quite similar outcomes, a result that requires addition comment given that the former incorporated additional land use information. This situation may be due to the time difference between the land use (1994) and borehole nitrate data (2017), as well as factors related to borehole distribution, but a simple explanation is not readily apparent. It is also difficult to detect any clear pattern as to which weighting variant produced the best results.

On the basis of these results, Variant 3 of the *specific* model was selected for further consideration. One advantage was that the absence of land use information implied that any decisions based upon this model would still be applicable even if current land use changed.

Statistically, the model variant performed strongly with a perfect Spearman correlation and the second highest ANOVA F statistic. In addition, specific vulnerability models were best able to identify the areas with the highest borehole nitrate concentrations and were the least sensitive to the weighting variant used. A map of the vulnerability classes for this model variant is shown in Figure 1.

DEFINING PROTECTION ZONES

The EU Drinking Water Directive [98/83/EC] sets a nitrate concentration of 50 mg/l as the limit for water destined for human consumption. In consultation with the Environment Agency, it was decided to define a *specific* vulnerability threshold that would encompass 75 % of the boreholes with a historical or predicted nitrate value above this limit. This resulted in selection of some 25 % of the aquifer area in England and Wales, but included zones where groundwater nitrate levels had never been measured or were known to be below the 50 mg/l limit. It was therefore necessary to refine the zone definition so that the final areas also had evidence of high nitrate values in boreholes.

As noted previously, the boreholes in the Environment Agency database had an uneven spatial distribution. A geostatistical approach, disjunctive kriging (Matheron, 1976), was consequently used to interpolate a groundwater nitrate concentration surface for England and Wales. This kriging technique estimates the probability that a critical value will be exceeded and has been proposed as suitable for modelling pollutants in groundwater (Oliver, 1994). In addition, a variance estimate can be calculated and this was used to identify areas where there were too few nearby boreholes to produce reliable results. The data were modelled with 50 mg/l as the critical threshold and results produced as a 1.5 km resolution grid covering England and Wales (Frogbrook and Oliver, 2000).

Areas were regarded as having evidence of high groundwater nitrate values if the kriged probability of groundwater nitrate concentrations $\geq$ 50 mg/l were above a threshold value of 0.20. In addition, areas were excluded if the estimation variance was high (greater than 500) (i.e. confidence in the kriged estimates was limited due to a low density of monitoring points). Overlaying the areas meeting the kriged estimate and vulnerability score thresholds provided an improved basis for zone delimitation, but it was also important to recognise that there would be some uncertainty in boundary positions due to the accuracy of the input data layers. One technique to account for such uncertainty involves generating epsilon bands (Blakemore 1984) around each boundary, the size of the band radius reflecting the scale of the data used. It was not possible to estimate an epsilon band for the disjunctive kriging results, but a radius of 707 m was calculated for the 1 km resolution leaching data. The soil, drift and aquifer layers were derived from the Environment Agency GVMs with a nominal 1:100,000 scale, but it is known that some of the source data were less accurate and so it was decided to make the conservative assumption of an effective resolution corresponding to a scale of 1:250,000. This generated epsilon distances of 125 m. Making the assumption that the errors in the four data layers were independent of each other they could be combined using the formula suggested by Smith and Campbell (1989). This produced an overall epsilon radius of 740 m and because the purpose of the exercise was to protect groundwater from nitrate pollution the existing boundaries were buffered outwards by this distance (see Figure 2a).

The resulting zones often contained small polygons classed as non-vulnerable areas. Many of these were substantiated by the accuracy of the input data and would cause problems from a management point of view. The calculated epsilon radius of 740 m around a single point equates to an area of around 172 hectares and so it was decided to delete non-vulnerable 'islands' smaller than 200 hectares in size. Figure 2 illustrates the impact of the buffering and elimination procedures.

CONCLUSIONS

This paper has described the implementation of a GIS-based methodology for the identification of areas vulnerable to groundwater pollution. The vulnerability model that best predicted variations in groundwater nitrate concentrations contained a nitrate leaching model, but did not include information on land use. This may be explained by the time lag between the land use data in the model and the projected borehole nitrate data. In addition, the *risk* models using actual land use performed relatively poorly in areas where there were localised pockets of heavy nitrate leaching potential. This highlights the limitation of omitting groundwater flow, as the borehole nitrate concentration is likely to be representative of a wider catchment. One future research priority, therefore, might be to try to incorporate groundwater flow into national scale vulnerability models. It is also worth noting that information on the intake depth of boreholes was not available at the time the analysis was undertaken, but subsequent work (Betson and Lovett 2001) has shown that both this factor and *specific* vulnerability influence groundwater nitrate levels.

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Table 1 Components of the three nitrate vulnerability models.

	Vulnerability Models		
Layer	**Risk**	**Specific**	**Intrinsic**
Leaching	LEACH1	LEACH2	LEACH3
Soil	SOIL2	SOIL2	SOIL1
Drift	DRIFT	DRIFT	DRIFT
Aquifer	AQUIFER	AQUIFER	AQUIFER

Leaching

LEACH1: Simulated mean nitrate-nitrogen concentrations in land drainage (mg/l NO_3) using current land use

LEACH2: Simulated mean nitrate-nitrogen concentrations in land drainage (mg/l NO_3) assuming 100 kg N/ha applied to all land

LEACH3: Simulated mean annual soil drainage from all land (mm)

Soil

SOIL1: The seven soil categories present on the Environment Agency GVMs

SOIL2 SOIL1 reclassified to remove information about the soil's ability to attenuate. Consists of two classes HI (high + intermediate) and L (low).

Drift

DRIFT: Indicates the presence or absence of low permeability drift taken from the GVMs.

Aquifer

AQUIFER: Aquifer classification from the GVMs. It consists of three classes, namely major aquifer, minor aquifer and non-aquifer.

Table 2 Classification of the leaching layers.

	Class	**LEACH 1 & 2** **Nitrate concentration (mg/l NO_3)**	**LEACH3** **Soil drainage (mm)**
Most Vulnerable ↓	1	>200	<100
	2	175-200	100 – 150
	3	150-175	150 – 200
	4	125-150	200 – 250
	5	100-125	250 – 300
	6	75-100	300 – 350
	7	70-75	350 – 400
	8	65-70	400 – 450
	9	60-65	450 – 500
	10	55-60	500 – 1000
	11	50-55	1000 – 1500
	12	45-50	1500 – 2000
	13	40-45	2000 – 3000
	14	35-40	>3000
	15	30-35	

	16	25-30
	17	20-25
	18	15-20
	19	10-15
Least Vulnerable	20	5-10
	21	<5

Table 3 Classification of soil, drift and aquifer characteristics.

Risk and Specific Vulnerability Models			Vulnerability Classification	Intrinsic Vulnerability Models		
AQUIFER	**DRIFT**	**SOIL2**		**AQUIFER**	**DRIFT**	**SOIL1**
Major	Absent	HI	1	Major	Absent	HI
Major	Absent	L	2	Major	Absent	H2
Major	Present	HI	3	Major	Absent	H3
Major	Present	L	4	Major	Absent	I1
Minor	Absent	HI	5	Major	Absent	I2
Minor	Absent	L	6	Major	Absent	L
Minor	Present	HI	7	Major	Present	HI
Minor	Present	L	8	Major	Present	H2
			9	Major	Present	H3
			10	Major	Present	II
			11	Major	Present	I2
			12	Major	Present	L
			13	Minor	Absent	H1
			14	Minor	Absent	H2
			15	Minor	Absent	H3
			16	Minor	Absent	I1
			17	Minor	Absent	I2
			18	Minor	Absent	L
			19	Minor	Present	H1
			20	Minor	Present	H2
			21	Minor	Present	H3
			22	Minor	Present	I1
			23	Minor	Present	I2
			24	Minor	Present	L

Table 4 Mean nitrate levels in risk and specific model vulnerability classes.

Vulnerability Class	% of Vulnerable Area	Mean Nitrate Concentration (mg/l)					
		Risk Vulnerability Models			Specific Vulnerability Models		
		Variant 1	Variant 2	Variant 3	Variant 1	Variant 2	Variant 3
1	0-2.5	42.32	42.09	42.06	43.16	43.16	43.16
2	2.5-5	46.26	46.26	45.14	41.91	41.91	41.75
3	5-10	38.89	38.29	39.31	41.58	41.50	40.95
4	10-20	32.46	32.38	32.85	31.65	31.65	32.82
5	20-30	32.74	32.09	28.05	32.19	32.09	30.85
6	30-40	26.16	26.23	31.02	27.20	27.33	26.61
7	40-50	20.47	25.86	27.61	22.91	22.40	22.69
8	50-75	24.56	22.98	24.12	23.01	22.39	22.38
9	75-100	16.26	15.66	15.00	15.37	15.92	15.45

Table 5 Comparative statistics for vulnerability model performance.

Model		Is highest mean value in class 1?	Range of mean NO_3 values across classes	Spearman rank correlation	ANOVA F statistic
Intrinsic	**V1**	No	17.3-42.0	-0.867	33.00
	V2	No	16.4-38.8	-0.933	25.48
	V3	No	13.2-38.1	-0.933	18.04
Specific	**V1**	Yes	15.4-43.2	-0.967	45.02
	V2	Yes	15.9-43.2	-0.983	44.78
	V3	Yes	15.5-43.2	-1.000	45.93
Risk	**V1**	No	16.3-46.3	-0.950	46.13
	V2	No	15.7-46.3	-0.983	42.50
	V3	No	15.0-45.2	-0.967	36.35

Figure 1 Vulnerability classes in the Specific model, Variant 3.

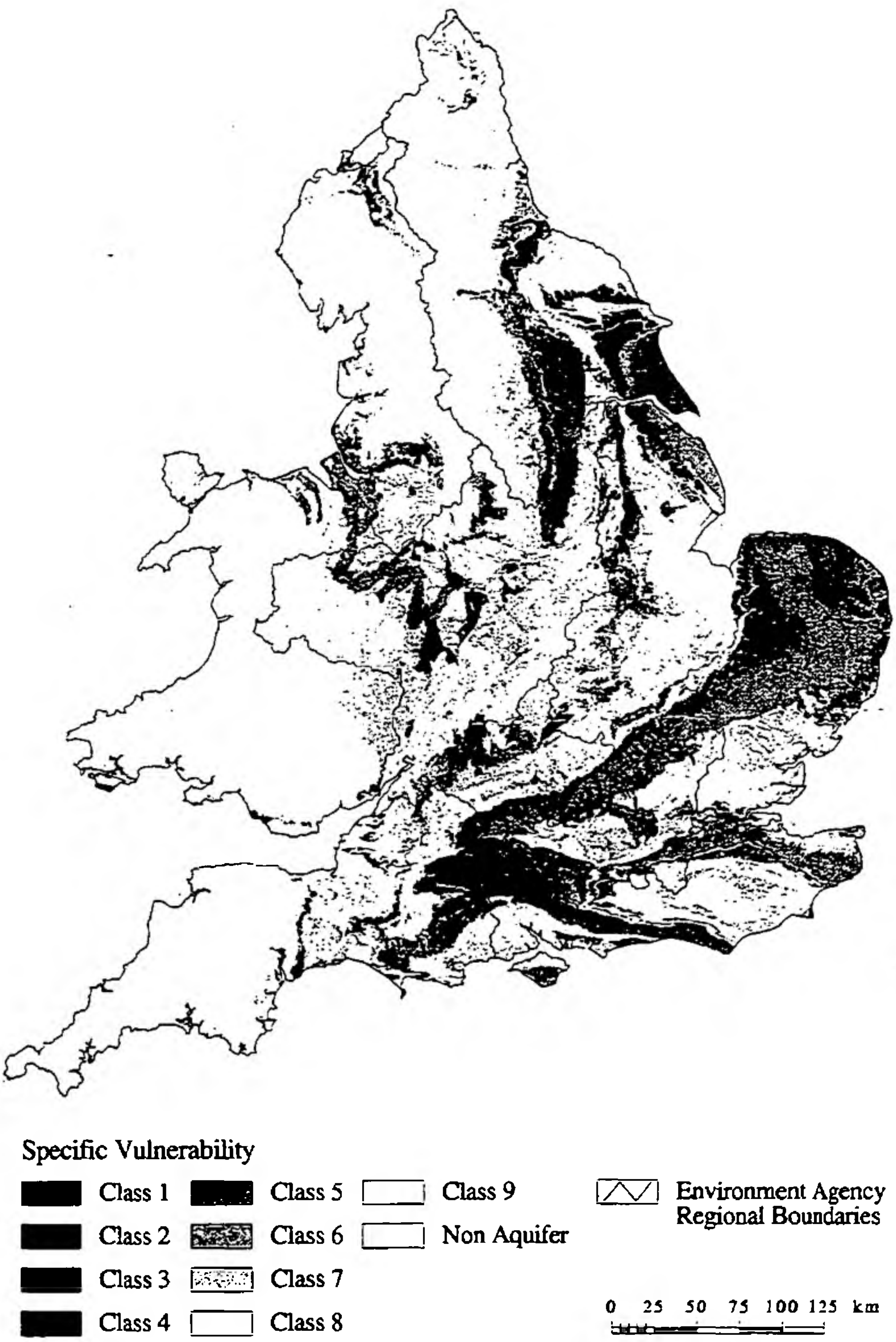
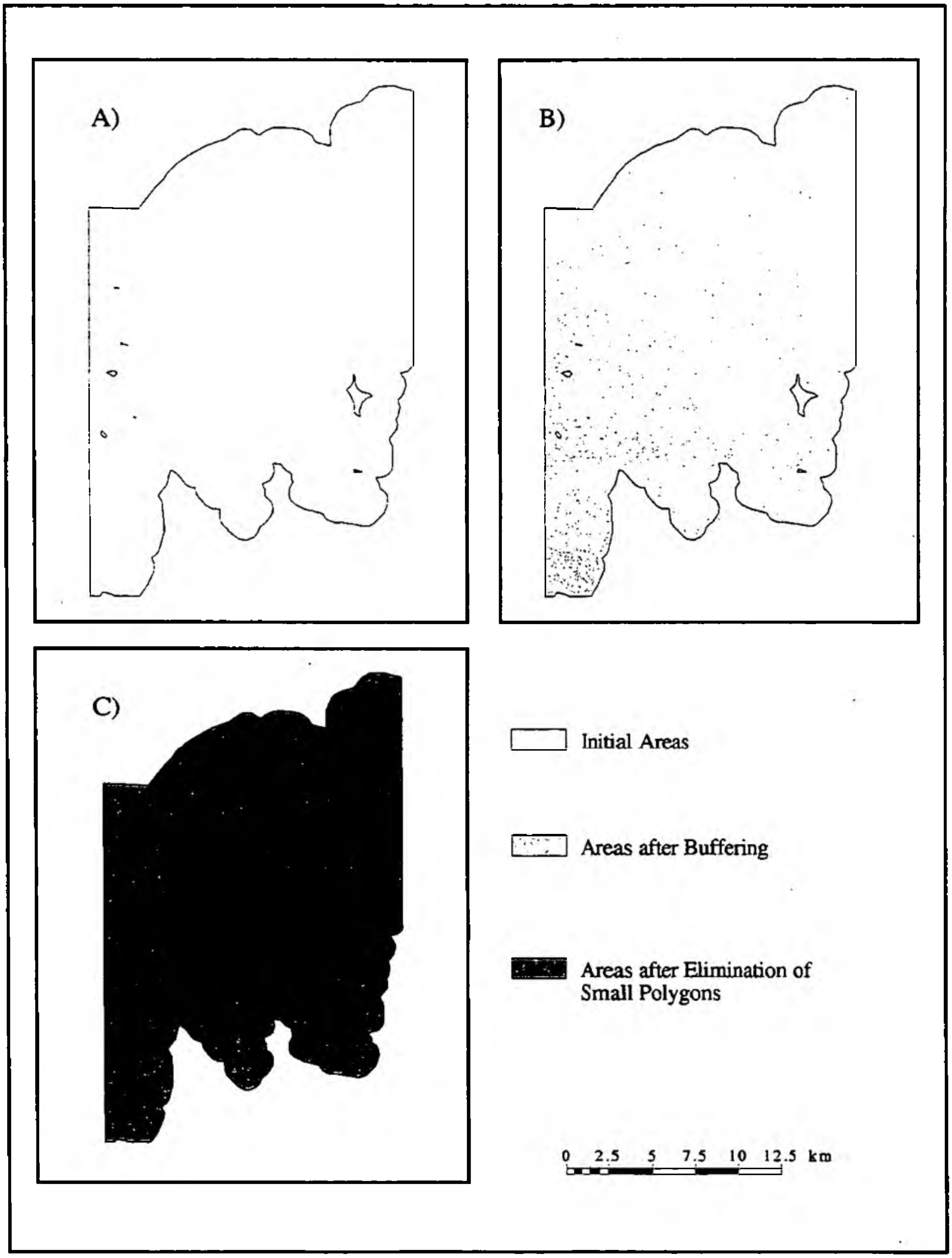


Figure 2 The impact of buffering and elimination on zone boundaries.



28. INTEGRATING GROUNDWATER PROTECTION POLICY WITH LAND USE PLANNING AND RISK ASSESSMENT – AN EXAMPLE USING THE DEVELOPING GUIDANCE IN ENGLAND & WALES WITH RESPECT TO LANDFILL LOCATION.

