National Groundwater and
Contaminated Land Centre

Groundwater Quality: A Framework for Improved Monitoring

ENVIRONMENT AGENCY

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Scope

This booklet summarises the key issues affecting groundwater quality and outlines the Environment Agency's framework for improved groundwater quality monitoring. It aims to inform all interested groups of the need for and benefit of improved groundwater quality monitoring in England and Wales.

Introduction

The Environment Agency (the Agency) monitors the quality of groundwater in England and Wales to protect and manage groundwater resources effectively and gain a better understanding of the impact of pressures on groundwater quality. We also need to monitor groundwater to ensure it complies with domestic and European legislation and other environmental obligations (such as the Agency's Vision).

We already have a substantial groundwater monitoring network. However recent changes in legislation, coupled with the Agency's desire to contribute to sustainable development through its 'Environmental Vision' and 'Frameworks for Change', means that the way we monitor groundwater needs to be improved. Any improvements must also take account of the information needs of other organisations and individuals (*stakeholders*) with an interest in groundwater quality. These groups include the Government and the European Union, water companies, industry, farming and the public. To meet these needs, a national framework for groundwater monitoring has been developed that identifies the prioritised requirements for groundwater quality monitoring throughout England and Wales.

In developing the framework for monitoring, an understanding of the issues that control groundwater movement and affect its quality is essential. This booklet introduces some of the main considerations that underpin the framework before then going on to describe the framework itself.

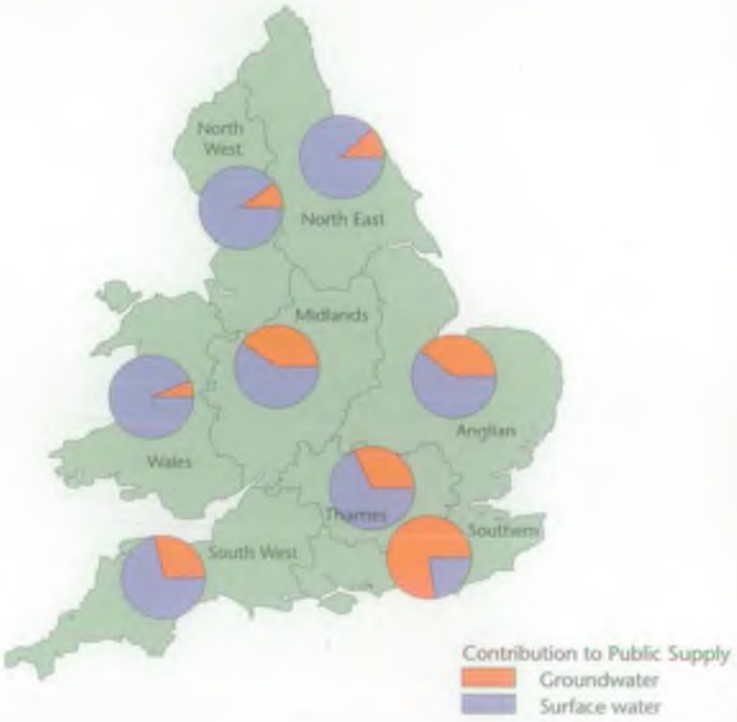
The role of groundwater

Groundwater makes up 92% of the world's available freshwater resources. It plays a very important role in providing both drinking and industrial water supplies, and also in sustaining natural water environments. It is often crucial in maintaining the wellbeing of surface water systems.

On average, 35% of public water supplies in England and Wales depend on groundwater resources. However, the proportions used vary from over 70% in south-east England to around 10% in Wales and the north of England (see **Figure 1**). Groundwater is also extremely important for private water supplies. Often the greatest concentrations of private groundwater abstractions are in areas where public supplies are generally not available. It is therefore critical to maintain and protect the many small household supplies.

Groundwater flows and seepages through river beds (*baseflow*) are often vital for maintaining summer flows in rivers and streams, and also in maintaining wetland habitats throughout England and Wales. The summer flows of many rivers in eastern and southern England, for example, are totally dependent on groundwater. This situation is most extreme in parts of East Anglia where a large percentage of the total groundwater resource is required to maintain river flows and wetland areas. The quantity and quality of groundwater is therefore extremely important to sustain both water supply and sensitive ecosystems.

