Groundwater Resources: Balancing Perspectives on Key Issues Affecting Supply and Demand

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Abstract

Sustainable groundwater management requires (a) maximizing the use of aquifer storage to reduce water-supply costs while limiting environmental impacts, and (b) maximizing groundwater protection to reduce water-supply treatment needs while not unduly restricting land-use activities. These key issues are evaluated from the experience of a recent and comprehensive national strategic study, involving detailed consultation with many stakeholders with an interest in groundwater resources. Such balances are not easy to achieve because groundwater systems are complex to analyse and slow to respond to change, resulting in considerable uncertainty in assessment and prediction without in-depth research and high-resolution monitoring. Current institutional and regulatory arrangements for the water sector in England and Wales do not appear to be achieving the best possible use of aquifer storage and optimal investment in groundwater protection.

Key words: **Demand; groundwater resources; regulation; supply.**

Introduction

Importance of Groundwater Resources

Groundwater resources are of strategic significance since they:

(i) Provide a relatively local, high-quality, low-cost source of public and private water-supplies, totalling 2500 million m^3/annum;
(ii) Contribute more than 50% of mains water supply over most eastern, central and southern England, and indeed more widely in Europe; and
(iii) Maintain dry-weather flows in streams of significant environmental and/or amenity value, and sustain numerous wetland habitats.

The first need is for greater emphasis on demand management (through more effective mains leakage control and economic constraints on peak summer demand), where justified further local groundwater development remains the least-cost option for future water-supply development[1]. Costs are typically in the range £0.1–0.5 million/Ml. d, which is in line with demand management gains and more favourable than most surface-water development options. However, environmental costs need to be 'factored in' where there are quantifiable impacts on streamflows and wetlands.

Characteristics of Aquifers in UK

The principal British aquifers lie in the post-Carboniferous rocks of lowland England and comprise the Cretaceous Chalk, the Jurassic Limestones, and the Permo-Triassic Sandstones. Their outcrops underlie about 34 000 km^2 of lowland England. Estimates of replenishment to, and abstraction from, the major aquifers are shown in Table 1.

The information is now somewhat dated, but abstraction is considered to have increased on average by only about 10% since 1977. The data demonstrate that, overall, recharge substantially exceeds exploitation and implies significant under-utilization. In most of Britain, the level of direct exploitation of groundwater for water-supply is less than 30% of the average rate of recharge – a low figure by standards of densely populated lowland nations. However, not all replenishment is available for abstraction, because groundwater discharge to rivers (and in some coastal regions) must be maintained. A priority list of twenty small catchments, where unacceptably low dry-weather streamflows are considered to be caused by excessive (but licensed) groundwater abstraction, have been identified for priority action[1].

In general, groundwater supplies are very resilient to drought because of the large storage volume in aquifers and in overlying hydraulically connected Tertiary or Quaternary deposits. While infiltration in drought years can reduce to less than 30 % of average, yields of wells are not reduced to the same extent[2]. However, while the total primary porosity of all the principal aquifers is relatively high, the drainable unit storage of the sandstones is generally about ten times larger than those of the limestones. Groundwater flow is strongly influenced by secondary fracturing, which results in greater uncertainty in predicting hydraulic behaviour. This effect is especially predominant in the limestone formations, where fracture development is critical in controlling transmissivity and storage variations, both in space and depth.

Groundwater Resource Regulation and Management

Although groundwater has been exploited in Britain for millennia, its use has been regulated for less than fifty years, and experience of pro-active management is restricted to the last three decades. During this period, the parallel development of groundwater resources (and

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Table 1. Overall groundwater resources balance for principal aquifers in England and Wales[2]

Aquifer	Water-supply abstraction (million m^3/annum)	Average replenishment (million m^3/annum)	Exploitation level (%)
Cretaceous Chalk	1255	4631	27
Jurassic Limestones	108	713	15
Permo-Triassic Sandstones	587	1443	41
All Aquifers	2077	7309	28

of hydrogeological science) was strongly influenced by successive legislation and associated institutional changes, and fell into the following distinct phases[2]:

(a) An era of groundwater resource assessment (1945–63);
(b) An era of hydrological cycle management (1963–74); and
(c) An era of groundwater quality concern (1974–89).