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INTRODUCTION

The "Policy and Practice for the Protection of Groundwater" (PPPG) published by the former National Rivers Authority in 1992 was the first attempt to produce a national framework and set of policy statements for groundwater protection in England & Wales. (see paper by Bob Harris in these proceedings). At the time there was little UK legislation that specifically promoted the protection and prevention of pollution of groundwater and the main focus of the PPPG was to encourage others to take such issues into account. These stakeholders included other regulators (including planners), developers, industrialists and their consultants, and the public generally. The PPPG has been acknowledged as a successful document and was adopted by the Environment Agency on its inception, with a second edition published in 1998 (Environment Agency, 1998).

Since 1998 there have been sweeping developments in groundwater protection in the UK. A raft of new legislation has been introduced and the pace of change will be further accelerated as the Water Framework Directive is implemented over the next few years. From a relatively low base several years ago, the Environment Agency now has extensive duties and powers to implement groundwater protection measures. To reflect this change and developments in groundwater management, the PPPG is now being extensively revised and is to be re-launched as a Groundwater Strategy for England & Wales. This paper describes some of the key issues to be considered in the revised document and focuses on the interface of groundwater protection with the development planning system, including the role and scope of risk assessment. This is illustrated by reference to new guidance with respect to landfill developments.

KEY GROUNDWATER PROTECTION ISSUES IN ENGLAND & WALES

Nowhere is the need to protect groundwater resources more evident than in the UK, with a legacy of industrial development stretching back over 200 years, intensive population and land-use pressure, and highly developed groundwater resources. Conventionally the importance of groundwater has been gauged by its contribution to public water supply, which is only 30% nationally but over 75 % in southern England. However, groundwater contributes significantly to the baseflow of most watercourses, supports many wetland habitats and is extensively developed for private water supplies, for both domestic and industrial uses.

With a relatively low overall fresh water availability per person in England & Wales (factors of 7 and 15 less than the USA and Australia respectively) and continued development of groundwater and upon aquifers, the pressures on groundwater resources remain. These pressures are likely to be increased by the uncertainties surrounding climate change and the developing legislative need to give adequate protection to surface water ecosystems.

Since the privatisation of the water industry in the early 1990s there has been a heavy regulatory emphasis on improvements to water quality by dealing with point sources of pollution and in particular, authorised discharges to surface water. River water quality has improved substantially as a consequence, to the extent that it is generally recognised that only marginal further improvement can be gained by additional efforts in this area. Diffuse sources of pollution are the next major challenge. Groundwater, with its long residence time and "memory" of past pollution activity, is not only directly affected but can also be a major source of diffuse pollution in surface water. Tackling this issue will not be easy and will require a more detailed understanding of the interaction between surface water and groundwater.

There will also need to be a re-evaluation of some of our activities. What is regarded as the beneficial use of many substances can lead to groundwater pollution. Many activities give rise to groundwater contamination with little awareness on the part of their operator/developer. Agricultural practices in particular have been major sources of diffuse groundwater contamination, yet many of these activities have escaped effective regulatory controls.

In order to bring about improvements in groundwater protection there will need to be continuing emphasis on the control of discharges to ground via the new permitting regimes that have been established in the past few years. In addition, several key areas will also need to be examined, namely:

- the adequacy of environmental testing for products that give rise to groundwater pollution, over their entire life cycle;
- a combination of regulatory refinements, such as codes of good practice, and partnership approaches to environmental issues, to improve awareness of the need for groundwater protection; and
- stronger participation in the use land use planning system to influence the siting and operation of potentially polluting activities where groundwater is vulnerable to pollution.

It is the latter point that will form a focus in this paper, combined with several issues relating to existing duties and activities, specifically:

- the application of the duty to contribute to sustainable development when carrying out the Agency's activities;
- the balance of effort in relation to groundwater protection that should be devoted to strategic planning, pre-planning consultation, planning applications and operating permits;
- the extent of risk assessment activity during each of the above.

Regulatory duties and powers

There is a clear distinction between the duties placed by legislation on the Agency (for example, to authorise a range a potentially polluting activities) and the powers the Agency has been given to proactively take action (for example, to serve a notice to ensure that an operator bunds a chemical tank or to clean up contamination resulting from a recent spill). Duties tend to have absolute requirements laid down by the legislation and statutory guidance and there is often limited flexibility in applying risk-based approaches to their implementation. In contrast, discretionary powers can only be sensibly used by adopting a risk-based approach, to focus the available resources on the most urgent needs.

A framework has been developed within which the Agency applies risk assessment to its activities (DETR, 2000). This tiered approach to environmental risk assessment and management is becoming commonplace, but its application to the detailed planning and authorisation of, for example, a typical construction project is not explained in formal guidance. The term risk assessment is commonly used in the regulatory sphere but the scope of assessment needed in relation to the various stages of a development scheme is often unclear. Within the planning context, the scoping of an Environmental Impact Assessment (EIA) is now a formal requirement for most significant development schemes (Environmental Impact Assessment Regulations, 1999).

In the past the consultee role within the planning system, particularly at a strategic level has been regarded more as a power rather than a duty and has often not received a high priority. This focus is likely to shift as, in line with its Vision (Environment Agency, 2000), the Agency seeks to take a more active influencing role as one means of achieving its long-term environmental goals.

The Agency has a primary, statutory duty in undertaking its activities to contribute to the objective of sustainable development. This is increasingly being reflected in guidance and procedures. The interface between the planning, risk assessment and the sustainability aspects of proposed schemes is an area where policy and practice are rapidly developing.

Further Legislation and the Groundwater Strategy

The implementation of the Water Framework Directive (WFD) over the next few years will highlight the need to take an integrated approach to water quality and quantity issues, in order to achieve sustainable ecosystems. The WFD will be a driver for dealing with diffuse pollution and reinforce the need to consider the management and protection of groundwater resources rather than sources of supply. Concentration on the latter dominated the thinking and approach to groundwater issues during most of the 1980s and 90s and eventually led to threatened action against the UK by the EU Commission in respect of incomplete implementation of the Groundwater and Nitrate Directives. The changes in UK legislation and guidance that resulted from this pressure, such as the implementation of the Groundwater Regulations, 1998 has raised the profile of groundwater protection. The WFD is likely to build on these changes, with a requirement to define groundwater bodies and identify "at risk" groundwater bodies. The latter will be subject to detailed groundwater quantity and quality monitoring and action plans to reverse anthropogenic trends that might compromise established standards (which are yet to be set).

The policies and tools that the Agency will need in order to respond to these changes and new developments in groundwater management are being developed rapidly and will be eventually be reflected in a new Groundwater Strategy, which will replace the existing PPPG. Although many of the principles outlined in the PPPG will remain substantially the same, the developments noted above will result in a shift of emphasis that reflects the additional powers and duties that are available to protect groundwater and the developing requirements of the WFD. The Groundwater Strategy, which is likely to be an evolving document over the next few years will comprise:

- policy statements, with an overarching policy statement on the Protection and Sustainable Management of Groundwater;
- background notes outlining the key principles of groundwater management and protection;
- supporting, more detailed guidance notes on operational aspects; and
- descriptions of the main technical tools that are complementary to and facilitate implementation of groundwater protection measures.

There will be much more emphasis on an integrated approach to groundwater quality and quantity issues, and, looking forward to the implementation of the WFD, the integration of these issues with the protection of surface water ecosystems.

Some parts of the Strategy will interface closely with other legislative regimes, such as the contaminated land and waste management regimes. In the case of the latter, new guidance has already been developed, partly in response to existing pressures, but partly to reflect the introduction of the Landfill Directive and revisions to the system of EIA under the development planning regime.

GUIDANCE ON THE LOCATION AND IMPACT ASSESSMENT OF LANDFILL SITES

A modern landfill for municipal wastes is typically a complex engineering structure that represents a long term (decades to centuries) potential source of polluting substances. New or extended landfill developments attract a great deal of scrutiny from both the public and regulators and often take many years to bring from project initiation to operation. A new landfill development represents a substantial commitment on the part of an operator before all the planning and operating permits necessary for the site to take waste can be obtained and there is a continuing liability long after the site has ceased to operate.

In the past, the majority of landfills have been sited in former quarries, as convenient holes in the ground, often with a need from the planning perspective to achieve some restoration of the land surface. However, many former quarries are in major or minor aquifers and, from the groundwater protection perspective, these may be far from ideal sites for landfill.

The trend from groundwater source to resource protection, the pressure from the EU to ensure strict implementation of the Groundwater Directive and the introduction of the duty to consider the contribution to sustainable development, are all factors that require the Agency to take a more precautionary view of developments that have a long term potential to pollute groundwater resources.

Most recently the introduction of the Landfill Directive has resulted in potential further restrictions on the location, design and operation of landfills. The stated aims of the Landfill Directive are:

> to provide for measures, procedures and guidance to prevent or reduce, as far as possible, negative effects on:

- the environment, in particular with respect to the potential pollution of surface water, groundwater, soil and air, and

- the global environment, including the greenhouse effect; as well as
- any resulting risk to human health;

during the whole life-cycle of the landfill.

The Directive contains a variety of requirements to meet these aims, including measures to protect surface and groundwater. Annex I of the Directive requires that a landfill can only be authorised if the characteristics of the site with respect to certain locational requirements indicate that the landfill does not pose a serious environmental risk. These include:

- the existence of groundwater in the vicinity; and
- the geological and hydrogeological conditions in the area.

Locational issues are the remit of the planning authority but the Agency, as a statutory consultee on planning applications for waste management facilities, has a responsibility to inform the planning authority if, on carrying out an assessment, it considers that an application for a site fails to meet the requirements of the Landfill Directive.

In response to regulatory pressure there have been substantial improvements in operating practices and rapid developments in landfill technology with improved liners and monitoring facilities. Providing that they are not sited in close proximity to sensitive resources, most landfills constructed and operated to current standards do not pose a major threat to groundwater.

However, there remain residual areas of concern in relation to:

- The extended duration of the potential pollutant loading in comparison with the operating life of the site, institutional controls and the regulatory duty to contribute to the objective of sustainable development;
- In view of the above, the potential consequences of an apparently low risk being realised at some point over an extended timescale within a sensitive resource;
- The high costs of remediation of groundwater if it becomes polluted;
- The need to comply with the Landfill Directive;
- The volume of assessment work that is needed on the part of both the operator and the regulators in ensuring that a site can be developed in compliance with the legislation.

It is in recognition of these concerns that the Environment Agency has developed new guidance on the location and impact assessment of landfills. This will form part of the supporting guidance to the Groundwater Strategy on operational aspects. The guidance seeks to discourage the siting of landfill or land-raise developments with a long-term pollution potential in sensitive groundwater resource areas, namely all major aquifers, and minor aquifers within groundwater source protection zones. The Agency will object to the development of such landfills where there is long-term (post closure) reliance on engineered structures and/or active controls to protect controlled waters. This implies that if passive measures or natural attenuation in the subsurface are adequate to protect the identified water resources, then the site may be acceptable. Similarly if steps are taken to reduce the period over which there is a potential to give rise to polluting leachate to the operating life of the site, then this also may be acceptable.

The guidance is directed at several levels (see Table 1). At the Strategic Planning level it commits the Agency to providing constraint maps on the location of sensitive resources and encourages the location of waste facilities away from such resources, via a full appraisal of options for waste management facilities. The objective is to ensure that any sites that do come forward for development represent the Best Practicable Environmental Option (BPEO). As indicated in Table 1 and Figure 1 these sites will have gone through a risk screening process to determine their inherent suitability, but there will not necessarily have been any detailed consideration of site engineering.

At the Planning Application stage (Table 1), the site location would not be raised as a matter of principle by the Agency, providing the process noted in Phase 1 has been undertaken.

The Agency is a statutory consultee on the pre-planning application Scoping Opinions that can now be required under the Environmental Impact Assessment Regulations. At this stage the Agency will indicate the extent of the EIA needed to satisfy its concerns based on the submitted details of the proposed site and will highlight the need to have particular regard to groundwater resources in Major aquifers, all Source Protection Zones defined under the PPPG, and the water quality of sensitive surface waters. The guidance highlights that the Agency is likely to object to planning applications where there is reliance on engineering or active post closure controls within sensitive groundwater resource areas, as noted earlier.

The guidance encourages the co-ordinated application for planning permission and operating permits for a proposed facility, so that the technical details can be progressed in parallel and that impact assessments are undertaken within a consistent framework. Currently considerable wasted effort is common in risk assessments due to inconsistency between the planning application and the application for an operating permit. Table 1 and Figure 1 highlight that there are likely to be differences in emphasis and degree of detail in such risk assessments but if the framework is consistent, the impact of potential changes to schemes can be assessed more readily and effectively.
At the operating permit stage (Phase 3) the majority of additional assessment needed should be to detailed elements of the design. However, the guidance notes that the assessment must address the long-term viability of pollution control measures over the whole life of the site, including any aftercare period.

CONCLUSIONS

Whilst many developers or operators may regard the new landfill location guidance as restrictive, it is considered that it represents a much clearer exposition of the Agency's approach to the entire process of assessment of a landfill development, from strategic planning through to operating permit. This is driven entirely by the Agency's duties under the prevailing legislation. Moreover, the guidance will constitute one of the means by which the Landfill Directive is implemented in England & Wales.

Too often in the past there has been a lack of clarity with respect to the respective roles of planning and operating permits and a tendency to postpone key decisions on the acceptability of a landfill proposal to the final stages of assessment. Frequently, highly detailed and inappropriate risk assessments are undertaken when the fundamental principles of landfill location and operation have not been dealt with. It is hoped that the new guidance will assist in optimising assessment work and focus attention on the key issues in site development.

The guidance is an example of how the Agency wishes to influence the planning phases of new developments rather than leave our input to the detailed permitting stage when developers have often committed themselves. We anticipate that, through the new Groundwater Strategy, many other activities (e.g. chemical and fuel storage) that can give rise to groundwater pollution will be addressed in a similar tiered manner to landfills.

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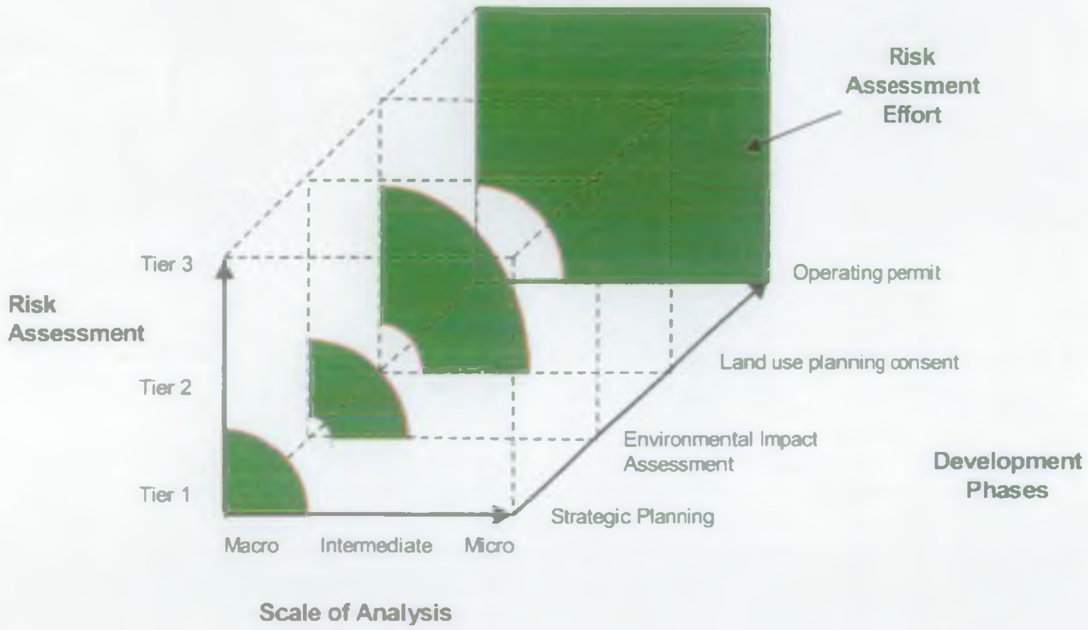
RISK ASSESSMENT EFFORT RELATED TO DEVELOPMENT PHASES



Macro: e.g. Site location, basic function Intermediate: e.g. Site layout, major construction elements & processes
Micro: e.g. Material specifications, operation details.

Figure 1 Risk assessment effort related to development phases.

Table 1: Relationships between the policy and site development, design & environmental risk assessment.

DEVELOPMENT PHASE	KEY ISSUES	RISK ASSESSMENT & POLICY PHASE	ASSESSMENT TOOLS
Strategic e.g.: - Regional Planning Guidance - Structure Plans **- Unitary Development Plans (Wales & some areas of England)** - Local Plans	Site location Basic function (e.g. broad types of waste, overall capacity)	Risk Screening (identify major hazards and receptors) **PHASE 1**	Maps of location of major and minor aquifers (vulnerability maps) – eventually locations of "groundwater bodies" under the Water Framework Directive; Catchment protection zones (e.g. Groundwater Source Protection Zone 3, Dee catchment);
Pre-planning assessments – screening and scoping assessments for Environmental Impact Assessment Regulations.	Fundamental elements of design and operation.	Risk screening (identify all hazards and receptors) **PHASE 2A**	As above, but all groundwater protection zones, mapped conservation areas etc. Scoping guidance.
***Planning applications**	Operational principles, site layout, major construction elements e.g. type of landfill lining. Initial design without benefit of planning conditions.	*Tiered risk assessment on major elements of design, construction and operation. *(assess all pathways and impacts)* **PHASE 2B**	Site specific assessment – site investigations, local mapping etc. Risk assessment guidance and tools (e.g. LandSim)
***Environmental authorisations** e.g. Waste management site licence, IPC/PPC permits.	Detailed design, finalised taking into account planning conditions, formal feedback from Agency etc.	*Tiered risk assessment on detailed design, construction and operation elements. *(assess all pathways and impacts)* **PHASE 3**	Site specific assessment etc, as above. Guidelines for Environmental Risk Assessment & Management.