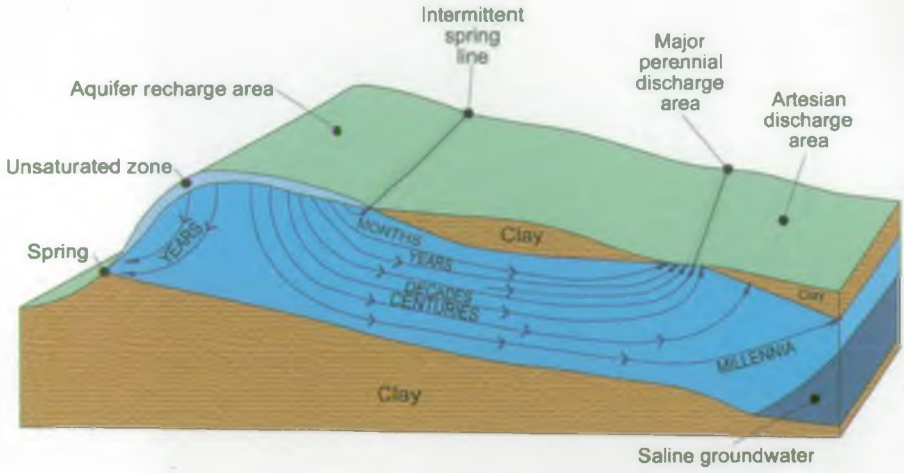
Figure 1. Proportion of groundwater used for public drinking water supply in each of the Agency's Regions and Environment Agency Wales



Groundwater quality

Most groundwater resources are naturally of excellent quality and tend to be less polluted than surface water. Groundwater is replenished mainly by rainwater soaking into the ground, percolating down to the water table, then flowing through permeable rocks (*aquifers*) and eventually emerging as springs or seepages into rivers or along the coast. Many natural processes are involved in the gradual evolution of the groundwater's quality as it flows slowly through this system.

Figure 2. Variations in groundwater residence time in an aquifer



(With permission of the UK Groundwater Forum)

Natural groundwater quality

The length of time that groundwater remains in an aquifer (*residence time*) is fundamental in determining its natural quality. A long residence time allows slow rock-water interactions to continue, forming the groundwater's chemical characteristics. These slow flow rates also mean that once groundwater has been polluted, it will take a very long time – often equivalent to many generations in terms of human lifetimes – before the polluted water is flushed out of the aquifer.

Figure 2 shows a simple example where rainfall directly recharges the aquifer. Groundwater in the aquifer flows towards two main spring lines, as well as some seasonal (intermittent)

springs. These springs depend on high groundwater levels and will dry out during the summer. For nearby intermittent springs, relatively quick groundwater travel times of only a few weeks or months are possible. In contrast, it takes the groundwater a few years to reach the springs at the base of the steep slope (scarp slope) to the left of the diagram. However, most of the groundwater is flowing towards the major perennial discharge area/spring line that is furthest away. The natural flow pattern in the aquifer causes the groundwater to move throughout the full depth of the aquifer. The length of time it takes the groundwater to reach these springs can range from decades to centuries or even millennia. In a typical aquifer of this type, some 20 kilometres long, calculations show that the average flow times can be more than 1,000 years.

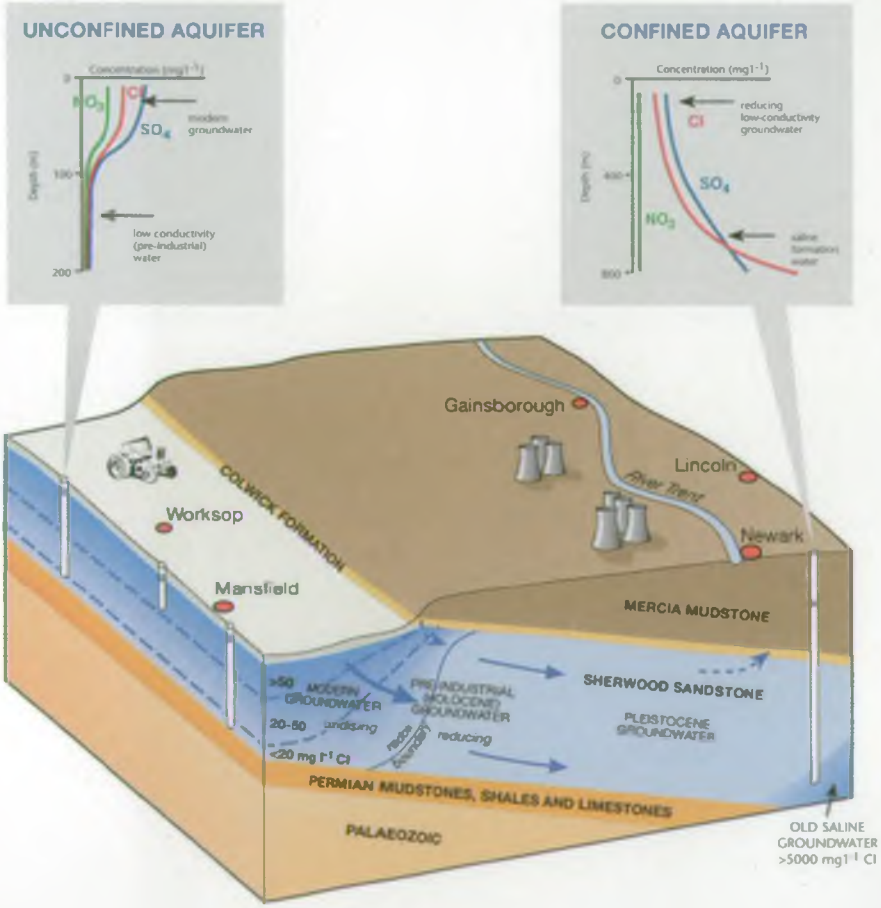
The component travelling at the greatest depth follows a very much longer flow path than that travelling through the shallow parts. These different flow paths result in varying chemical compositions of the groundwater.