Therefore, following the radical changes stemming from the privatization of the water authorities in 1989, the reorganized water sector inherited many favourable factors from its predecessors; notably, a high level of resource management by regulation and a morality for compliance with (if not achievement of) directives and legal provisions. Restructuring has led to (i) clearer regulatory arrangements, (ii) an increased ability to mobilize investment, and (iii) a greater consciousness of the need for asset management. Nevertheless, where groundwater is concerned, a number of significant problems need to be resolved if the requirements of stakeholders with interest in groundwater resources are to be addressed at the lowest social cost.

Identification of Issues and Perspectives

National Groundwater Strategic Study

This study arose from growing concerns about the limited scope and fragmentation of groundwater research, due in part to restructuring of the water sector and to tightening budgets during the recent recession. These concerns were set against a background of growing environmental focus on groundwater and of enhanced public awareness of groundwater during recent droughts.

The study was sponsored by the National Rivers Authority (NRA)†, the Natural Environment Research Council (NERC), the Foundation for Water Research (FWR), the Water Services Association (WSA) and the Water Companies Association (WCA) (and corresponding institutions for Scotland and Northern Ireland), and was undertaken by the British Geological Survey (BGS). It sought to consult widely through a variety of mechanisms with the main stakeholders in groundwater, and involved dialogue with 228 individuals from a wide range of organizations.

The study first set out to identify the main issues (threats to groundwater quality or quantity, constraints on groundwater development, etc) by a lengthy process of consultation and review[3], and 31-issue discussion papers were prepared. It became apparent that the major stakeholders had different opinions on, and perspectives of, the issues (Table 2). This paper draws on the analysis of perspectives, and the insight that they present on the balance between the supply of, and demand for, groundwater; although the study was UK-wide, this paper focuses on England and Wales.

† Now the Environment Agency

Table 2. Differing prioritization of groundwater issues by water regulator and water-service utilities[3]

Groundwater issue	Water regulator	Water utilities
Low streamflow	**	**
Wetland discharge	**	o
Reliable catchment yield	**	**
Pesticide contamination	**	**
Contaminated land	**	*
Private water supplies	*	o
Landfill impacts	*	*
Nitrate contamination	*	**
Aquifer vulnerability	**	o
Water-source protection	*	**
Well efficiency	o	**
Acid mine drainage	*	o

** Highest priority * Moderate priority o Lower priority

Role of Uncertainty and Risk

Because of the large storage volume and inherent geological complexity of groundwater systems, they are difficult to analyse and slow to respond to change, and this may result in greater uncertainty in the assessment and prediction of their behaviour than is normally the case for surface-water resources. At the core of the findings of the National Groundwater Strategic Study[3] there are different perspectives of the risks associated with such uncertainties, as a result of the new water-sector regulatory framework. Moreover, many of the emerging fundamentals of water resource management (especially statutory water quality objectives and the 'polluter pays' principle) are more difficult to apply to groundwater systems because of their three-dimensional complexity and time-scales.

The environmental regulator has an institutional responsibility and a legal mandate to conserve and

