

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 poses 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 depend 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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