Figure 3 shows how the groundwater has evolved in a major sandstone aquifer in Nottinghamshire. Fresh groundwater has penetrated into the aquifer to a depth of about 500m over the last 30,000 years. During geological periods known as the Holocene (up to 10,000 years ago) and Pleistocene (10,000 – 30,000 years ago), the groundwater has an increasing chloride content (sodium chloride is common salt) with depth. (It ranges from less than 10mg l^{-1} in water recharged during the Holocene, increasing to about 20mg l^{-1} in the deeper Pleistocene water, and up to 5,000mg l^{-1} in the much deeper and older brines that are seawater derived). The relatively high chloride content (>20mg l^{-1}) of the modern groundwater reflects contamination derived from man's activities.

Groundwater pollution

Once groundwater has been polluted it is generally very difficult and very expensive to clean (*remediate*). After pollution by some chemicals, such as chlorinated solvents, it may be virtually impossible to remediate groundwater.

Figure 3. The evolution of groundwater chemistry in the Permo-Triassic sandstone aquifer in Nottinghamshire



(From: *Baseline – the Natural Quality of Groundwater in England and Wales.* A joint programme of research by the British Geological Survey and the Environment Agency)

Figure 4. Land-use pressures and potential sources of pollution that can impact on groundwater

(With permission of the UK Groundwater Forum)

This is why, when considering the protection of groundwater, preventing pollution is always better and cheaper than curing the effects of pollution.

Groundwater is vulnerable to contamination from a wide variety of sources, many of which are illustrated in **Figure 4**. Both industry and agriculture provide possible pollutants. These range from leaks and spillages of fuels and chemicals, to the use of pesticides and fertilisers. Spillages and leaks are regarded as *point source pollution*, where it is usually possible to identify the actual source of a pollution incident. In contrast, the use of fertilisers and pesticides spread over the land for long periods may cause *diffuse pollution*. This may build up over many years and the exact source of the problem can be difficult to identify. In many large urban areas, such as parts of Birmingham and Coventry, the concentration of individual spillages and leaks, for example, from the use of chlorinated solvents is so great that they have combined to form diffuse pollution.

Groundwater monitoring

Monitoring is needed to understand how groundwater quality changes at different locations and depths within an aquifer. The Agency achieves this by regularly taking samples from boreholes, wells or springs. The exact number of sampling points and their locations varies from one aquifer to another, and is matched to the local hydrogeological conditions and land-use pressures.

For example, contamination of groundwater from the agricultural use of nitrate fertilisers has resulted in nitrate concentrations increasing over several decades. The nitrate enters the aquifer by percolation from the ground surface. It has been found that nitrate concentrations in groundwater vary with depth below the water table and also with time. In these circumstances, a monitoring programme to predict changes in nitrate concentration needs samples over a long period to pick up seasonal changes. The depth within the aquifer at which the sample was taken also needs to be taken into account when interpreting the results.

Legal and environmental needs for groundwater monitoring

As part of its regulatory and statutory activities, the Agency gathers a great deal of information about the environment. This includes surface water flows and quality, along with groundwater systems. The information obtained from these monitoring programmes is needed for the Agency to fulfil its legal obligations as the primary environmental regulator. We also provide information to other organisations, including Government.

The relationship between the Agency's monitoring programmes and the different legal requirements are shown in **Figure 5**.

In terms of groundwater quality monitoring, the Agency currently undertakes only a limited sampling programme, although it also receives some groundwater quality data from other bodies such as water companies. Recent developments in UK and European law – particularly the EU Water Framework Directive (WFD) – require more extensive groundwater monitoring in terms of both its quantity and quality.

Strategic framework for groundwater quality monitoring

As part of its response to these legal changes, particularly the WFD and the Nitrates Directive, the Agency has developed a framework for groundwater monitoring that will provide a comprehensive national programme to meet these new needs. Identifying the details of the framework and its implementation will be completed in stages. **Figure 6** shows each of the stages with the associated needs and key considerations.