* Planning applications and environmental authorisations may be progressed in parallel.

29. LINKING GROUNDWATER AND SURFACE WATER MANAGEMENT

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INTRODUCTION

The field of hydrogeology is rendered complex by the unknown nature of the media within which the water moves. This has resulted in a strict demarcation between the consideration of surface water and groundwater that has affected the way in which hydrogeological systems have been investigated.

The legislative changes brought about by the Water Framework Directive are described. It is clear that this will enforce a radical change in the way in which groundwater resources are assessed

This paper examines the reasons for the former dichotomy and details some of the measures put in place to ensure that surface waters and groundwater are considered in a linked way.

Although this paper make no mention of groundwater or surface water quality, this is through lack of space rather than a suggestion that they should not be considered together. The Water Framework Directive makes no such omission and clearly requires a holistic view of surface and groundwater, quality and quantity

HISTORICAL SEPARATION OF GROUNDWATER AND SURFACE WATER

There has, in the past, always been a wide separation between surface and groundwater hydrology and this can be put down to a number of causes. Firstly, the science of hydrology is much more established than hydrogeology. Less than 30 years ago, at least one of the River Authorities in the UK did not employ any hydrogeologists, but there were many hydrologists. Additionally, the first geologists employed in the same River Authority were viewed with some suspicion and often their advice was disregarded.

Universities also separated out the two disciplines. For example hydrology was often taught in the Department of Civil Engineering and hydrogeology in the Department of Earth Sciences (good universities overcame this limitation by coordinating training for the two branches).

Hydrology and hydrogeology is still separated in the two major government research bodies and even in the Environment Agency, it is not unusual to have the two sections dealing with surface and groundwater in different part of the building or possibly in different buildings.

None of these examples prevent the holistic treatment of surface and groundwater but they do indicate an artificial split that needs to be recognised and "worked round".

Since, the two branches of what appear to be similar subjects have developed separately, the question is posed "are they really different". It is believed that there is a fundamental difference between the two: -

- Rivers and surface water flows can be seen and studied directly whereas groundwater cannot.

- Surface water is directly dependent on current rainfall patterns whereas most groundwater systems buffer the rainfall events so that levels are dependant upon a succession of events rather than the current one.

- Surface water flow can be considered as mainly two-dimensional whilst groundwater flows are three-dimensional (the realisation of the importance of this has only come about over the last fifteen years).

The first of these means that hydrogeologists need to consider where water is flowing to and also the nature of the medium through which it flows. These flows can never be measured but must be inferred from level measurements at very sparse observation points.

The second means that hydrologists develop statistical relationships to describe the surface system. Hydrogeologists tend to parameterise physical processes and rely to a much smaller extent on so called "black box relationships". This is not universal and for example, Russian hydrogeologists tend to use complex statistical relationships much more that UK practitioners would in the same situation.

CONCEPTUAL MODELLING

The fact that groundwater cannot be seen nor studied in situ, means that to a large extent, groundwater hydrogeologists give their advice based upon their own ideas as to what is happening in the aquifer, backed up by experience (where this is available). In the past, these intuitive ideas were often in the head of each hydrogeologist and often were lost in time. To prevent this, the Agency is currently trying to formalise the investigation process and is developing the conceptual model as a means of achieving it.

Conceptual models are simply the ideas that the hydrogeologist has about the way an aquifer system works and have been used within groundwater modelling for many years. This use is now being extended and it is now felt that any conceptual model will have a number of attributes:

- It will be written down

- It will contain diagrams and cross sections

- It will be sufficiently detailed for the problem in hand

- Importantly, it will be tested

Currently, the conceptual models are portrayed as a hierarchy of increasing complexity, increasing confidence and increasing cost. This cost element in both finance and time means that the model should be appropriate. Where a detailed model is available, it should be used for all work. However, where a detailed model is not available, a decision needs to be taken as to how much detail is required for the work on hand.

The conceptual model is always tested against the water balance for the aquifer. In simple terms, water enters the model via a recharge model (often separate in the Agency) and leaves the model via flows to rivers and the sea. Thus, understanding how rivers and aquifer interact is one of the fundamental mechanisms that must go into the conceptual model. Similarly, recharge is obviously a function of the rainfall / runoff relationship that a hydrologists might develop for a catchment. This explicit necessity to understand both river / aquifer interactions and rainfall / runoff relationships in order to test any conceptual model means that surface and groundwater hydrology can no longer be considered in isolation. The ultimate way of testing a detailed conceptual model is by producing a fully distributed groundwater model and the team that does this will inevitably include both surface and groundwater hydrologists. A substantial part of the modelling effort will therefore go towards elucidating the surface and groundwater interactions.

INTEGRATED SURFACE AND GROUNDWATER MODELLING

In the past, integrated groundwater and surface water models have been suggested as the best way for the Agency to undertake whole catchment modelling. In the future, it may well be the case that these are the tools to be used to produce predictive models capable, for example, of running climate change scenarios. It is felt that at present, that these are too complex for the current modelling programme to use. We are at a stage where we are trying to use the modelling process to test increasingly complex conceptual models. We are not trying just to develop a set of parameters that reproduce given datasets of river flows or groundwater levels. This in no way devalues such integrated models and in certain circumstances they produce excellent models of hydrological systems. However, for the present it is believed that the ability to investigate individual elements of a hydrogeological system, using simple and well understood code to achieve the Agency's limited aims, is the most cost effective way forward.

European Water Framework Directive

Since the groundwater abstraction licensing system came into being as a result of the 1963 Water Resources Act, it has always been a requirement to assess the effects of any new abstraction licence on surface water in the form of streams or wetlands. This requirement became more explicit with the advent of the Environment Agency but there has never been any rigorous advice as to how these effects should be determined nor how such effects should be allowed for or treated during the licensing process.

The Water Framework Directive has addressed this gap in the legal framework in a number of ways. While the EU presidency lay with the UK in 1997, the Environment Agency was able to input to the drafting process. One of the strong themes we tried to insert was the acceptance that groundwater and surface water are merely two aspects of a single system such that neither should be treated separately.

It may not be well known that colleagues from other European bodies dealing with groundwater do not necessarily agree that the WFD as it stands has any impact on groundwater quantity. Indeed some countries believe that quantity considerations are explicitly excluded from the text. It is not the view within the Agency and it is felt that at last, the WFD will be the legislation that ensures that surface and groundwater are treated holistically.

In order to see how the Directive controls groundwater quantity, it is necessary to look in detail at the definitions in Article 2 and the provisions in the Annex 2 & 5.

Firstly, the Directive deals with "bodies of water".

A "body of surface water" means a discrete and significant element of surface water such as a lake, a reservoir, a stream, river or canal, part of a stream, river or canal, a transitional water or stretch of coastal water.

A "body of groundwater" means a distinct volume of groundwater within an aquifer or aquifers.

Both of these "water bodies" will have a "status".

"Surface water status " is the general expression of the status of a body of surface water determined by the poorer of its ecological status and its chemical status.

"Groundwater status" is the general expression of the status of a body of groundwater, determined by the poorer of its quantitative status and its chemical status.

"Quantitative status" is an expression of the degree to which a body of groundwater is affected by direct and indirect abstractions.

"Ecological status" is an expression of the quality of the structure and functioning of aquatic ecosystem associated with surface waters.

Finally, the WFD defines the term available groundwater resource.

"Available groundwater resource" means the long term annual average rate of overall recharge of the body of groundwater less the long term annual average rate of flow required to achieve the ecological quality objectives for associated surface waters specified under Article 4, to avoid any significant diminution in the ecological status of such waters and to avoid any significant damage to associated terrestrial ecosystems.

There is a clear indication here that the quantity of water that can be abstracted from a groundwater body is directly related to the effects of that abstraction on surface water ecology. There is thus an explicit connection between surface water and groundwater and a welcome reinforcement of the holistic approach favoured by the hydrogeological community.

The definition of good quantitative status is classified according to the **level regime,** so a body having good quantitative status can be recognised by the following attributes: -

The level of groundwater in the groundwater body is such that the available groundwater resource is not exceeded by the long-term annual average rate of abstraction.

This means that in the long-term (which is not specified), the amount of water abstracted plus the amount of water required to achieve the ecological quality objectives for the associated surface water should not exceed that being recharged.

Accordingly, the level of groundwater is not subject to anthropogenic alterations such as *would result in:*

- *failure to achieve the environmental objectives specified under article 4 for associated surface waters*

- *any significant diminution in the status of such waters*

- *any significant damage to terrestrial ecosystems which depend directly on the groundwater body.*

And alterations to flow direction resulting from level changes may occur temporarily, or continuously in a spatially limited area, but such reversals do not cause saltwater or other intrusion, and do not indicate a sustained and clearly identified anthropogenically induced trend in flow direction likely to result in such intrusions

This definition of quantitative status re-emphasises the "whole system" approach to groundwater, expressing the health of the system as a function of surface water ecology and environmental objectives.

The Directive states that the level of groundwater should be used to monitor how well the current management scheme is achieving the objectives. This element will need some thought as to how it can be effectively applied. All the emphasis in the definitions is aimed at ensuring that the available resource always exceeds the abstracted quantity. This in itself requires a good understanding of all the mechanisms operating in the surface groundwater system and it is by no means simple to distil this quantified understanding into the measurement of a single parameter. In simple terms, if abstraction exceeds available resource, water levels will fall. However, the Directive specifies that equality should be determined "in the long term". In UK aquifers it will require up to 15 years data in order to determine, from level values alone, that abstractions are exceeding available resource.

The Directive requires some knowldege of how the systems works but a fairly detailed quantification of this understanding will be necessary.

There are directly analogous definitions of groundwater chemical status eg

The chemical composition of the groundwater body is such that the concentrations of pollutants for example:-

- *as specified below, do not exhibit the effects of saline or other intrusions*

- *do not exceed the quality standards applicable under other relevant community legislation*

- *are not such as would result in failure to achieve the environmental objectives specified under Article 4 for associated surface waters nor any significant diminution of the ecological or chemical quality of such bodies nor in any significant damage to terrestrial ecosystems which depend directly on the groundwater body.*

The definition of the status of a water body with its dependence on both quantitative status and chemical status for both surface and groundwater further enhances the holistic view to encompass the quality and quantity aspects and ecological effects of both surface and groundwater systems.

This ready acceptance and insistence upon the "whole system" approach is a great strength of the WFD and should encourage different ways of thinking and working within the hydrogeological community.

Impact of Groundwater Abstraction on River Flow (IGARF)

In 1998, the hydrogeological community within the Environment Agency made an assessment of the knowledge gaps, which might prevent the implementation of the Water Framework Directive. The single most important of these was our lack of understanding of the way groundwater abstraction impacted upon river flows. The only methods available were analytical, dated and in most instances inapplicable to practical situations. A three strand programme of research was developed aimed at providing analytical tools to help licensing staff make decisions in cases where river flows were likely to be affected. This programme, which considers the impact of groundwater abstraction on river flows, is continuing and links with other research programmes.

The first stage took the three most useful analytical methods and produced a spreadsheet tool to simplify their application. A subsequent stage looked at refining these estimates using numerical methods and the final continuing work is of longer duration. This will monitor levels under impacted rivers to get more data on which to work.

The work is now being done in consultation with the hydrologists working on new low flow simulation methodologies.

Whilst this programme has produced tangible benefits, the estimation of impact will remain a problem since the combination of flows, bed sediments, and geology produce many variations in river / aquifer connectivity.

Resource Assessment & Management (RAM) Framework.

The work on linking surface waters and groundwater culminated in the development of the Resource Available Methodology (RAM) Framework. This is intended to allow assessments to be made of the available resource for any particular area. The groundwater resources are calculated by:

- Determining the river flow required to maintain the ecology of the river at its current or aspirational level.

- The abstraction impacts on the river are calculated for all existing abstractions whether surface or groundwater

- It is explicitly acknowledged that any licences that abstract groundwater or that are not constrained by minimum river flows will modify the low flow statistics of the river. A restriction is set upon the amount by which these statistics can be changed.

- The impacts of all the licenses on the naturalised river flow are assessed and the impacted flow compared with the ecologically acceptable flow.

- In addition to assessing the impacts of groundwater abstraction on river flow, a separate check is made to ensure that individual areas of the aquifer are not over abstracted regardless of whether the impacts on the river are acceptable.

- These data are then used to indicate the potential for further development or of over commitment.

This new methodology is being applied for the first time now and already further research topics are arising relating to how the impact of all abstractions that affect a river system can be apportioned to the various river stretches

SUMMARY

Over the past three years, major steps have been taken to ensure that surface and groundwater are considered as parts of one system. These changes cover methodologies, thought processes and organisation. Despite this, the area of river / aquifer interaction will remain for some time one of the most complex areas of hydrology.

POSTER PRESENTATIONS

30. MONITORING POINT CONSTRUCTION AS A CONSTRAINT FOR VULNERABILITY MAPPING WITH GIS

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ABSTRACT

GIS techniques were used to derive classifications of groundwater vulnerability to nitrate pollution in England and Wales. These classifications were verified by comparison with predicted nitrate data from 3714 Environment Agency observation wells (Lake *et al.* 2001).

Construction details for a majority of the wells were obtained from the Environment Agency to investigate the depth of sources sampled. These details were used to classify wells based on their depth open to groundwater ingress. Two depth definitions were generated based on the minimum and maximum depths open to groundwater down each well.

The classification of the wells by depth was combined with the vulnerability classes to examine trends in nitrate levels. This statistical analysis indicated that nitrate levels decline with vulnerability irrespective of well depth. When variations in vulnerability were controlled for, it was found that the minimum depth definition had a slightly stronger relationship with nitrate levels than maximum depth. It is also likely that the minimum depth provides a better indication of the geological units acting as the major sources of nitrate entering a well, though the extent of the length open to groundwater ingress in many wells means that some caution is required when making such assessments.

INTRODUCTION

The increasing input of nitrate into the groundwater system through mainly diffuse agricultural sources since the Second World War, combined with an increasing awareness of the potential risks to human health of high nitrate levels, has led to the need for preventative measures. The Environment Agency is the regulatory body within England and Wales seeking to provide these measures by defining Nitrate Vulnerable Zones (NVZs). Within an NVZ agricultural practices are controlled and farmers are required to keep detailed records of all fertilizer applications to their fields to ensure that nitrate inputs do not exceed crop requirements.

Current groundwater NVZs are based on the modelling of the capture zones associated with public water supply boreholes (Environment Agency 1998). This approach, however, only protects the groundwater destined for public water supply. Lake *et al.* (2001) have recently described a more generic GIS-based method for defining vulnerability zones. This involved ranking areas using four layers of information; the quality of the water leaving the root zone of a piece of land (leaching); soil characteristics; the presence of drift material; and aquifer properties. The impacts of employing three different forms of leaching data and varying the weights placed on the layers were also examined through a verification exercise based on predicted nitrate concentrations in 2017 for 3714 Environment Agency observation wells. As a result of this exercise, a model based on a blanket nitrate application with the leaching layer given double the weight of soil, drift and aquifer characteristics was selected as the best vulnerability classification (subsequently referred to as the *specific* model, Figure 1).

In this study, we examine relationships between predicted nitrate levels in 2017, vulnerability classes from the specific model, and sampling depth estimates for the Environment Agency observation wells. The depth data were obtained for a subset of just over 2,000 wells (out of 3,714) where construction details were available. Two different methods of estimating the depths open to groundwater ingress within each well were used. This information was employed to answer two main questions;

> How does the predicted nitrate concentration change with alterations in vulnerability classification and well depth?
>
> Does the method used to define sampling depth alter the association with nitrate concentrations?

Answering the first question helps to clarify the relative importance of two influences on nitrate levels, and allows assessment of the relationship between the vulnerability model and nitrate concentrations when variations in well depth are controlled for. Resolving the second question provides useful information when interpreting trends in nitrate concentrations with borehole sampling depth.

DEFINITIONS

Vulnerability Classes

Four layers of leaching, soil, drift and aquifer data were combined by Lake *et al.* (2001) using a polygon overlay procedure. The different combinations of attributes were converted into relative scores with low numbers representing high vulnerability and larger ones a reduced pollution potential. A similar approach has been used in the DRASTIC model (Merchant 1994) and other studies of groundwater vulnerability assessment in the UK (Hiscock *et al.* 1995). The scores were subsequently grouped into categories, a narrower class interval being used in the highest vulnerability areas because there were more measurements of nitrate concentrations in such regions. Figure 1 shows the resulting classification (note that Class 1 represents the highest vulnerability).

Minimum and Maximum Well Depth

All of the Environment Agency observation wells were assigned a vulnerability score and corresponding class using point-in-polygon procedures within a GIS. For some 55 % of these wells it was also possible to define depths based on their construction details. A distinction was first made between wells open to groundwater ingress (i.e. screened or unlined) and those sections of wells cased or grouted (i.e. closed to ingress). This information was then used to derive the depth range over which each well was open to groundwater and could therefore sample nitrate concentrations. Two different measurements were defined as shown in Figure 2. Minimum depth represents the uppermost depth open to groundwater in the well, while maximum depth is the deepest point. From the original set of 3714 observations it was possible to create a *Max Depth* subset of 2008 and a *Min Depth* subset of 2036 due to the availability and quality of the construction details for each well.

Figure 1 The groundwater vulnerability classification for England and Wales.