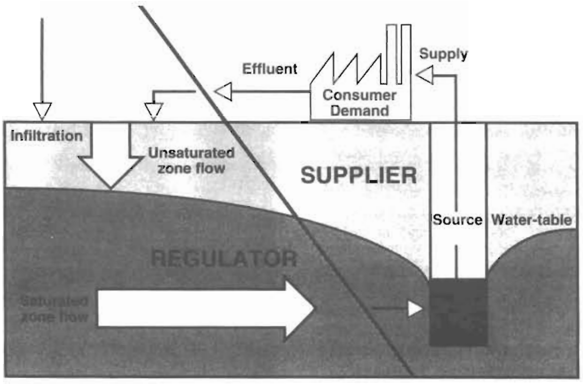

Fig. 1. Differing focus of interest in groundwater systems between environmental regulator and water supplier[3]

protect the water environment. However, he does not bear any clear accountability for the consequences of inadequate action (such as not preventing pollution of downstream supplies) or of excessive action (e. g. raising water-supply costs unnecessarily). With regard to groundwater, the regulator focuses on key catchment area processes (Fig. 1) and on discharges to and abstraction from aquifer systems.

The water suppliers have an entirely different perspective on groundwater, with a focus on sources (boreholes, wells and springs) as a major physical asset (Fig. 1), and on services to the customer, with groundwater being a key tradeable commodity. Although they are concerned about the quality of the raw resource, they have no mandate for the conservation or protection of groundwater sources, but have accountability – both to consumers (for delivery of adequate quantity and quality) and to courts (for compliance with strict quality standards).

Increasingly, there is a communication gap between regulator and supplier. Although in part an obvious and necessary consequence of their 'poacher' and 'game-keeper' roles, this can have serious consequences for resource management, with major economic implications – given the current level of uncertainty on various key issues[3]. It has also led to:

(i) Reduced freedom of access to key hydrogeological data (such as raw-water quality analysis; and
(ii) An underfunding (especially by the water industry) of longer-term strategic groundwater research generating new data to the public domain, with excessive emphasis on short-term (often confidential) investigations which do not contribute to the knowledge base[3]; the global level of investment in groundwater research (less than £2.0 million/annum) bearing little relationship to the value of groundwater sales (£1200 million/annum)[3], with only less than £0.2 million/annum being funded on a cooperative basis by the water companies.

Groundwater – a Tarnished Image

Another overall perspective gained by the study[3] was that of 'groundwater, the culprit'. The public image of groundwater, although limited, is generally poor, and its benefits (relatively high reliability, security and quality at low capital outlay) are not appreciated. Groundwater abstraction is now often perceived to be the lone culprit for deterioration in the aquatic environment, irrespective of land-use changes, land-drainage measures, river engineering and recent droughts. While this image is promoted by the environmental lobby, the water industry generally believes that it has been accepted by the regulator, prejudicing decisions on groundwater management. Furthermore, publicity about aquifer pollution incidents have led to a distorted view of the state of groundwater quality overall. Therefore there is a need to rebuild public confidence in groundwater and to increase awareness of its nature and role, despite the fact that ready access to wells and springs has, historically, been the single most important factor in human settlement. A further paradox is the rapidly increasing demand for bottled natural mineral water; now standing nationally at over 500 Ml/annum (with a value of about £250 million/annum). All natural mineral waters are groundwaters!

Balancing Perspectives on Groundwater Resources

Urban Lawns or Rural Landscapes or Both by Design?

Nature of Conflict

Domestic demand for water is growing[1], as are expectations of water-supply security. The burgeoning number of recreational gardeners (the lovers of the English lawn) are aggravated by potential restrictions on water use. Concomitantly, there is growing concern for preserving rural aquatic landscape features, some of the most important of which are groundwater related. However, trade-offs between the two are rarely perceived by the average water consumer.

The water regulator has both responsibility and authority to protect the water environment. The main concern in assessing applications for new groundwater abstraction licences, or the need for revoking existing ones, is their perceived impact on upper courses of rivers and on wetland habitats. However, in reality, given hydrogeological and ecological complexity, there remains significant uncertainty about evaluating the environmental impacts of increased groundwater abstraction and the environmental benefits of reduced abstraction. The precautionary principle is therefore applied, and this will inevitably lead to conservative judgements when applied at low levels of knowledge.

For the water industry the difficulties of obtaining or varying abstraction licences, and the threat of environmental licence-clawback, are a significant business threat. Scientific arguments favour greater flexibility with the issuing of licence variations and much more experimental operation with close hydrogeological, hydrological and ecological monitoring, given the current uncertainties about evaluating impacts on the water environment[5]. There is opportunity and need for varying:

(a) Licences to allow higher rates of abstraction for short periods during peak demands; and

(b) Groups of licences to enable redistribution of abstraction and allow high rates of abstraction during summer months;

both of which could, in many cases, be achieved without measurable deterioration in the water environment. There is also scope for restructuring the payment schedules of licences with escalating charges according to usage. However, the current institutional arrangements appear to hinder this type of approach.

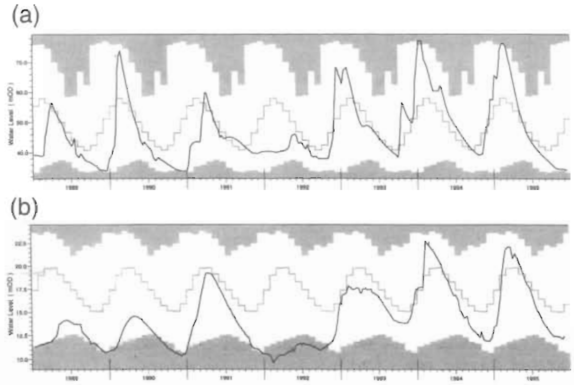

Fig. 2. Recent groundwater level hydrographs for Chalk aquifer at (a) Chilgrove House (West Sussex) and (b) Dalton Holme (East Yorkshire) compared to historic long-term extreme and mean condition (N.B: latter site has been influenced by major abstraction since the 1980s)

Natural Water Environment or Engineered Landscape

A critical issue in considering the constraints placed on future groundwater resource development is the definition of the condition in which the water environment should be preserved. In lowland Britain, a pristine water environment or natural landscape does not exist. The cumulative effect of centuries of agricultural development and decades of progressive urbanization have totally transformed the landscape (in general) and the water environment (in particular). In the case of groundwater-fed streams and wetlands, agricultural land drainage had the major impact many decades ago.

Maintaining the current *status-quo* on groundwater levels and/or discharges for the water environment (so-called 'ecoflows') or restoring them to what is perceived to be an earlier and better condition, is clearly not an unreasonable goal. However, important questions are "How much is society prepared to spend on the required measures?" and "Who should pay for them?" While the general public widely express concern about conserving the water environment, it is suspected that they mean conserving 'the visual environment at reasonable cost' but not 'the natural environment at any cost'.

More engineering of groundwater, to artificially sustain important water-environment features should be an acceptable option and is now being practised in some heavily exploited catchments, such as the Darenth in Kent. Compensation flows for surface-water impounding reservoirs has been accepted water management practice since the nineteenth century, but inadequate technical understanding has prevented the same concept being fully applied to the management of aquifers (groundwater reservoirs). However, how far to go in engineering perennial, rather than ephemeral flows, or sustaining naturally vulnerable wetlands, are questions which are fraught with dilemma and raise difficult ethical questions.

Groundwater Storage – a Market Asset?

Britain has relatively abundant water resources: the water-supply problem is mainly one of meeting peak demands in times of low rainfall and low riverflow[2]. Where available, aquifers provide storage capacity which buffers such temporal variations, and could be of critical importance if accelerated climatic change led to more frequent and protracted droughts. While water-table levels were generally below average for long periods in recent droughts, reaching all-time lows in a few instances (Fig. 2), groundwater supplies held up reasonably well – provided that there were sufficient production wells. For example, it was no coincidence that those water companies with a high proportion of groundwater in their total licensed reserves generally fared much better in the 1995 drought.