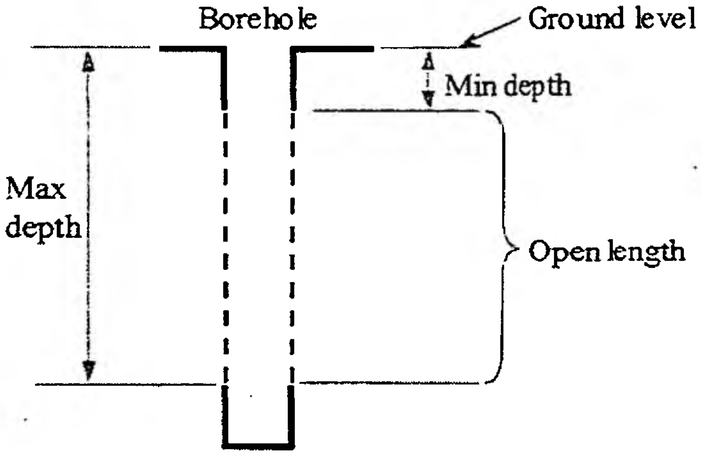

Figure 2 **The definition of observation well sampling depths. The dashed line indicates the depth over which the well is open to groundwater ingress.**

The depth measurements were subsequently grouped into categories to allow cross-tabulations with the vulnerability classes. Initially, the depth categories were based on fixed definitions for very shallow, shallow and deep ranges, but this produced highly skewed results with large numbers of wells falling into the deep category for *Max Depth* and the very shallow group for *Min Depth*. To overcome this problem, four categories were defined using the quartile values for each depth definition (this approach gave approximately similar numbers of observations in each class).

RESULTS

Table 1 shows the mean predicted nitrate concentration (mg/l) in 2017 for wells grouped by vulnerability class and *Min Depth* quartile. Table 2 does the same using the *Max Depth* measurements. It should be noted that both tables exclude wells in non-aquifer areas (as defined in Figure 1) so Table 1 is based on 1849 observations and Table 2 on 1827. The great majority of cells in both cross-tabulations contain at least 30 observations, but there are four cells in Table 1 and three in Table 2 with fewer than 20 observations (these all occur in vulnerability classes 8 and 9).

Spearman rank correlation coefficients (r_s) were calculated to assess the association between mean nitrate values and vulnerability classes for each depth quartile. The correlation coefficient varies from –1.0 (perfect negative association), through zero (no correlation), to +1.0 (perfect positive trend). In this instance, strong negative correlations were anticipated, representing a situation where nitrate values declined across the vulnerability classes. The correlation coefficients are shown in the bottom rows of Tables 1 and 2.

Multiple regression techniques were used to examine the extent to which variations in well nitrate concentrations could be predicted from their vulnerability scores and depth measurements. These analyses provided an indication of the relative importance of vulnerability scores and depth measurements as predictors of nitrate concentrations, and also made it possible to assess the relative merits of the *Min Depth* and *Max Depth* variables. It should be noted that the regressions used numerical vulnerability scores and depths (not categories), and that the possibility of using various variable transformations (e.g.

logarithmic) or functional forms (e.g. quadratic) was thoroughly explored. In the event, however, no obvious improvement on a standard linear model could be identified and the results obtained are summarised in Table 3.

Table 1 Mean nitrate level (mg/l) by vulnerability class and Min Depth quartile.

	Min Depth Quartile (m)				
Vulnerability Class	0	1-12	13-28	29-1056	Total
1	43	48	42	37	43
2	45	48	42	38	43
3	41	43	46	34	41
4	35	36	36	25	33
5	31	32	31	22	30
6	29	41	24	19	27
7	27	20	24	16	21
8	31	31	16	10	23
9	9	22	15	11	14
Spearman Correlation	-0.93	-0.90	-0.93	-0.97	-0.98

Table 2 Mean nitrate level (mg/l) by vulnerability class and Max Depth quartile.

	Max Depth Quartile (m)				
Vulnerability Class	0-45	46-76	77-120	121-1140	Total
1	50	40	41	42	44
2	44	42	48	40	43
3	41	51	33	39	41
4	38	39	27	34	34
5	33	29	28	27	30
6	41	22	33	16	28
7	22	25	21	15	20
8	32	26	15	8	23
9	12	25	3	7	14
Spearman Correlation	-0.88	-0.82	-0.87	-1.00	-0.98

Table 3 Results of the multiple regression analyses.

Regression Parameters	Model with Min Depth	Model with Max Depth
Intercept	50.55	53.34
Slope Coefficient for Vulnerability	-1.15	-1.29
T Statistic	14.07	15.74
Slope Coefficient for Depth	-0.16	-0.04
T Statistic	7.97	5.97
R^2 (% of Variance Accounted For)	13.60	13.00

DISCUSSION

Examination of the mean values in Tables 1 and 2 indicates that nitrate concentrations are associated with variations in both vulnerability and well depth. There are consistent trends for average nitrate levels to decline down each column (e.g. as vulnerability decreases and well depth remains relatively constant) and these gradients are confirmed by the strongly negative coefficients for the Spearman correlations. Several of the correlations are slightly stronger in Table 1 (based on *Min Depth*) than Table 2 (*Max Depth*), but there is not a substantial difference in the results.

Looking across the rows in Tables 1 and 2 it is apparent that nitrate concentrations tend to decline with increasing depth in each vulnerability class. In general, the variation with depth is less than that by vulnerability and often the second depth quartile has similar or higher average nitrate concentrations than the first. This situation is particularly evident in Table 1 where the first quartile represents minimum depth values of 0 (i.e. the well is open to groundwater at the surface) and tends to show slightly lower values than the second quartile (1 to 12 m depth).

Several comments can be made about the regression results in Table 3. The first point is that with R^2 values of around 13 % neither model is an especially good predictor of overall variability in nitrate levels. This suggests that other factors aside from the vulnerability score and well depth may be important. On the other hand, the slope coefficients in Table 3 accord with prior expectations (i.e. a steeper gradient for minimum depth than maximum) and the T statistics indicate that all the variables are highly significant predictors (i.e. a T value of approximately two represents a significant predictor at the 95 % confidence level). Comparing the T statistics suggests that the vulnerability score is a more important factor than the depth measurement and it is also worth noting that the value for *Min Depth* is slightly larger than that for *Max Depth*. This implies that when the variations in vulnerability are controlled for, there is a little stronger association between nitrate concentration and *Min*

Depth than *Max Depth*. Overall, the regression results suggest that *Min Depth* is a preferable measure of well depth for the purposes of investigating variations in nitrate concentrations, though the difference from *Max Depth* is not especially large.

The depth classification acquires more significance when viewed in a wider geological context. An interpretation of the geological units acting as the source for nitrate entering each well will depend on this classification. It is important to consider the range of depths, and hence range of geological units, open to groundwater ingress all of which may act as sources of nitrate. From the general trends with depth shown here and in other investigations of nitrate trends with depth (e.g. Parker *et al.* 1991, Foster *et al.* 1982) it is likely that nitrate levels decrease with depth. Thus the shallower regions are likely to contribute more to the nitrate concentrations in a well than the deeper ones and consequently the *Min Depth* definition is likely to provide a better indication of the source regions depth.

The uncertainty in the delineation of the source region attributed to a well depends on its open length. The difference between *Max* and *Min Depth* definitions for each well was calculated as a measure of this uncertainty, and the mean values derived for each of the vulnerability classes. When plotted in increasing class number this produced a trend with a Spearman correlation of –0.73 indicating that the greatest uncertainty occurred in areas with the highest vulnerability (i.e. Class 1). The implication, therefore, is that some caution may be needed when seeking to identify the depths of nitrate sources.

CONCLUSION

This research has combined information from a nitrate vulnerability classification with details of well depth for a set of Environment Agency observation wells. Two methods of depth estimation were examined based on the minimum and maximum depths to which wells were open to groundwater ingress.

From the results presented, it is clear that nitrate concentrations are associated with variations in both the vulnerability classes and well depth. The gradient of decline in nitrate levels was more strongly associated with reduced vulnerability than greater depth, but the latter was still a significant predictor. There was some statistical indication that the *Min Depth* definition was a better basis for nitrate trend analysis than *Max Depth*, and there are also theoretical reasons to prefer the *Min Depth* measurement for source depth identification.

It should be noted, however, that the differences between the *Min* and *Max Depth* results were not great, and that groundwater nitrate concentrations may often be influenced by other factors aside from the vulnerability score and well depth.

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31. PREDICTING THE IMPACT OF LAND COVER CHANGE ON GROUNDWATER RECHARGE

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ABSTRACT

Land cover change may have a critical impact on the water balance of an area, yet most work in the UK to date had been conducted only in upland areas supplying surface water. This paper uses current hydrological process understanding in a spatially distributed model to illustrate the impacts on groundwater recharge that may result from lowland land cover changes, principally due to changes in agriculture. An example is given for a lowland catchment, but the modelling framework could as easily be applied to larger scales, such as aquifer units or administrative regions. Some of the unresolved issues in process models are discussed, i.e. defining the vegetation rooting depth, bare soil evaporation, soil moisture deficits on the Chalk, forest edges and coupling socio-economic and hydrological models.

INTRODUCTION

For a given climate, the vegetation cover imposes a major influence upon the water balance and the hydrology of an area. For example, it is well established that, in upland areas, forests use more water than shorter vegetation, due to their higher interception losses (rainfall intercepted by the canopy and returned to the atmosphere by evaporation) which result from their greater aerodynamic roughness, e.g. Calder (1990). Vegetation also serves to bind together the soil to prevent erosion, and a good cover of leaf litter beneath a long established forest will result in a much more permeable and organic-rich soil, which has a higher infiltration capacity and a higher soil water storage capacity. The cultivation of some agricultural crops, such as spring-sown cereals, results in land being left bare for several months each year, during which time, transpiration will be zero.

The land cover in the UK is approximately 75% agricultural (18.5 x 10^6 ha), 10% forestry (2.5 x 10^6 ha), and 15% urban or unclassified (DETR, 1998). Almost three-quarters of the agricultural land cover consists of grasses and rough grazing; the remainder is crops, bare soil and fallow. Wheat and barley account for nearly three-quarters of the cropped area.

Prior to the mid 1950s, the area of broadleaved trees was greater than that under conifers (DoE, 1992). However, in the 1980s the government encouraged the planting of lowland forests with indigenous broadleaved species (Countryside Commission, 1996). As a result, between 1980 and 1997, there has been more than a 10-fold increase in the planting rate of broadleaved species, and since 1994 new planting (excluding restocking) of broadleaved trees has exceeded that of conifers.

The 1995 Rural White paper for England (HMSO, 1995) announced the UK government's intention to double the area of lowland forest in England by year 2045, from 7 to 14% of the country (approximately 2 Mha). Additional land might also be given up to short rotation coppice of willow or poplar for biofuel production.

Applying catchment studies to lowland areas is perhaps a greater challenge than to upland catchments. The land cover is often more patchy in space and dynamic in time as annual crops often dominate. In addition, the underlying geology is often more permeable than in ancient mountain massifs. The surface and subsurface divides of catchments rarely coincide, with the result that it is difficult to obtain reliable estimates of the catchment water balance.

For these reasons, as well as uncertainties in how the results at one site might be extrapolated to other areas where physical characteristics might be different, the need for physically-based process studies has been recognised, e.g. Calder (1993). These have the advantage that the controlling factors and their interrelationships are analysed, and can then be incorporated in a model that should have much more general applicability than the purely empirical relationships derived from catchment studies alone. A further advantage of the processes approach is that, because the models are causal, they have the ability to predict and so can be used to evaluate the impact of change of, for example, land cover or climate. However, they have the disadvantage that it is necessary to extrapolate from the plot scale to catchment or regional scale. This requires a thorough understanding of the physical processes and extensive digital spatial data sets.

Sellers and Lockwood (1981) demonstrated the potential of a physically-based model by comparing the predicted long term water balance of a small catchment in lowland southern England for different vegetation types. They predicted that the total evaporation loss for pine was 40% greater than for grass, principally due to the total interception losses being four times greater. This was reflected in the total annual runoff for a hypothetical pine cover, 152 mm, which was half the value of 303 mm predicted for a land cover of grass. Furthermore, the predicted peak daily streamflows generated under grass were often 30% higher than those predicted for the same storms under pine.

Spatially distributed, physically based models require datasets with appropriate spatial resolutions; such data are increasingly becoming available. The UK has good digital spatial datasets for landscape scale studies: for example, the Institute of Terrestrial Ecology's (ITE) land cover dataset, Soil Survey and Land Research Centre's (SSLRC) soil maps and databases of properties, and the Institute of Hydrology's digital terrain model (IH DTM). These datasets have spatial resolutions between 25 and 100m. Internationally the situation is not as good but there are global and European datasets covering land cover and soil type at about the 1 km resolution e.g. International Geosphere Biosphere Programme (IGBP), Coordinating Information on the European Environment (CORINE).

This paper explores the potential hydrological impacts of land cover change by the application of relatively simple, but physically based and spatially distributed models.

The Model

The model is fully described by Finch (2001) and so only a resumé will be given here. It combines the Penman-Monteith (Monteith, 1965) evaporation model, which is gaining wide acceptance for estimating evaporation in operational hydrology (e.g. Allen *et al*, 1998), with a simple soil water model based on the capacity approach. The original Penman-Monteith model assumes that the vegetation canopy totally covers the land surface and so the modification of Shuttleworth and Wallace (1985) for sparse vegetation is used for land cover types whose annual growth cycle includes a period of sparse or absent canopy, e.g. cereals. It describes the energy partition of a mixture of bare soil and vegetation. The model of canopy rainfall interception described by Gash *et al.* (1995) is included when the land cover is woodland.

The soil water model consists of four layers. The topmost layer represents the zone from which evaporation takes place in both ways, as direct evaporation from the soil and water loss due to root abstraction and evaporation from the vegetation canopy. This layer also allows the model to simulate the rapid increase in evaporation following rainfall, even in the presence of a soil moisture deficit throughout the root zone (Finch and Harding, 1998). In the second layer, losses to evaporation are solely due to root extraction by the vegetation. Evaporation losses do not occur from the lower two layers, which represent a zone from which water can be drawn upwards, in response to increasing soil moisture deficits in the root zone. This process is significant in some soils as deficits can develop at depths substantially greater than the rooting depth, (see for example Gregory, 1989 and Wellings and Cooper, 1983). It is assumed that below the fourth layer, the soil (or rock) is at a constant water content, field capacity. Drainage between layers is based on a capacity approach as in the model of Ragab *et al* (1997). If the inflow to the first layer exceeds its field capacity then the excess water drains down to the second layer and so on for each of the layers. Water in excess of the field capacity of the bottom layer is considered as potential recharge.

Runoff as overland flow is calculated as a function of the soil water content of the top layer of the soil model (Finch, 1998). Interflow, that is lateral flow through the soil, is calculated in a similar manner to that of Abramopoulos *et al.* (1988).

The model uses a rectangular grid of 'cells' to represent the spatial variability of the land surface and driving variables. A single value of direct groundwater recharge is obtained for each grid cell by running the water balance model for each combination of land cover type and soil type. The direct groundwater recharge for the cell is calculated as the area weighted average of these combinations. This so-called 'mosaic' approach (Koster and Suarez, 1992) retains the variability of the land so making reliable estimates of groundwater recharge possible, even when there is an extreme variation of soil and/or land cover types.

The model incorporates some GIS functionality which has a number of advantages:

- the ability to integrate information from a variety of sources;
- the ability to display technical data for ease of comprehension by managers;
- the generation and comparison of different scenarios.
-

Case Study

This study applies the above model to the catchment of the River Pang. This catchment has an area of 175 km^2 and is located on the Berkshire Downs in southern England. It lies on the Chalk, the UK's most important aquifer. The catchment has a maritime climate with an average annual rainfall of about 700 mm and gauged annual runoff of 177 mm. The river flows for a distance of approximately 35 km to its confluence with the River Thames and has a high baseflow index of 0.87, indicating that the river is in close hydraulic contact with the aquifer (Marsh and Lees, 1998). The hydrogeology is principally unconfined Chalk with approximately 15% covered by impermeable clay and alluvium, mainly in the south. The catchment is predominantly rural, agricultural land cover consisting dominantly of cereal crops and grassland. There are numerous abstraction boreholes, for municipal supply and agricultural use, throughout the catchment.

Woodland occurs mainly in the southern part of the catchment, Figure 1, in particular on the relatively infertile Southampton soils (very stony, very acid, sandy soils developed in Plateau Gravel and river terrace drift) and Wickham soils (typical stagnogley soils, fine loamy or fine silty over clay). The land cover of the northern part of the catchment is mainly grassland or tilled land, mainly on Chalk soils, with the dominant crop being winter wheat. The main land cover change between 1990 and 1997 has been an increase in tilled land at the expense of grass, the majority on the Chalk soils in the northern part of the catchment (Finch, 1999a), Table 1.

Table 1 Percentages of land cover in the Pang catchment

	1990	1997	2045
% Grass	40	23	17
% Tilled land	43	59	55
% Deciduous woodland	14	14	26
% Coniferous woodland	3	4	2

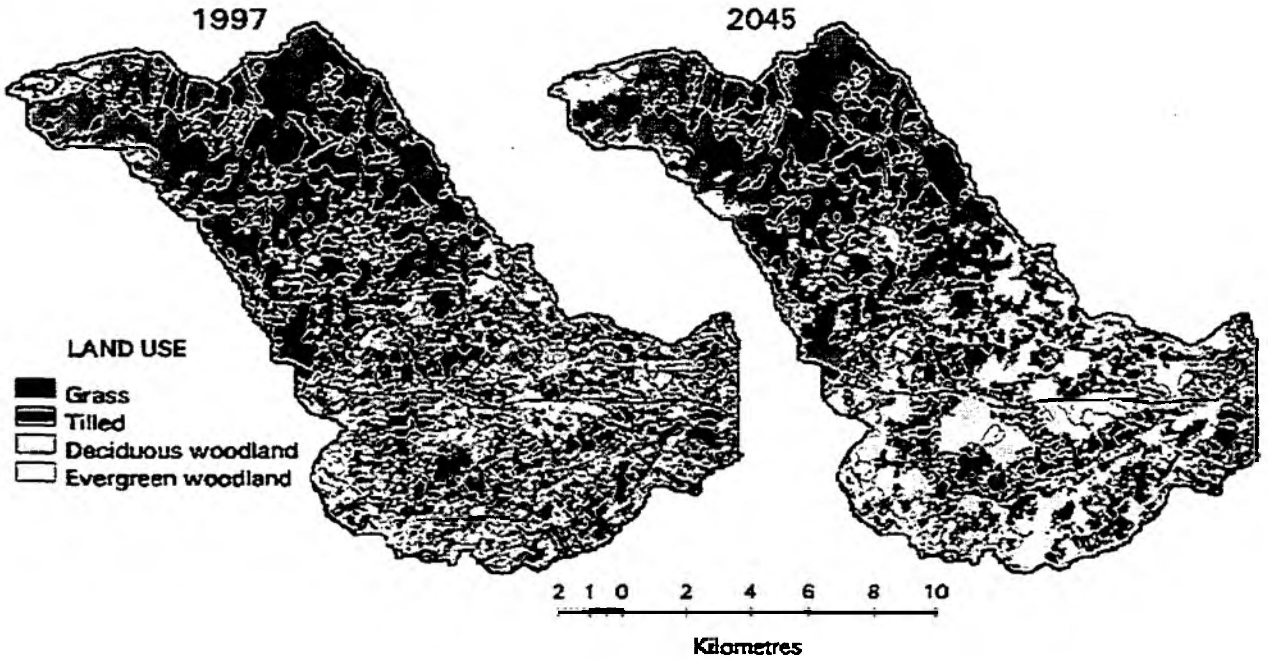


Figure 1 Pang catchment land cover in 1997 and potential land cover in 2045

Finch (2000) compared the measured soil moisture deficits which developed under grass and deciduous woodland at a site in the south of the catchment. The trees had a significantly higher water use than the grass. This was attributed to a combination of increased evaporation of intercepted rainfall by the woodland canopy from the trees and the deeper rooting depth of the trees, which meant that transpiration was rarely limited by soil water availability. For a 25 year period (1972 - 1997), the estimated mean annual soil drainage under grass was 198 mm whilst, for deciduous woodland it was 71 mm. A dramatic reduction of nearly two-thirds in the water available for recharge if grass were to be replaced by deciduous woodland. If extrapolated across similar parts of the country, this change could have an enormous impact on ground and surface water resources.

Impact of Woodland Increases at the Catchment Scale

The potential impact on the groundwater resources of the catchment by the policy of encouraging the planting of deciduous woodland can be illustrated using the spatially distributed model. There is currently little woodland planted on the Chalk soils of the catchment as these are the high quality agricultural soils. It is likely that this will continue and future planting will be on the poorer and heavier soils. This control on the distribution of land cover has been accommodated by using a GIS to generate a realistic potential land cover scenario for the year 2045, Figure 1. This was achieved by changing to deciduous woodland the land cover of parcels of between 0.1 and 15 Ha, on soils other than high quality agricultural that were not already deciduous woodland, see Table 1.

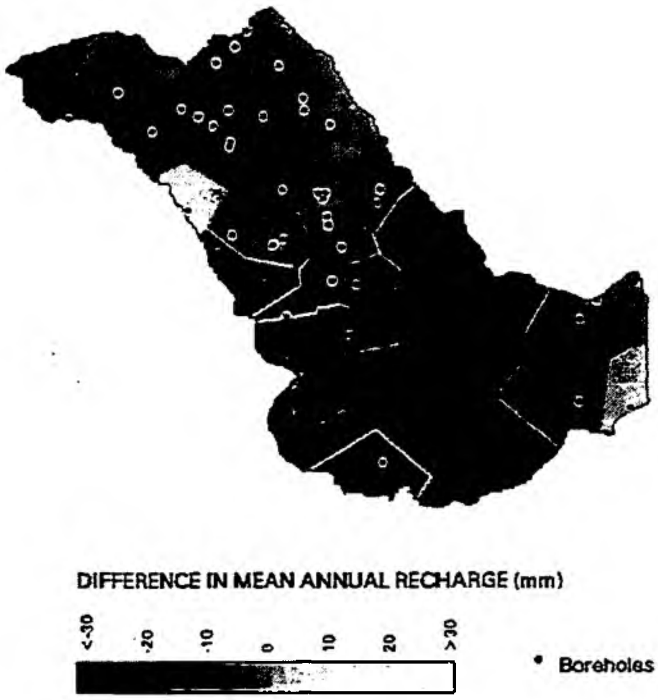


Figure 2 Modelled 25 year mean annual recharge for the 1997 land cover

The model was run for the land cover of 1997 and the potential scenario for 2045, using 25 years of meteorological data for the period 1972 to 1997. Daily meteorological variables (maximum air temperature, minimum air temperature, wet and dry bulb temperatures, sunshine hours and average wind speed) were available for a station near Wallingford (51° 36.1' N, 1° 6.7' E.). Daily rainfall records were available for a number of raingauges both in the catchment and in the surrounding area. Figure 2 shows the spatial distribution of mean annual recharge for the land cover in 1997. The highest recharge rates are associated with the Hornbeam soils (stagnogleyic paleo-argillic brown earths) in the central eastern portion of the catchment. This is because the available water content of these soils (209 mm) is less than the Chalk soils (338 mm) under a land cover of grass. The result is that evaporation becomes restricted by the soil water content sooner, hence limiting the soil moisture deficits that are developed. In the autumn, as rainfall again begins to exceed the evaporation losses, less rainfall is required to replenish the soil water store and thus recharge begins earlier. Low values of recharge generally occur in the south of the catchment as a result of the low maximum drainable water content of the soils, which tend to have a higher clay content, resulting in greater runoff. The recharge is further reduced as woodland makes up a larger proportion of the land cover.

The change in mean annual recharge for the two land cover scenarios shows that the total recharge for the catchment falls by about 7.5% from 106 mm to 98 mm. However, there are much bigger changes in the spatial distribution, with the largest reductions in annual recharge in the south of the catchment, with localised reductions of up to 50 mm. There are some localised areas of increased recharge, due to coniferous woodland being replaced with deciduous trees. Thus, although the impact of the potential land cover change on the catchment as a whole is small, locally the changes can amount to a reduction in recharge of up to 50% which may have a profound effect on the potential for abstraction from particular boreholes. A simple analysis can be carried out by defining Theissen polygons for each of the boreholes in the catchment and then calculating the average change in recharge predicted by the model within each polygon, Figure 3. This clearly defines a group of 12 boreholes in the centre and south of the catchment for which a significant decrease in mean annual recharge, and hence the reliable water yield, can be anticipated.

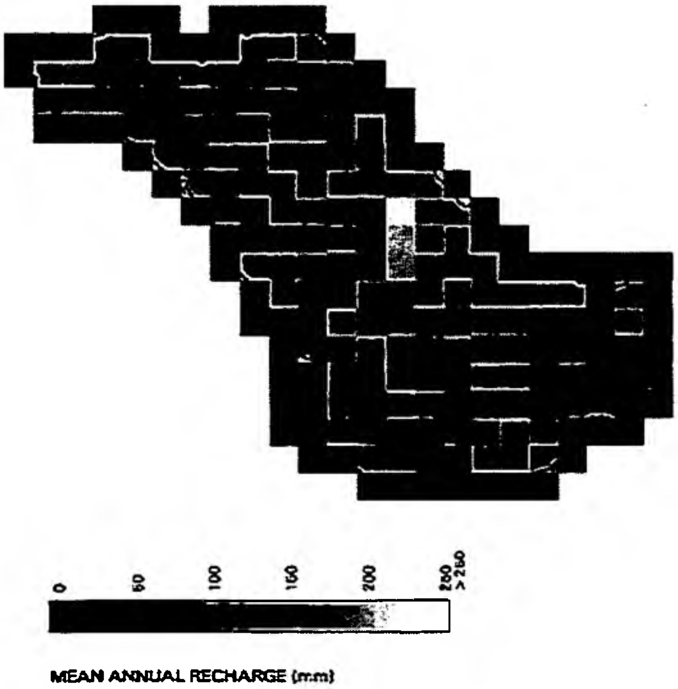


Figure 3 Predicted changes in mean annual recharge, as a result of land cover change, for the boreholes in the catchment

Change to Winter Sown Cereals

Cereal crops, such as the winter wheat which dominates the agriculture of the catchment, have a period in the late summer when the land cover is stubble. This is followed by a period of bare soils after which the canopy begins to appear. However, through the winter months, the canopy cover is constant until growth begins again in spring. During this period the canopy has not closed and so there is a component of evaporation from bare soil. The impact of this on the annual water balance is demonstrated in Figure 4 which shows the modelled cumulative potential evaporation, i.e. not limited by soil water availability, of grass and winter wheat, using the model of Shuttleworth and Wallace (1985). The effect of harvest is clearly shown by the abrupt reduction in evaporation. The potential evaporation only becomes comparable to that of grass again at the end of October. The result is a difference in the total annual potential evaporation of 107 mm.

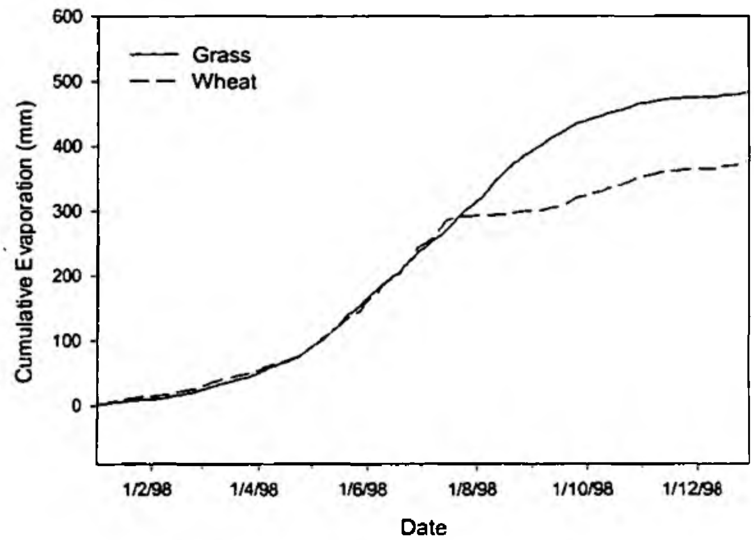


Figure 4 Modelled cumulative potential evaporation from land covers of grass and wheat

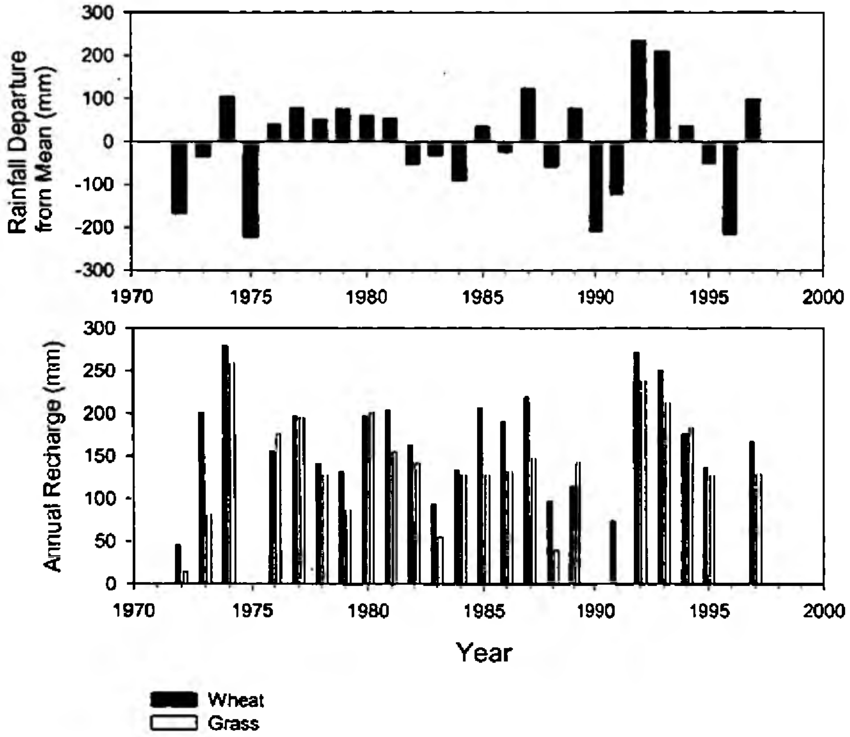


Figure 5 Comparison of modelled annual recharge for land covers of grass and wheat

The impact on groundwater recharge is demonstrated in Figure 5 which shows the predicted annual recharge from a Chalk soil for land covers of winter wheat and grass for the water years (1 October to 30 September) 1972 to 1997. The mean annual recharge for grass and wheat are 119 (s.d. ±76) mm and 148 (s.d. ±79) mm respectively. However, inspection of Figure 5 shows that the differences are not consistent from year to year. There are years, such as 1980, when the recharge under grass is greater than that under winter wheat, reflecting differences in the timing of rainfall events during the year.

UNRESOLVED ISSUES

Defining the Rooting Depth

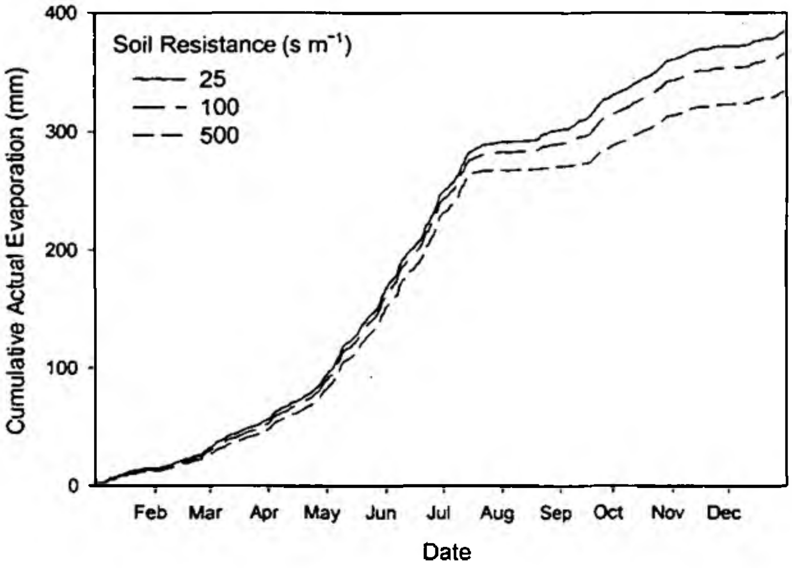
Major sources of uncertainty in modelling the recharge under a land cover of cereal crops are the rooting depth and the representation of the bare soil/stubble surface. Finch (1998) suggested that the rooting depth is one of the most important parameters in estimating groundwater recharge using water balance models. Canadell *et al* (1996) compiled a wide ranging summary of information on maximum rooting depth for different vegetation types, but there is little information in the literature on the factors which may limit it to less than these values. However, this may not be as crucial for cereal crops as it is for permanent vegetation.

The actual evaporation for 1998, was calculated with three different rooting depths (0.7, 1.2 and 1.7 m) for a cereal crop. The model predicts different evaporation rates are limited to the period of June and July, with the result that the cumulative totals only shows a difference of about 20 mm. This is because the crop is harvested soon after soil water deficits begin to limit transpiration, with the result that the soil water availability has little influence on the annual water balance. For comparison, the cumulative actual evaporation for grass shows a difference of about 43 mm, confirming that annual water balances calculated for permanent vegetation are likely to be more sensitive to rooting depth than those for cereal crops.

Bare Soil Evaporation

There is uncertainty in how to represent evaporation from bare soil, which has a complex response to diurnal changes in atmospheric and soil water conditions. This is because, as the soil dries out, a dry surface layer (DSL) develops. During the night, water evaporated from the bottom of this layer condenses in the upper part. In the morning, evaporation is initially at a high rate. As the day proceeds, the evaporation rate falls as evaporation is limited to the bottom of the DSL (Yamanaka and Yonetami, 1999). Daamen and Simmonds (1996) concluded that a Penman-Monteith type surface resistance could be used to represent this process but that its value was a function of the surface soil water content and the atmospheric vapour pressure deficit. Yamanaka *et al* (1998) have suggested that the thickness of the DSL depends on the soil hydraulic properties, and hence texture – it follows that the function relating surface resistance to surface water content will also depend on soil texture. However, it is unclear how the function would vary with the texture of the soils and whether it could be constructed so as to work with the daily meteorological values commonly used to drive the water balance models. The impact of uncertainty in the value of soil resistance on the water balance is demonstrated in Figure 6, the cumulative actual evaporation of a cereal crop in 1998, calculated with three different values of soil resistances. The evaporation rates differ from the beginning of the year until the end of May when canopy closure occurs. There is then a strong difference from harvest, in early July, until the end of the year. The effect of these differing evaporation rates is that the annual water balances differ by about 60 mm.