Pioneering work by the Water Resources Board 20-30 years ago demonstrated the benefits of exploiting groundwater storage for riverflow regulation to (a) meet peak demands downstream and (b) provide compensation flows for environmental purposes[2]. These schemes proved more difficult (but still feasible) in the Chalk aquifer, due to its low storage coefficient and high transmissivity, causing more rapid propagation of pumping effects, than in the Permo-Triassic Sandstone aquifer which has higher storage coefficients and generally lower transmissivities. Despite the development of several successful conjunctive-use schemes, these do not appear to be fully exploited today, and new schemes are not under serious consideration. There are inconsistencies in the way these are managed and operated under the new institutional framework, and a way needs to be found to recover the costs from the respective beneficiaries.

Despite the potential for enhanced use for groundwater storage, it is questionable whether adequate incentives to do so exist. Almost uniquely, in a world where privatization of water supply provision is occurring widely and rapidly, in England and Wales the assets themselves were sold to the private operators. This placed groundwater storage (which is a natural feature of the land, over which property rights do not exist under present legislation) in an anomalous position. All other physical water supply assets (such as storage reservoirs, treatment plants and distribution mains) add to capital stock and affect market perceptions of value. The development of surface storage involves significant land purchase and major works, where the cost is recoverable through raised water tariffs, if accounted for within the K factor. On the other hand, exploiting groundwater storage will involve only a fraction of the capital outlay and will add little to capital stock, unless alternative accounting mechanisms are introduced.

This situation is a particular deterrent to the more innovative opportunities for exploiting natural groundwater storage through its augmentation by artificial recharge – despite pioneering artificial recharge works by the Thames Water Authority in the Lee Valley[2] and continued by Thames Water with the New River Scheme[4]. In these, surplus treated mains water is injected into the dewatered Chalk aquifer and overlying Lower Tertiary Sands to provide strategic drought storage, demonstrating that imaginative management of groundwater can provide a sustainable resource with minimal environmental impact.

The newer concept of aquifer storage and recovery (ASR) would suggest that this whole area needs to be revisited. ASR involves the use of non-potable (normally saline) aquifers for storage of water which is normally treated to potable quality. The injected water forms a lens or bubble within the saline water for later recovery. Areas which would lend themselves to ASR schemes include coastal holiday resorts, where summer demand far exceeds that in winter and nearby storage opportunities are few and expensive.

Possible Role for Economic Instruments

As a result of current legislation, water resource management in Britain remains at the regulation end of a regulation-pricing spectrum. Some constraint is placed on abstraction by the way in which the business rate for water utilities is calculated. Although the NRA's groundwater abstraction charging scheme includes a weighting on abstraction licence cost (depending on a number of location and use factors), overall charges are based on average NRA administration costs, and do not reflect environmental scarcity or increased monitoring and research needs. Basically, groundwater is regarded as a product and not as a resource.

Another anomaly is that 'environmental use' is not charged at all. If the policy of protecting small groundwater-fed watercourses and ponds (even where

Table 3. Summary of principal groundwater pollution issues[3]