Figure 6 Modelled cumulative actual evaporation from wheat for different soil resistances



Soil Moisture Deficits on the Chalk

The special characteristics of the Chalk (Price *et al.*, 1993) provide a particular challenge for soil water models. Soil moisture deficits have been recorded at depths several metres greater than roots are likely to reach. Gregory (1989), reported that roots from cereal crops over Chalk were generally restricted to the top 0.8 m, although occasionally roots were found down to 1.0 m in cracks, yet the soil moisture deficits were observed to extend down to 3 m. In a comprehensive study at a Chalk site in Hampshire, Wellings (1984) concluded that a field capacity water content could not be defined, because rainfall percolated through the soil profile even when a soil moisture deficit was present. This occurs because the hydraulic conductivity of the matrix changes little with falling soil-water potential with the result that water continues to flow, albeit slowly, through the soil as the water content decreases. It also implies that soil water can be drawn up from depths significantly greater than the rooting depth in response to the matric potentials developed near the surface as water is extracted from the soil by roots. These processes are not represented in many of the simple water balance models used for estimating groundwater recharge, e.g. Ragab *et al.* (1997), with the result that the predicted values are likely to be in error. There is therefore a need to formulate soil water models that can represent the characteristics of the Chalk soils in a form comparable to the Penman-Monteith evaporation model in complexity.

Forest Edges

The majority of new forest planting in lowland UK is likely to be in small plots, of perhaps between 1 and 5 ha. This raises the question of the impact of forest edges on forest evaporation. Frequent forest edges would be expected to have a number of effects: firstly they will increase the roughness of a landscape, which will increase the interception losses. Secondly, trees at the forest edge may have a higher leaf area and more extensive rooting system, increasing the transpiration losses. Harding *et al* (1992a) describe a transect of interception measurements in a beech forest in southern England. Measurements of throughfall and stemflow were made at 5 distances between 20 m and 250 m from the forest edge. Only the site at 20 m shows any impact of the forest edge, however, even at 20m, the effect of the edge is only a few percent and insignificant in terms of the water balance of the forest. Kinniburgh and Trafford (1996) looked at water and solutes from boreholes in the same forest and found very low soil moisture and high solute concentrations very close (8m) to the forest edges, although there was a discernible effect up to 50 m from the edge. The implication of these measurements is that there are indeed enhanced evaporation rates close to the forest edge – primarily as a result of enhanced transpiration due to the high leaf area of the edge trees.

A simple calculation of the forest edge effect on the water use of a small plantation, typical of a farm forestry scheme, can be made by assuming a recharge of 155 mm a^{-1} within 20 m of the forest edge and 300 mm a^{-1} elsewhere. On a one hectare square plot the average recharge will be reduced to 68% of the value estimated without an edge effect. The reduction would be even larger if the plot is irregular or an elongated rectangle (such as a shelter belt) (Harding *et al.* 1992b). It is concluded that edge effects may be significant for forest plots less than 1 ha (strips less that 50 m in width) but not enough is known about these effects to quantify them with any confidence.

Coupling Economic/Social Models to Hydrological Models

Economic analysis is being increasingly applied to water issues, whereby water is treated as an economic good (e.g. Cameron, 1997). This helps reduce the complexity of decision making by enabling cost benefit analyses to be conducted. In the context of forestry, the value of timber production and any associated social benefits (including amenity value and employment income) may be balanced against disbenefits such as environmental considerations, including a reduction in reliable water yield due to higher evaporation losses.

This type of analysis could be studied in a spatial manner by consideration of the distribution of factors (such as soil fertility, climate, proximity to markets etc.) which will influence the relative economics of different land uses. Land use allocation models (Parry *et al.*, 1996) can indicate the likely impact upon agricultural practices of changes in climate, market conditions or government policies, such as reforms to the Common Agricultural Policy. This can be used to identify areas where changes in policy will most likely result in changes in land cover. The resulting land cover change scenarios provide a basis for assessments of the environmental consequences, using hydrological models such as that described in this paper, to assess the likely impact on water resources. The challenge is to link socio-economic models and hydrologic models which are formulated in fundamentally different ways, e.g. Ward and Lynch (1996). The increasing interest in integrated catchment management (e.g. Blackmore, 1995) is likely to provide an increasing demand for this kind of coupled model.

CONCLUSIONS

The land cover has a significant impact on the hydrology. In particular it is well established that forest cover evaporates more water than most other vegetation covers - through the dual influences of large interception losses and large rooting depths. There are, however, other land covers which have distinctive water use patterns, a good example of which are cereal crops, which only cover the ground with a complete vegetation cover for a few months of the year, with consequent impacts on the total evaporation.

In the UK there have been significant changes in woodland cover, and other agricultural practices, in the past decades. The impact of these changes have been mostly studied in the upland regions, where the high rainfall amounts lead to high interception losses and large percentage changes in total evaporation. In lowland regions the impact of forest (and other land use changes) on the absolute amount of evaporation is likely to be less. In these regions, however, the evaporation is a much larger proportion of the rainfall and land cover change is likely to make a much bigger effect on the excess water going into river flow or groundwater.

This paper presents a spatially distributed model of evaporation and groundwater recharge. The model makes use of the considerable increase in our understanding of the physical processes of evaporation and soil water movement in recent years and the current availability of spatially distributed data sets describing land characteristics, such as soil, land cover and elevation. The model provides a powerful tool to assess the hydrological impacts of realistic projected land cover changes.

An example of the implementation of the model is shown for a small chalk catchment in the south of England. A realistic example of the impact of planting of broadleaf trees on the poorer and heavier soil is shown. The reduction in groundwater recharge for the whole catchment is 7.5%, but locally this can rise to 50% - illustrating the advantages of a spatially distributed model.

Such a model is only as good as its underlying physics. However the model structure allows the analysis of the sensitivity of the predictions to some of the underlying assumptions and this is illustrated by an analysis of some of the perceived weaknesses in the model. It is shown, for example, that the accurate specification of rooting depth is important for the estimation of groundwater recharge under grass but not cereals. However under cereals the correct specification of bare soil evaporation is vital. Other uncertain issues, such as water movement in the chalk and the importance of edge effects (and hence plantation size) are also discussed. The model thus provides a tool to set future research agendas.

The importance of the integration of physical water resource models to social, economic and policy models is being increasingly recognised. The ability of the spatially distributed model to consider quite complex, but realistic, land cover change scenarios makes a link with economic and policy models, and agricultural and land use change very possible. Such a development will provide a powerful and flexible tool for the future.

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32. PLANNING NON-MAINS SEWERAGE DISCHARGES TO GROUND

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ABSTRACT

In areas without mains sewerage, sewage disposal is either through package treatment plants or septic tank systems, both disposing of effluent to ground. As with any disposal to ground, there is a risk of contaminating groundwater resources. To minimise risk of groundwater contamination careful control of the design and maintenance is necessary. In England and Wales, the consenting process is primarily via the planning system with some involvement from building control and the Environment Agency. The local nature of these regulatory paths brings the possibility of variation in regulatory decision making across the country. The absence of consistent records on existing septic tank systems means that cumulative pollutant loading cannot be taken into account. The planning system generates no evidence of compliance with consents for septic tank systems. There is almost no research on septic tank systems in the UK, and therefore the Environment Agency is embarking on such a programme so that any necessary changes in regulatory practices can be based on a firm scientific footing.

INTRODUCTION

In the UK some 750 000 households (approximately 5% of the population) are not served by mains sewerage (Payne and Butler, 1993). The majority of these are instead served by septic tank systems (STSs), with a smaller proportion served by package treatment plants (PTPs). STSs and PTPs offer relatively low cost treatment of waste water, minimise the need for pipe connections and their discharges contribute to groundwater resources close to the point of use. By comparison, installation of large scale sewage treatment requires major capital investment and may involve construction of many kilometres of pipeline. It also generally results in the movement of water downstream, or even out to sea in coastal areas. The sustainability of water resources is increasingly given consideration in the planning process and the local disposal of waste water helps to meet this objective.

The effluent from septic tanks contains a number of chemical contaminants, such as phosphate, organic compounds and ammonia and also large number of bacteria and viruses and can include pathogenic micro-organisms. As such the effluent has the potential to pollute, adversely affecting the quality of water resources beneath and downgradient of a soakaway.

The soakaways of individual STSs serving a single household constitute only a small discharge and are likely to have only a limited impact on groundwater quality. However, in unsewered areas of the UK (e.g. rural Hampshire) many individual septic tanks and often entire villages use septic tanks and the cumulative impact of many small discharges on groundwater quality may be considerable.

High densities of septic tanks are known by the Environment Agency to have led to groundwater and surface water contamination in parts of the UK, although such cases are not documented in the literature.

An estimated 7000 septic tanks are installed per year in the UK (Payne and Butler, 1993). In some areas the rate and size of proposed developments is sufficient to raise concerns regarding the cumulative effect of adding more septic tanks in areas where a significant number already exist. In addition, developers are keen to avoid costs associated with connections to mains sewerage or ownership problems associated with PTPs serving multiple properties and prefer individual septic tanks, even for high-density housing.

This paper first describes the functioning of STSs and PTPs and then reviews the existing legislation and procedures for the control of discharges from septic tanks and PTPs. Weaknesses in the current licensing system are identified and measures to improve it are suggested.

SEPTIC TANK SYSTEMS AND PACKAGE TREATMENT PLANTS

Septic Tank Systems

A septic tank consists of one or more water-tight chambers to which waste water is directed. Within the tank heavier solids settle out to form a sludge and floating material rises to form a scum layer. The remaining, mainly liquid, effluent is directed to a drainage field (or sub-surface irrigation system) where it soaks into the ground via perforated pipes. During the passage through the drainage field and the unsaturated zone important physical and chemical changes occur which reduce the impact of the effluent on the receiving groundwater and it is therefore appropriate to consider a septic tank system as comprising the sewage treatment system, and not the tank in isolation. As the drainage field is an integral part of the system, its design is critical, and discharging effluent directly to surface water courses is unacceptable because of the lack of treatment. A schematic diagram of a septic tank system is shown on Fig. 1.

STSs are not a maintenance-free sewerage solution; tanks require routine desludging to maintain their capacity. The capacity of the septic tank determines effluent residence time and hence the effectiveness of the tank in achieving physical separation of liquids and solids. In addition, soakaway drainage fields may clog over time due to bio-fouling and may require remediation after several years of service.

STSs can fail for a number of reasons, primarily as a result of inadequate sizing, or infrequent maintenance. In older tanks leakage directly from the tank can occur. Drainage fields can fail due to clogging, poor soil properties, uneven distribution of effluent within the drainage field or a high water table preventing infiltration. The effectiveness of STSs depends upon the microbiological treatment of waste water. These systems can be sensitive to the chemicals added to them and require care to maintain a healthy and effective microbiological population. Factors which might adversely affect the successful treatment include intermittent flow, with periods of inactivity and then periods of increased flow, e.g. at holiday homes, disposal of inappropriate chemicals, e.g. disinfectants, bleaches or solvents and changes in the pattern of use of domestic chemicals.

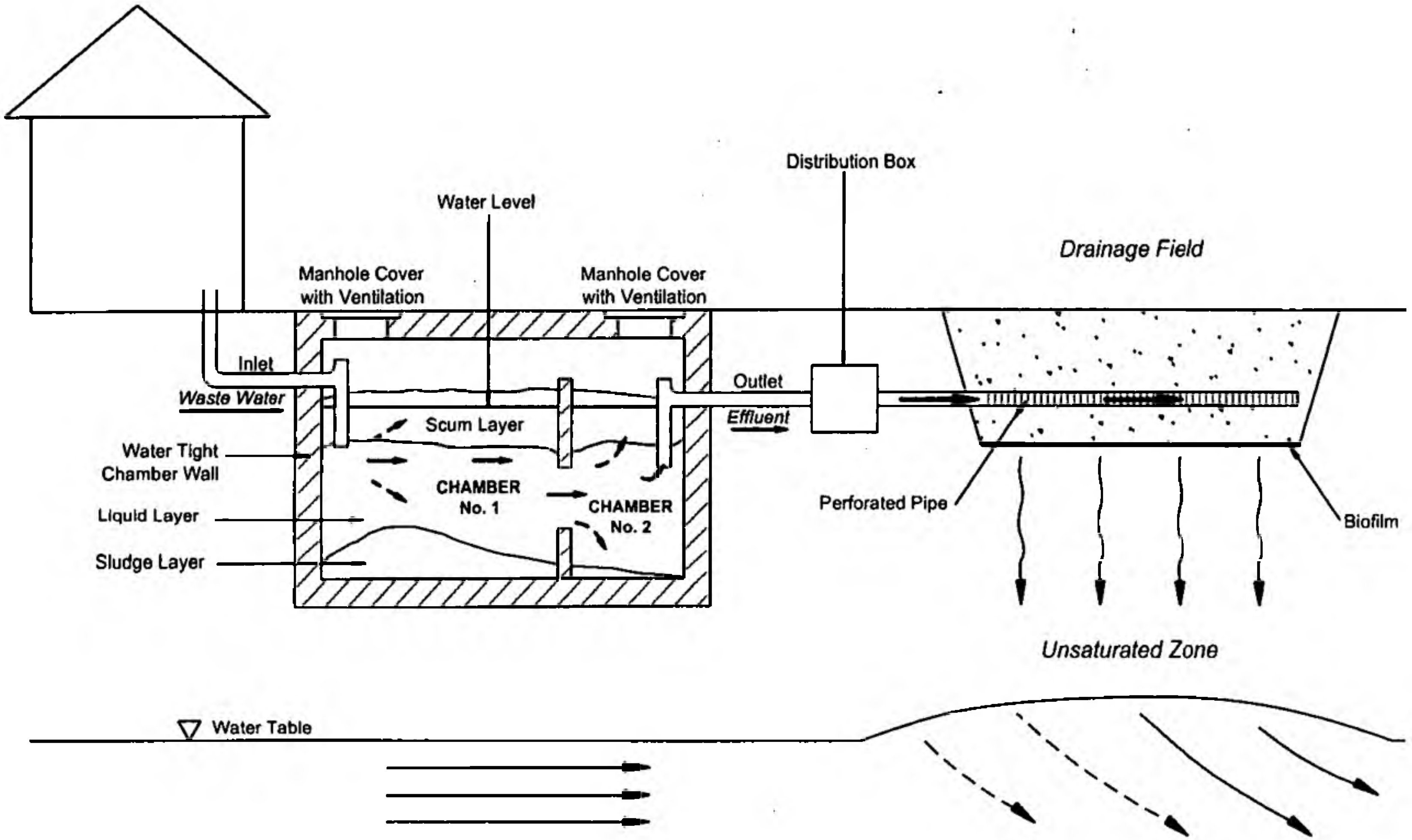

Figure 1 Septic tank system: general arrangement

Package Treatment Plants

PTPs are, in effect, small scale sewage treatment works and can produce effluent of a similar standard to full scale works. PTPs produce an effluent discharge which is either directed to a surface watercourse, to ground, or to both (as a seasonal soakaway) depending upon location. PTPs can serve individual houses up to communities of 1000 people (population equivalents) or larger. PTPs require regular maintenance to ensure that they perform correctly.

LEGISLATION

Discharges from STSs and PTPs are controlled through the Water Resources Act (WRA) (1991). Under Section 85 of the WRA (1991) it is an offence to discharge or knowingly permit the entry of polluting matter into controlled waters whilst under Section 88 a discharge consent can be issued by the Environment Agency which offers protection against prosecution. Discharge consents impose conditions on a discharge which can be quantitative, often in the form of limits for biological oxygen demand (BOD) and suspended solids concentration, or qualitative, setting installation requirements and maintenance conditions.

Regulation 19(1) of the Groundwater Regulations (1998) permits the use of conditional prohibition notices, used to ensure that adequate controls are put in place. Absolute prohibition notices can be issued to prohibit a discharge where such a discharge is undesirable.

The Groundwater Regulations (1998) implement European Groundwater Directive (80/68/EEC) and reinforce the provisions of the WRA (1991),with respect to the protection of groundwater. These regulations require that all discharges to ground require an authorisation, with the exception of isolated single dwellings well away from the public highway and outside Zone 1 of a source protection zone (SPZ). Discharge consents issued under the WRA (1991) meet the requirements of an authorisation. The Groundwater Regulations (1998) also identify the need for discharges to undergo 'prior investigation' and 'requisite surveillance', terms which are being explained in Environment Agency guidance documents. The Water Framework Directive (2000/60/EEC) requires that sources of diffuse pollution, such as numerous septic tank system discharges, are considered.

PLANNING AND LICENSING OF NEW SEPTIC TANKS

<u>Local Authority planners, building control and the Environment Agency (the Agency) are involved in the planning, construction control and regulation of STS and PTP discharges to ground.</u>

Planning Circular 3/99

Guidance to planners on non-mains sewerage is contained in Planning Circular 3/99 'Planning Requirements in Respect of the Use of Non-Mains Sewerage Incorporating Septic Tank in New Development'.

The Circular requires that the applicant provide an assessment of the use of septic tanks and suggests a series of circumstances in which septic tanks should not be considered, these include:

- Contravention of recognised practice;

- Adverse effect on water sources/resources;
- Health hazard or nuisance;
- Damage to controlled water;
- Damage to the environment and amenity;
- Overloading the existing capacity of the area;
- Absence of suitable outlets/insufficient land area;
- Unsuitable soakage characteristics;
- High water table;
- Rising groundwater levels;
- Flooding.

The Circular indicates that proof of suitability of any proposed system rests with the applicant. It also highlights that planning permission should be granted with the views of the Environment Agency taken into account.

The Circular includes a detailed list of requirements that the applicant is required to provide, but in a survey of Environment Agency practice (Entec, 2001) it has been found that very few planning applications include the information requested in the Circular, and in fact not all the necessary data are available for this to be possible.