Issue	Status	Trend	Learning curve
Nitrate	There is extensive pollution of the unconfined parts of the major UK aquifers. In many boreholes concentrations are at, or approaching, the maximum permissible concentration for drinking water. Treatment or blending is often required. In extreme cases, boreholes have been closed down completely.	Nitrate might take 5–50 years to reach the water table. Nitrate concentrations in groundwater have been rising steadily in many areas. This trend is likely to continue in the short term, although locally there is some levelling off.	A large amount of research and monitoring has been undertaken, and the key processes have all been identified. Improved understanding of natural *in-situ* denitrification, the effectiveness of land-use change in reducing nitrate leaching and the significance of preferential flows in the unsaturated zone are still required.
Pesticides	Pesticides are widely used both by agriculture, industry and public authorities. There is the danger that some residual pesticide may find its way into groundwater. The maximum admissible concentration of any pesticide in drinking water is currently set at the very low level of 0.1 μg/l. Groundwaters are well protected compared with surface waters but some pesticides, especially the triazine herbicides, mainly of non-agricultural origin, have already been detected in groundwaters.	Increasingly sensitive analytical methods mean that confirmed detections of pesticides in groundwater are increasing. There is no systematic national survey to detect trends. The use of less persistent pesticides and lower concentrations means that the problem should eventually diminish.	Limited research on the occurrence of pesticides in UK groundwaters. Preferential flow, including through soakaways, may be important for rapid transmission to water table. Rate of degradation in aquifers likely to be slow but parameters unknown.
Non-aqueous phase liquids	Non-aqueous phase liquids, both those denser than water (DNAPLs) and those lighter than water (LNAPLs) have been, and remain, in very widespread industrial use and are insidious groundwater pollutants. Small amounts of solvent can contaminate large volumes of groundwater.	DNAPLS give rise to greater concern that LNAPLs. Groundwater beneath industrial sites and airfields is especially likely to be contaminated but DNAPL contamination also appears to be widespread in aquifers situated beneath major cities.	The behaviour of LNAPLs is reasonably well understood, although more closely monitored experience of the evolution of pllution/ remediation incidents is needed. It is still difficult to predict the fate and migration of DNAPLs in UK aquifers, and further detailed research and monitoring is required.
Microbiological contamination	Contamination of groundwater with pathogenic organisms (e.g. *Cryptosporidium*) is rare but not unknown in British aquifers. *Cryptosporidium* does not respond to the normal chlorination process, but can be removed by slow sand filtration.	Recent work has been stimulated by the occasional detection of groundwater contaminated with pathogenic organisms.	Subsurface microbiology is a new discipline. There is interest in the transport and survival time of micro-organisms in aquifers.

these may be naturally ephemeral) is to continue, would it not be more consistent to require that the principal beneficiaries (the owners of property and fishing rights in the rural areas) make a direct contribution to the opportunity cost which is foregone by water consumers due to its unavailability for water supply? By this route, society might be a step nearer to defining true environmental value and balancing interests between rural landscapes and urban lawns.

Balancing Perspectives on Groundwater Quality

Upstream Protection or Downstream Treatment or Both Uncoordinated?

Nature of Problems and Concerns

The natural quality of groundwater which is abstracted from the major British aquifers is normally very good, and most quality problems result from anthropogenic pollution. The major concerns (Table 3) include elevated concentrations of nitrate[5], but problems of pollution with pesticides[6] and industrial halogenated organic compounds[7] have also become relatively widespread, and there is also concern in some aquifers about the penetration of more persistent microbiological contaminants.

As a result of (a) the generally long retention times of aquifers, (b) the complexity of groundwater flow regimes, and (c) the much greater persistence of some contaminants in the subsurface, the pollution of groundwater systems has unique characteristics which present the following problems:

(i) Most existing pollution is the legacy of agricultural and industrial practices in previous decades;
(ii) The liability for groundwater pollution is difficult to prove, making the 'polluter pays' principle difficult to apply directly; and
(iii) Remedial measures for cleaning up aquifers are technically problematic and costly.

Implementation of Recharge Protection Measures

The NRA Groundwater Protection Policy[8] represented a scientifically founded, balanced and pragmatic approach to (a) preventing serious groundwater contamination, (b) protecting groundwater supply sources against future potentially polluting activities, and (c) assigning priorities for the more stringent inspection, detailed monitoring and closer control of existing potentially polluting activities. The policy is specifically designed to specify appropriate protection for all potable groundwater resources, and not just those currently exploited by the water service utilities[9]. It has been widely welcomed by the water sector and accepted by most of those representing industry and agriculture. However, its implementation appears to be handicapped by the lack of adequate human and financial resources. Moreover, resources for dealing with the legacy of past industrial land and groundwater contamination are scarce, and responsibilities remain poorly defined. There is no economic incentive to ensure adequate protection levels, because the current legal basis does not allow groundwater abstraction licence fees to be increased to finance protection activities or be reduced if the protection of a water supply source fails. Underlying this situation is an inadequate scientific understanding of some of the key processes, especially the effectiveness of natural *in-situ* contaminant attenuation and the long-term persistence and transport of certain pollutants in aquifer systems. This leads to unacceptably high levels of uncertainty in determining the risk of groundwater pollution impacts[3].