BUILDING CONTROL

Once planning approval has been granted, the installation of STSs and PTPs are inspected by local authority building control. However, as a result of a judgement in the case of (*Chesterton RDC v. Ralph Thomson Ltd*) there is doubt as to whether building control have the right to inspect the construction of soakaway drainage fields. The lack of control over drainage field design limits the degree of control over STSs. The robustness of the judgement in the case which gives rise to this situation should be examined to determine its applicability.

THE ENVIRONMENT AGENCY

The Agency is a statutory consultee on planning applications for new septic tank system and PTP discharges. The response of the Agency to a planning application will depend upon the type of aquifer on which the septic tank is situated, the location with respect to sensitive receptors and groundwater protection zones and the region in which the proposed septic tank is situated. There are significant regional differences in practice within the Agency, principally in the size of discharge requiring a discharge consent. These differences are generally related to the sensitivity of aquifers within a particular region. In some Agency regions with few sensitive aquifers, small discharges in non-sensitive locations are filtered out of the assessment system.

Where control is desirable, or required under the Groundwater Regulations (1998), then the Agency require a discharge consent application. On the basis of a discharge consent application, Agency officers will conduct an assessment using their local knowledge, information on the aquifer vulnerability, soakage characteristics of the soil, depth to the water table, distance to receptor(s) and size of discharge to determine the scale of risk. For applications with a low assessed risk, then a discharge consent (WRA, 1991), or conditional prohibition notice (Groundwater Regulations, 1998) will be issued. In areas where septic tanks are not an acceptable waste water disposal solution, the Agency can issue a prohibition notice under the same Regulations.

Discharge consents for septic tanks are typically qualitative, i.e. they identify good practice for installation and maintenance of septic tanks. For large septic tanks and PTPs, quantitative discharge consents may be issued with specified maximum suspended solids and BOD concentrations.

EXISTING SEPTIC TANKS

An important consideration in assessing the impact of an application for a new septic tank system is the density of existing septic tanks to prevent overloading the attenuation capabilities of underground strata (Planning Circular 3/99). However, information on the location of existing STSs is not generally held by any of the regulatory bodies or sewerage undertakers. Agency databases with records of existing septic tanks, where they exist, are incomplete and records are rarely updated.

Once a qualitative discharge consent has been issued, the Agency will typically inspect the site of a discharge only when a problem is drawn to their attention. Building Control officers will often inspect the installation of the septic tank, but there is some debate as to whether they have powers to inspect the soakaway construction and in many areas the soakaway is not inspected.

Visits to a number of STS owners by Entec in 2001 revealed a very low level of understanding of the correct functioning of septic tanks, some owners were not even aware that they had a STS. Consequently many STS are likely to be poorly maintained, with maintenance being undertaken only when a problem arises.

SUMMARY OF CURRENT PRACTICE

The current regulatory framework is fragmented and issuing of qualitative discharge consents critically lacks a system of post-construction policing. The Agency, as a statutory consultee can advise that a discharge is undesirable but, even if a prohibition notice is issued, cannot prevent a septic tank system discharge from being granted planning permission. Under such conditions, enforcement action to prevent such a discharge may be the first course open to the Agency, creating a confrontational situation where one need not exist.

In some other countries (e.g. USA, Australia) the licensing and control of STS discharges is much stricter and requires applicants and owners of such systems to demonstrate that their system can and does function correctly. The stricter control may reflect the greater proportion of the population using non-mains systems (around 30% in the USA) but also the significantly larger body of research into STSs in both those countries. The Republic of Ireland is, notably, also moving towards a tighter regulatory system.

In the UK, the present system for assessing whether septic tanks are an appropriate disposal method is based around expert judgement and local experience. There is an absence of appropriate, UK based, scientific research on the effects of STS and PTP discharges to ground to support the assessment process. Without the support of research findings, it will be difficult to justify tightening of assessment procedures as any changes are likely to involve additional cost to STS and PTP owners and are therefore likely to be challenged.

RECOMMENDATIONS FOR IMPROVED PRACTICE

New Septic Tanks and PTPs

There is a need for all roles within the planning and licensing process to be more clearly defined and for improved two-way communications between all parties. In particular the roles and responsibilities of the Planning Authority, Building Control and the Agency need to be more clearly defined to avoid duplication of effort and eliminate gaps in the system.

Planners should encourage consultation between the Agency and the applicant at the pre-planning stage should be encouraged to determine the information that is required and whether the application is likely to be successful. Where the Agency is likely to object, the applicant should be advised of an appropriate course of action. Planners are likely to be the initial point of contact and should have sufficient information to be in a position to advise applicants. Planners should also have a sufficient supply of relevant Agency leaflets for issue to applicants.

Planning Circular 3/99 should be used as strict guidance by planners. The planners may require the help of the Agency in the assessment to provide data but it should not be left to the Agency to carry out the entire assessment.

A copy of decision notices from the Local Authority should be passed to the Agency in order to get feedback on their recommendations and conditions. Local Authorities should be requested to clarify any situation in which they do not follow the recommendations of the Agency.

The entire septic tank system, including the drainage field, should be inspected by the Local Authority Building Control during construction, and before it is covered. Additional training may be necessary for building control officers to enable them to carry out such inspections. The lack of control over drainage field design limits the degree of control over STSs. The robustness of the judgement in the case of *Chesterton RDC v. Ralph Thomson Ltd* which gives rise to this situation should be examined to determine its applicability.

Those sites not requiring a discharge consent (isolated single dwellings outside Zone I of an SPZ) should have standard conditions imposed to include construction and maintenance. These conditions should be standardised nationally and apply to certain installations on a national basis. They should include the requirement to design and construct the system to at least the requirements of BS6297:1983 (but see comments below). Recommendations made, and conditions imposed, by the Agency should be taken into full account when planning permission is considered.

All applications, whether consented or not, should be recorded to create a national database of non-mains sewerage systems to enable the Agency to manage the cumulative load imposed by small discharges.

There is a case for issuing, or declining, consents for all applications, thus giving the Agency a degree of control and generating a record. Consents could be issued on a time-limited basis, requiring the applicant to, as a minimum, maintain the septic tank by undertaking desludging on an annual basis. There is scope to implement such conditions as a Code of Practice under the Groundwater Regulations (although such conditions would be consented under the WRA (1991) rather than the Groundwater Regulations (1998)).

A decision to grant a consent, or to carry out an assessment of the suitability of a septic tank application, or other application for discharge of treated sewage effluent to ground, should be made only after as much information as it is practicable to collect has been gathered, this is likely to include:

- Site map, including ownership boundaries, the exact location of the septic tank and national grid reference;
- Full postal address of the site, site ownership details and proposed use;
- Minimum and maximum number of persons that the non-mains sewerage system is to be designed for including any predicted seasonal and temporal fluctuations in usage and number of persons;
- Groundwater level and fluctuations (depth of unsaturated zone);
- System design and exact location;
- Proximity to surface features
- Geology of the site, including information on soils and underlying rock;
- Soil type and depth and results of percolation test and results of the investigation carried out at the planning stage.
- Source of water supply to the property, i.e., mains, well or private borehole,

A nationally consistent procedure for decision-making based on this information should be drawn up with extensive communication between regions to ensure standardisation and transparency. Any proposed national scoring system will need careful evaluation and validation to ensure that it is effective and soundly based.

The emphasis of the assessment should change from the hydraulics of the disposal of effluent (will the effluent soak into the ground?), to pollution prevention to protect water resources. Post-construction, those sites granted a discharge consent (qualitative or quantitative) should be policed to ensure compliance with consent conditions.

A critical area, where there appears to be a lack of control, is in the design of the drainage field. Current standards, as given in BS6297: 1983 suggest that soakage pits can be considered in some circumstances, however, there is no literature on the use of soakage pits. The higher hydraulic loading which will occur at soakage pits, and the bypassing of the soil zone, could lead to a significant reduction in the amount of attenuation which occurs in the unsaturated zone. The use of drainage fields is to be strongly preferred as they make better use of the attenuation capabilities of the unsaturated zone, although even for these systems, the literature suggests that failure is common.

The British Standard is dated in some aspects and should not be used without consideration as to whether the advice contained within it represents good practice. Areas where BS6297:1983 is likely to require updating are in drainage field design, where insufficient consideration is given to the treatment aspect of the pit, the aim is principally to ensure that infiltration can be achieved. The standard states that soakage pits can be considered suitable in porous subsoil '...such as gravel, sand or Chalk'. The use of soakage pits is unlikely to represent good practice. The standard also lacks information on design of alternative drainage fields such as sand filters, in areas where conventional designs are not appropriate. The design information on package treatment plants was noted by Payne and Butler (1993) seven years ago to have been overtaken by technical developments. A new European standard to replace BS6297:1983 will shortly be issued for consultation.

EXISTING SEPTIC TANKS AND PTPS

Existing STSs and PTPs in Zone I of a Source Protection Zone should be investigated and granted or declined consent on the basis of those findings. Where a consent is declined a prohibition notice should be served to prevent any future discharges from the site.
There is currently only minimal regulation of existing septic tanks. Septic tanks come to the attention of regulators only when a problem develops. As a result there is little incentive for owners to maintain their STSs properly. Additional effort is required to educate and persuade owners of the need for maintenance. The Agency has considerable powers to prevent pollution from STSs and PTPs: exercise of these powers over poorly maintained STSs could be used as a reminder to owners of their duties to prevent pollution through correct maintenance.

The location of existing STSs should be determined to permit assessment of their density. Initial estimates of septic tank system density could be made by identifying areas not served by mains sewerage using sewerage undertakers' information. Census data or electoral rolls could be used to determine population density and household size. Initial efforts could be concentrated on areas where problems are already known to occur and areas which are likely to be sensitive to septic tank density.

Criteria should be drawn up for determining when density is too high, and a process for converting areas of high density to other forms of sewage treatment initiated. The development of such criteria will require a scientific basis to ensure robustness and therefore may need to be postponed until the results of research are available. However, such a process is likely to prove unpopular - a septic tank is often considered a low cost option, particularly where maintenance is not carried out.

The development of a zoning system, based on soil and aquifer type, could be used to identify areas in which septic tanks are not desirable either because of sensitivity, high water table or lack of infiltration capacity (low permeability soils). The groundwater vulnerability maps incorporate much of this information, but have a somewhat different focus. For instance, an area of low vulnerability, due to extensive cover of low permeability drift, may not be suitable for a conventional septic tank system due to problems with infiltration.

RESEARCH REQUIREMENTS

Research on effluent discharges to ground in the UK has concentrated on large disposals of treated and untreated sewage effluent and very little research on septic tank soakaways has been conducted. Published research on septic tank drainage systems undertaken primarily in the USA has concentrated on disposal to unconsolidated sand deposits. In the UK, the principal aquifers are formed of consolidated, fractured rock and the applicability of the existing research to the UK situation is not known. The existing research has demonstrated the potential for chemical and microbiological contamination of groundwater. The principal concern is microbiological, in particular pathogenic contamination of groundwater. Research has demonstrated the potential for micro-organisms to travel up to 1600 m (Robertson and Edberg, 1997).

CONCLUSIONS

The current system for controlling discharges to ground from STSs and PTPs requires improvement both to comply with recent changes in legislation (Groundwater Regulations, 1998) and to give better control over discharges.

However, there is a lack of research on the impact of effluent discharge to ground over consolidated aquifers typical of those found in the UK. The lack of research makes assessment of risks from effluent discharges to ground difficult and as a result the development of a robust assessment system is difficult.

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33. URBAN WATER MANAGEMENT - AN INTEGRATED APPROACH

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Background:

A better understanding of the volume and pathways of water movement in the urban and industrial environment will be a vital ingredient if the Environment Agency and Local Authorities are to successfully carry out their responsibilities under the Contaminated Land Act Part IIa regulations and the EU Water Framework Directive.

To deal with problems of urban flooding, strategic decisions on the position of soakaways and temporary storage ponds to smooth urban discharges need to be based on clear scientific understanding.

Over the last year research in the British Geological Survey's (BGS) Urban Geosciences Programme has shown deficiencies in the understanding of the urban water regime. Using Manchester as a case study information on water levels, infiltration rates, surface sealing and soil type have been collated and brought together with more traditional BGS data, such as surface geology and 3-D models of superficial deposits, in a Geographical Information System (GIS). This project is not aiming to provide detailed site specific information but a regional planning tool for the use of planners and decision makers.

A trial study, covering 75km^2, in the centre of Manchester based at the 1:10 000 scale, follows the experience of similar studies in Berlin (Senatsvervaltung fuer Stadtentwicklung und Umweltschutz, 1990)

Methods:

1. Land Use

In urban areas there are generally strong links between most geo-environmental factors and anthropogenic activities. The study area therefore was divided into blocks of similar past and present land use as defined in the National Land Use Database (Partnership of DETR, IDeA, English Partnerships and Ordnance Survey, 2000). These blocks form the basic reference unit in the GIS to which most geoscientific data will be attributed.

2. Surface Sealing

The project area is subdivided according to the relative amount of built-up areas, open space and the degree and type of surface sealing. A surface is considered sealed if it is covered with impervious materials. This layer is provided from remote sensed data combined with ground-truthing and will provide realistic estimates of run-off and infiltration.

3. Substrate and Soil

BGS are collaborating with the National Soil Resources Institute (NSRI) (formerly the Soil Survey and Land Research Centre (SSLRC)) to develop a joint methodology on mapping urban soils. BGS will provide information about the substrate including thickness and composition of artificial ground and natural superficial deposits.

Where sufficient data is available, the classification of urban soils developed by SSLRC for English Nature (Hollis 1992) can be used to provide information on pathways of water movement and the filtering and buffering capacity of the top few metres of materials in the urban environment.

4. Depth to water table

The depth to water table is determined from Site Investigation and borehole records. The project database holds an average of 40 points of first water strike per km^2. This data will be gridded to produce a modelled surface for the mean annual water table. Using a Digital Terrain Model (DTM) the thickness of the unsaturated zone can be estimated.

5. Determination of percolation rate

Using block models of bodies with similar lithologies based on ca. 80 digital boreholes per km^2 the GIS can estimate the permeability of the unsaturated zone in the project area and depict areas of similar hydrogeological domains.

The method of building high resolution three-dimensional block models of the near surface are largely based on experiences from the Lower Saxony Soil Survey (Preuss, H. 2001; *Hinze et. al.* 1999)

Outlook:

This project aims to deliver information that forms the basis for urban groundwater vulnerability assessment and for sustainable urban drainage schemes (SUDS).

The project is devising methodologies and setting standards for further urban geoscientific projects in the British Geological Survey.

Results will be published as maps, and models on paper, CD and eventually over the WWW.

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34. THE INTER-RELATIONSHIP BETWEEN CIVIL ENGINEERING WORKS AND GROUNDWATER PROTECTION

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ABSTRACT

Civil engineering construction works often have significant impacts on groundwater conditions. Some effects, such as derogation of sources by dewatering abstractions, are easily identified. Others, such as creation of pathways by foundations or ground improvement processes, are less obvious and may not be identified sufficiently early during the planning process.

Under current UK practice there is little formal regulatory control of dewatering and related works, although this will change in England and Wales when new abstraction licensing regulations are introduced in the near future. Unfortunately, at present, not all of the construction industry is not familiar with the inter-relationship between construction processes and groundwater protection. The future challenge for environmental regulators will be to understand the full range of construction impacts and to increase the awareness of groundwater issues within the construction industry.

This paper describes the full range of potential groundwater impacts that may result from construction activities. Comparisons are made with the mining and quarrying industries, where there is greater awareness of potential impacts on groundwater. Recommendations are made on how environmental regulatory bodies can better deal with civil engineering activities.

INTRODUCTION

Many civil engineering works interact with groundwater regimes. In some cases detrimental impacts (both temporary and permanent) may result. Some of these impacts, such as the potential for derogation of existing groundwater sources during construction dewatering abstractions, are clearly understood. Other impacts, such as the creation of pathways by pipeline or foundation construction, are less easy to define and may not be identified sufficiently early in the planning process.

Groundwater is viewed quite differently by water resources managers (such as hydrogeologists) and construction engineers. To the hydrogeologist groundwater is a potential *resource*, available for abstraction or for its contribution to springs, streamflow, wetlands, etc. In contrast, to the construction engineer groundwater is a potential *problem* requiring a solution. Projects founded on or penetrating into water-bearing soils are often more difficult to construct than those entirely in the vadose zone or in very low permeability strata. Engineers will adopt methods to mitigate the effect of groundwater on construction, this might include temporary dewatering pumping (Preene *et al.*, 2000) or the construction of physical cut-off walls into the aquifer. In the permanent condition it is not unusual for large structures (such as basements, road or rail cuttings) below the water table to be equipped with permanent groundwater drainage systems to prevent flooding. In the past many of the impacts on groundwater have not been fully appreciated.

These contrasting views result perhaps from the training and education of engineers in the past, where the wider environmental impacts of construction processes may not have been considered. The relatively low level of historic regulation applied to construction activities such as dewatering may have contributed to this situation. This state of affairs is likely to change as a result of improved education of engineers, increasing appreciation of environmental impacts and forthcoming changes in regulation.

GROUNDWATER AS A RESOURCE WORTH PROTECTING

In England and Wales around one third of public water supply is obtained from groundwater. Government figures show that in England and Wales there are over 330,000 people dependent on private groundwater sources for their domestic water supply, being supplied from over 50,000 private sources. In Scotland there are almost 91,000 people supplied from a total of 18,500 private water sources, of which about 14,000 supply single dwellings. In addition, hotels, restaurants, schools and caravan sites that serve some 38,000 people in Scotland also depend on private supplies.

These statistics illustrate the importance of groundwater as a resource for both public and private water supply. Additionally, groundwater has a strong interaction with many surface water features such as rivers and wetlands – changes in groundwater levels or quality can have detrimental environmental impacts. In the UK groundwater protection policies, such as Environment Agency (1998), have been adopted to avoid over abstraction of aquifers and derogation of individual sources, to avoid damage to environmental features dependent on groundwater levels (e.g. river baseflows), and to control the risk of pollution of groundwater from point and diffuse sources. A framework for the assessment of the risk of groundwater pollution at a given point is based on the methodology of land use control described by Adams and Foster (1992). This approach aims to protect the aquifer as a whole by division of the land surface above an aquifer in areas on the basis of vulnerability to pollution from surface activities. Individual sources are protected by the delineation of source protection zones (SPZs) around the sources, within which various potentially polluting activities are either strictly controlled or prohibited.

The current groundwater protection policies in the UK are aimed primarily at managing the extent of potentially polluting industries and activities and limiting the impact of groundwater abstractions through the licensing system. A number of activities including uncontrolled abstraction, such as dewatering associated with civil engineering construction works can only be influenced through the planning control process. This approach is not ideal for controlling these activities and may, in part, be due to the lack of attention these issues have received in the literature, both from an engineering construction and a groundwater impact standpoint.

GROUNDWATER IMPACTS CAUSED BY CONSTRUCTION WORKS

A range of temporary and permanent impacts on the groundwater environment may result from civil engineering works. Perhaps because a full assessment of the impacts requires an understanding both of the construction and groundwater issues, it appears that no comprehensive summary of these potential impacts exists in the literature. A number of publications have dealt with discrete aspects of the subject. Powers (1985) described what he termed 'unwanted side effects' of temporary dewatering. The recent Construction Industry Research and Information Association (CIRIA) guide to best practice for temporary dewatering (Preene *et al.*, 2000) discusses environmental issues, mainly in relation to pollution risks during construction. Brassington (1986) discussed the potential derogation of springs and private water supplies resulting from temporary dewatering and from permanent disruption of groundwater flow by engineering works.

The major potential groundwater impacts from civil engineering works are discussed below and are summarised in Table 1. These impacts have been grouped into five main categories:

1. Impacts from abstraction from aquifers
2. Impacts from physical disturbance of aquifers creating pathways for groundwater flow
3. Impacts from physical disturbance of aquifers creating barriers to groundwater flow
4. Impacts from discharges to groundwaters
5. Impacts from discharges to surface waters.

Each category is sub-divided into temporary and permanent impacts.

Category 1: abstraction from aquifers – temporary

The construction activity with the most obvious potential to affect groundwater conditions is construction dewatering. More correctly known as groundwater control or groundwater lowering, this involves abstraction to lower groundwater levels to allow below-ground construction in permeable strata to proceed in dry and stable conditions. The methods available include pumping from wells or wellpoints or from sumps within the excavation or tunnel itself (Preene *et al.*, 2000). Under UK practice these are unregulated abstractions, with no mechanism for formal consenting by the environmental regulators. In the near future, while an abstraction licence will still not be required, a formal consenting procedure is to be introduced in England and Wales (Preene and Brassington, 2001).

By analogy with dewatering for mineral extraction, a number of impacts may result. Discounting ground settlement (see Preene, 2000) which is not normally considered a groundwater protection issue, the main impacts are: depletion of groundwater dependent features; effects on water levels and water quality in the aquifer as a whole and the derogation of individual borehole or spring sources.

However, the analogy with mineral extraction may be misleading. Many construction dewatering abstractions involve low flow rates for relatively short durations. Because these abstractions are unregulated no formal data exist, but it is estimated that more than half of all construction dewatering systems are likely to have maximum flow rates of less than 1 Ml/day, with pumping durations of less than three to six months. In reality, most construction dewatering abstractions are likely to be sufficiently short term and small in volume to avoid significant effects on the aquifer as a whole or on groundwater dependent surface features (unless they are immediately adjacent to the dewatering works). The effect on any nearby water supply boreholes may be more problematic.

Any construction projects planned near public water supply boreholes are likely to fall within one of the SPZs delineated around such sources, and the risk of derogation of the source is likely to be identified at planning stage. In contrast, small private borehole or spring sources (including domestic abstractions exempt from licensing), where SPZs have not been identified may be overlooked during investigation and planning for projects. Such small sources, which often exploit shallow granular drift deposits where construction dewatering is necessary, may be vulnerable to reduction in yield for the duration of dewatering works.

Although construction dewatering abstractions in England and Wales are currently exempt from licensing, abstractors are required, under Section 30 of the *Water Resources Act 1991* to notify the Environment Agency in advance of any dewatering works. This allows the Agency to issue a Conservation Notice, if necessary, specifying mitigation measures to protect water users or groundwater dependent features. Unfortunately, this measure is of little use to protect those private abstractors that are exempt from licensing, unless private sources have been identified in the project site investigation. Sadly, this is not always done, and the current British Standard *Code of Practice for Site Investigation* BS5930 (1999) does not explicitly specify the requirement to identify any nearby private groundwater sources by a groundwater features survey and from examination of municipal records.

Category 1: abstraction from aquifers – permanent

It is not universally realised that many structures and engineered features that extend below groundwater level involve some form of drainage system. For basements and tunnels a pumping system may be involved, or for road and rail cuttings discharge may be by gravity if the topography allows. These drainage systems are effectively unregulated abstractions. Systems to prevent flooding of discrete structures such as basements are unlikely to have a significant effect on local groundwater levels. In contrast, as described by Brassington (1986) more extensive structures such as tunnels, pipelines and deep road and rail cuttings with associated drainage may cause greater impacts. Their considerable linear extent can allow them to intercept and discharge groundwater flow, which would have otherwise fed nearby springs and supply boreholes (Brassington, 1995).

Category 2: physical disturbance of aquifers – pathways for groundwater flow

Some forms of engineering construction inadvertently form permeable pathways along which groundwater may flow preferentially. Some of these pathways may be temporary (such as investigation and dewatering boreholes) and can be sealed on completion. Other pathways are formed by parts of the structure or works and may exist in perpetuity. Examples of permanent pathways include the granular bedding of pipelines (which may allow horizontal flow) or some types of piling or ground improvement processes (which can form vertical pathways). Open excavations such as road or rail cuttings may themselves form potential vertical pathways.

The consequential impacts of these pathways include:

- Loss of yield if horizontal pathways act to divert water away from nearby springs or supply boreholes.
- Increased risk of aquifer pollution from land use or near surface activities. This is of particular concern if the confining bed above an aquifer is punctured by the works.
- Changes in groundwater quality if pathways are formed between different aquifer units. For example poorly sealed investigation boreholes could allow mixing of fresh and more saline water in aquifers where groundwater quality is stratified, or polluted groundwater at shallow depth may be able to flow into deeper aquifers.
- Uncontrolled flowing artesian discharges through inadequately sealed boreholes.

Category 3: physical disturbance of aquifers – barriers to groundwater flow

Where extensive structures form a barrier (e.g. due to the installation of concrete walls or groups of very closely spaced piles) interrupting horizontal groundwater flow through an aquifer, a damming effect may occur. Groundwater levels may rise on the upstream side of the structure, and be lowered on the downstream side. These effects may not be significant unless large structures fully penetrate significant aquifer horizons. In those cases a 'flow shadow' may develop immediately downstream of the structure. Any springs or boreholes in this zone may be affected.

Category 4: discharges to groundwaters

Temporary construction activities can create the potential for discharges to groundwaters, with the consequent risk of pollution. The main sources of potentially polluting discharges are: leakages and spills of fuels and lubricants from plant and vehicles; run-off from operations such as concrete placement; and run-off of turbid surface water as a result of topsoil removal and excavation. On most construction sites the risk of polluting discharges can be minimised by the adoption of good practice, based on guidance from the environmental regulators.

The risk of pollution is increased if pathways of groundwater flow (impact category 3) are associated with the works. Artificial recharge to mitigate the effects of abstraction (impact category 1) will also result in discharges to groundwaters.

Structures with deep basements or below ground spaces may also provide potential for discharges to groundwater in the longer term. If the structures are not watertight and penetrate confining beds over aquifers, leaks, spillages or surface water flooding may be able to percolate more freely into groundwater.

Category 5: discharges to surface waters

Civil engineering activities that abstract groundwater either for temporary construction dewatering or as part of longer-term drainage requirements will generate a discharge flow which must be disposed of. If the discharge is disposed of to surface waters the temperature, chemistry and sediment load may have a detrimental impact on the receiving water body. If the discharge flow rate is large, there is also the risk of scour and erosion at the point of discharge. Under UK regulatory practice these issues are controlled via the discharge consent system.

COMPARISON BETWEEN CIVIL ENGINEERING AND MINING AND QUARRYING WORKS

The analogy between civil engineering works and from mineral extraction has been raised earlier. The effect on private water supplies and other groundwater impacts has been a mineral planning concern for decades; the literature on groundwater impacts from mineral workings is far more extensive than for impacts from engineering works. This suggests that awareness of groundwater protection issues is greater within the mineral industry than in the engineering field. It is interesting to consider why this might be so. Perhaps the most obvious reason is that quarries are generally large and highly visible undertakings. The connection with water issues may be much more obvious than for roads, pipelines, etc and it is difficult for groundwater protection concerns to be overlooked, especially where long-term impacts are concerned. Consideration of the potential impacts on the water environmental are a common part of planning applications under UK practice.

Another reason may be that mineral companies routinely employ hydrogeological specialists when developing new workings. In the past this has been far from the norm in engineering works, when hydrogeological advice was often only sought when an impact manifested itself. The situation is improving, and the use of multi-disciplinary project teams is leading to earlier identification of groundwater and other impacts. However, there has still been no comprehensive review of potential groundwater impacts from engineering works, as there has been for the mineral industry (Thompson *et al.*, 1998).

CONCLUSION

Civil engineering works that involve excavation into the vadose and saturated zones may create significant impacts on the groundwater environment. In the majority of cases measures can be adopted to mitigate the effects of these impacts. However, mitigation and the associated monitoring can only be prescribed once potential impacts have been identified, and this is sometimes not done sufficiently early in a project. Table 1 summarises the principal groundwater impacts likely to arise from civil engineering works, and groups them into rational categories. Ideally, the potential for these impacts to occur needs to be assessed at an early stage in site investigation, so that the project design can be varied, and mitigation measures adopted, to control or avoid these impacts. Unfortunately this is not always achieved.

This may be because, at present, the complete range of interactions between engineering works and groundwater protection issues is not fully appreciated by all working in the construction industry. The challenge for environmental regulators is to change this situation in the future. Regulators will require construction specialists within their teams who understand the physical processes and organisational relationships that define civil engineering works. The regulators need to consider how they communicate and educate the construction industry – in part a constituency unaware of groundwater issues. By developing their understanding of, and communication with, the construction industry, environmental regulators may be better able to develop new consenting mechanisms to control the full range of groundwater impacts from civil engineering works.

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Table 1: Impacts on groundwater conditions from civil engineering works

	Category	Potential impacts	Duration	Relevant construction activities
1	Abstraction	Ground settlement Derogation of individual sources Effect on aquifer – groundwater levels Effect on aquifer – groundwater quality Depletion of groundwater dependent features	Temporary	Dewatering of excavations and tunnels using wells, wellpoints and sumps Drainage of shallow excavations or waterlogged land by gravity flow
			Permanent	Permanent drainage of basements, tunnels, road and rail cuttings, both from pumping and from gravity flow
2	Pathways for groundwater flow	Risk of pollution from near surface activities Change in groundwater levels and quality	Temporary	Vertical pathways created by site investigation and dewatering boreholes, open excavations, trench drains, etc. Horizontal pathways created by trenches, tunnels and excavations
			Permanent	Vertical pathways created by inadequate backfilling and sealing of site investigation and dewatering boreholes and excavations and by permanent foundations, piles and ground improvement processes Horizontal pathways created by trenches, tunnels and excavations
3	Barriers to groundwater flow	Change in groundwater levels and quality	Temporary	Barriers created by temporary or removable physical cut-off walls such as sheet-piles or artificial ground freezing
			Permanent	Barriers created by permanent physical cut-off walls or groups of piles forming part of the foundation or structure or by linear constructions such as tunnels and pipelines Barriers created by reduction in aquifer hydraulic conductivity (e.g. by grouting or compaction)
4	Discharge to groundwaters	Discharge of polluting substances from construction activities	Temporary	Leakage and run-off from construction activities (e.g. fuelling of plant) Artificial recharge (if used as part of the dewatering works)
			Permanent	Leakage and run-off from permanent structures Discharge via drainage soakaways
5	Discharge to surface waters	Effect on surface waters due to discharge water chemistry, temperature or sediment load	Temporary	Discharge from dewatering systems
			Permanent	Discharge from permanent drainage systems

35. GROUNDWATER SOURCE AND RESOURCE PROTECTION – POLICY EVOLUTION IN ENGLAND AND WALES, SCOTLAND AND NORTHERN IRELAND

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ABSTRACT

There are a number of differences in the approach to groundwater management between England and Wales, Scotland and Northern Ireland. Although England and Wales leads the development of policy and practice statements, different laws and needs (due to prevailing land use, topography and geology) have steered each country along different evolutionary paths. Although the requirements of the EC Water Framework Directive and earlier Directives are common to all areas, devolution of government, and in Ireland the international border, are producing new influences. The resulting requirements are reflected in the respective approaches to resource vulnerability and source protection. England and Wales are better placed to attain the scheduled requirements of the Water Framework Directive than Scotland and Northern Ireland, both of which require intensive data collection and monitoring campaigns to be carried out, including some form of groundwater abstraction licensing, to enable compliance.

INTRODUCTION

The landmark publication *Policy and Practice for the Protection of Groundwater* (NRA 1992) provided the foundation for systematic resource protection in England and Wales. It was emulated in Scotland (ADRIS 1995) and in Northern Ireland (EHS 2001), and revised versions have now been issued by the Environment Agency and by the Scottish Environment Protection Agency. The respective policies address the need to protect both groundwater resources, i.e. the groundwater contained within the aquifers, and groundwater sources, i.e. specific capture zones of wells, boreholes and springs. Embedded within these policy statements are two key groundwater quantity management concepts, those of groundwater (resources) vulnerability land zones and of source protection zones. The management strategy is encapsulated within sets of Groundwater Protection Strategy Statements, which are supported by a variety of enabling legislation and codes of conduct.

The enabling legislation has evolved during the 1990s with considerable speed in response to successive Directives issued by the European Community. Policy and law will evolve further over the next ten years, with regulators moving towards the requirements of the EC Water Framework Directive, which describes a rolling programme centred on integrated river basin management of both surface water and groundwater. Regional approaches to catchment water balance investigations are already discernible. The Environment Agency is pursuing its Catchment Abstraction Management Strategies (CAMS) programme (Environment Agency 2000) which will, in part, satisfy the water quantity requirements of the Directive. It has also recently instigated a residual resource development potential approach across all its regions under the title *Water Resources for the Future* (Environment Agency 2001), an initiative which will help towards sensible and uniform allocation of the available resource. Scotland and Northern Ireland (both of which are currently license exempt) need even more comprehensive data acquisition and investigation in order to begin to describe catchments adequately, and new work is necessary even to classify the groundwater bodies.

Given the considerable advances in groundwater management over the last ten years it is useful to review past regulation and likely future requirements in the United Kingdom. Downing (1993) identified three phases in groundwater regulation in England and Wales:

- The Water Act (1945) which promoted the start of resource assessment;
- The Water Resources Act (1963) which promoted an era of groundwater management, although there was also an increase in resource assessment work in response to the requirements of Section 14 of the Act; and
- The Water Act (1973) which promoted an era which concentrated on groundwater quality.

The current thrust was heralded by the formation of the National Rivers Authority in 1989 and reinforced by the Hague Declaration in 1991. Today the economic and ecological value of groundwater, the concept that groundwater is a finite resource which needs to be managed and protected, and the need for sustainable groundwater abstraction and protection of resources from adverse change, have all finally been recognised. The present era is, therefore, one of integrated management and development within the context of the river basin. The future is likely to require an additional element of resource development in order to satisfy increasing demand and the vagaries of climate change.

EARLY MANAGEMENT TRENDS

The protection of groundwater from known sources of pollution has been a concern in some areas long before the regulatory bodies were formally established. Safeguard of surface waters from effluent discharge and unlicensed wanton pollution has been in place since the Rivers Pollution Prevention Act (1876) and succeeding instruments. The Water Resources Act (1963) empowered 29 catchment based River Authorities in England and Wales with, amongst other duties, prevention of pollution. Although groundwater protection was primarily an English problem because of major groundwater abstraction from regionally significant aquifers in southern, central and eastern England, it has also been an issue for abstractors drawing from small but locally important aquifers in Wales, Scotland and Northern Ireland (Table 1).

One of the most intensively managed aquifer systems is that of the South Downs in the Chalk, notably in the Brighton area. A formal programme of management was instigated in the 1950s to deal with saline intrusion and urban contamination following exceptionally dry conditions between 1949 and 1956 (Robins *et al.* 1999). Much earlier, however, the Brighton, Hove and Preston Waterworks Company, which was formed in 1934, recognised the importance of retaining land above their water supply adits in the chalk as open park areas protected from the surrounding urban development of the early Twentieth Century. This innovation continued in later years with the introduction of aquifer protection guidelines in 1978 that developed into a regional aquifer protection policy (Southern Water Authority 1985). A number of other English authorities were also looking at issues of groundwater and source protection as part of the resource evaluation process (e.g. Selby and Skinner 1979) and a succession of regional aquifer protection policy documents followed in the latter part of the 1980s.