There appears to be only limited acceptance in the water industry of the need to invest in researching recharge mechanisms and pollution vulnerability of the groundwater system upstream (up hydraulic gradient) from production boreholes and in the control of groundwater pollution problems. This appears to relate to the following factors:

(a) It is perceived as the unique responsibility of the water regulator;
(b) Some EC potable water quality guidelines (which are more stringent than the corresponding WHO recommendations and questionable in relation to proven health benefits) act as a disincentive, because they appear unachievable without comprehensive water supply treatment or sole use of land for groundwater capture;
(c) The time limits set by the Drinking Water Inspectorate for compliance with EC water supply quality directives discourage investigation of the groundwater system and control of pollution problems – leaning heavily towards a more rapid, but probably (in the long term) higher cost solution; and
(d) Operational expenditure of this type (unlike investment in treatment plant to comply with EC directives) is more difficult to account for in the Office of Water Services (OFWAT) price negotiations, and is therefore unlikely to get full consideration during interim determinations or periodic reviews of water supply charges.

Water Supply Treatment Option

Uncertainty about the quality of raw groundwater greatly affects the water supplier. While the capital costs for nitrate removal are now moderate (up to £ 3 million for a 12 Ml/d plant), operating costs are very high (about £ 200/Ml or eight times normal groundwater treatment costs). Capital costs for pesticide treatment are commonly three times higher than for nitrates, but operating costs are somewhat lower[3]. Additionally, all these costs are sensitive to errors in the predicted level of contamination and very sensitive to changes in the potable water quality standards, especially where groundwater is concerned because of the large number of individual sources involved. However, groundwater supply treatment may not be the best overall long-term option because it (a) normally passes all the cost of pollution to the water consumer and recovers nothing from those responsible for the pollution, and (b) only addresses part of the pollution problem. Clearly, uncertainties about the effectiveness of groundwater pollution control lead to decisions of high economic cost, with expenditure on treatment being uncoordinated with investments in aquifer protection.

Conclusions

1. Since the privatization of the water authorities in England and Wales, perspectives on groundwater resource issues have become more polarized and decision-making has become more dominated by perceptions of uncertainty and associated risks within the new regulatory framework – rather than by weighing the balance of environmental and socio-economic interests.
2. There is need to (a) review some regulatory arrangements, (b) promote community research programmes, aimed at reducing uncertainty on the key issues, (c) facilitate more stakeholder dialogue, and(d) increase water-user participation in decision-making.

Acknowledgements

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Footnote

This paper was prepared late in 1995 for presentation at the *CIWEM/ICE Water Environment* Conference of March 1996. It dealt with a number of topical issues of policy development and implementation, following water-industry reorganization of the early 1990s, and the authors have requested that a brief up-date should be included.

The first key issue raised was sub-optimal use of groundwater storage. In the authors' view this remains generally the case, and it has become increasingly clear that the different ownership and operational status of the nation's water storage assets (aquifers, upland reservoirs, pumped reservoirs) has impeded their rational use in endeavouring to meet the needs of all water users in extended drought periods. Since appropriate groundwater development to augment peak water-supply capacity is much more benign environmentally than the alternative of surface reservoirs, it would appear desirable for the Environment Agency and the Office of Water Services to be encouraging innovative action in this respect, once mains leakage targets have been met.

The second key issue was under-investment in groundwater quality protection. Here, more interest is being shown by water utilities in becoming pro-active in the assessment and control of groundwater pollution hazards. However, there appears to be little incentive, in accounting terms, for them to invest significantly in such activity, despite the fact that protection will often be the lowest-cost solution globally.