Stakeholders

The Agency's stakeholders in the groundwater monitoring programme include Government, other regulators, water companies, industrialists, farmers, academic researchers and members of the public, each with their own distinct

Figure 5. Relationship of groundwater quality monitoring to other environmental monitoring, objectives and legislation

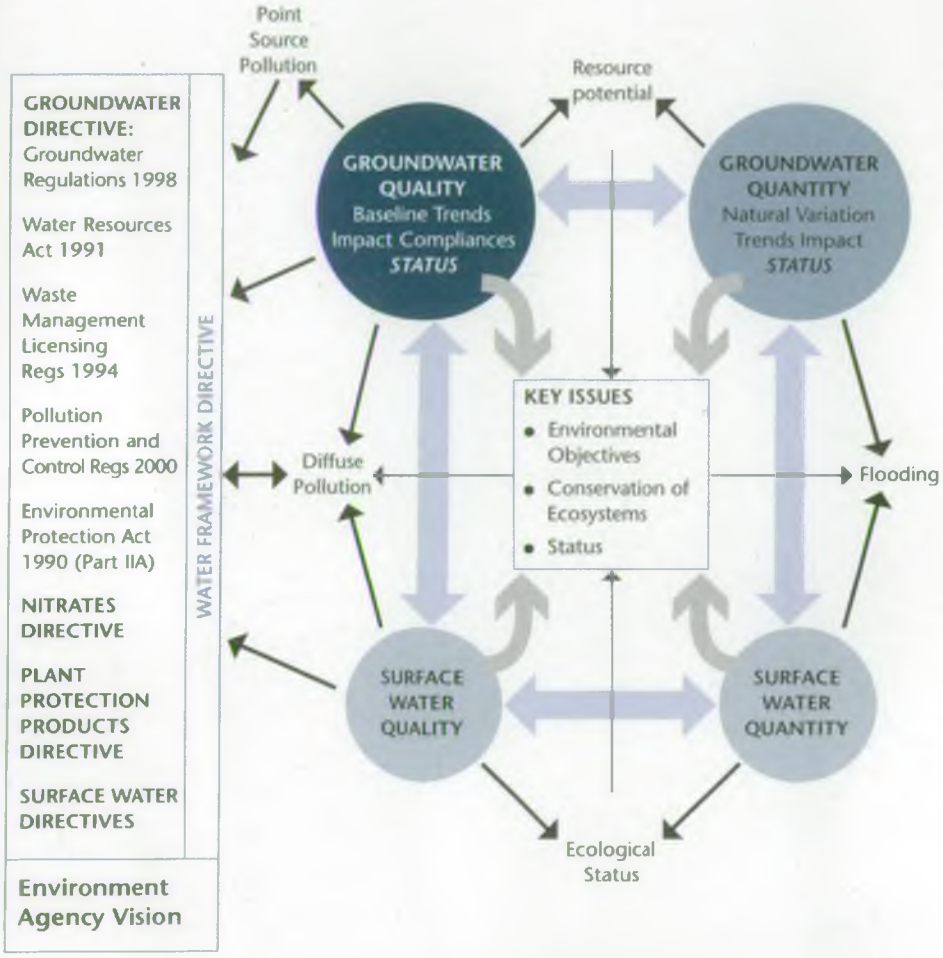


Figure 6. Steps and functions of the Agency's groundwater-monitoring strategy

Strategy stages		Principal needs	Key considerations
STAGE 1	**Objectives** Legislative and Environmental Framework (Drivers)	Definition of strategic objectives	• UK legislation • European legislation
		Policy and statutory needs: Agency, UK Government, EU, regulators, industry, local authority	• Environment Agency Vision and other initiatives • European initiatives • Public duty
STAGE 2	**Planning** Monitoring Strategy	Identification of specific objectives	• Development of a consistent national strategy • Needs and issues
		Co-ordinated programme development: short-term and long-term	• Development of guidance/protocols • Field/laboratory services • Data management and processing • QA/QC • Reporting
		Prioritisation of needs and actions	• Resources and service levels • Evaluation
		Regional Strategy: development and production	• Consultation • Identification of groundwater bodies • Prioritisation for monitoring • Quality plan
STAGE 3	**Implementation** Monitoring Programme	Development of conceptual model for each aquifer and/or groundwater body	• Collation and evaluation of existing data/information on aquifers • Hydrogeological regime; quality and quantity • Pressures; land use • Influencing factors; environment
		Design of sampling networks and data collection procedure	• Application of prioritised planning tool • Assessment of existing network
		Regional resource requirements	• Additional monitoring needs
		Business case	
		Operation of network	• Sampling and analysis • Maintenance
		Analysis and interpretation of data	• Data management and provision • Relate to Conceptual Model and feedback
		Presentation of results and reporting	• Standard reports • Recommendations • Education • Feedback

information needs. For example, the Government and the EU require data on a consistent basis over the whole country for planning purposes. On the other hand, farmers may require data on a very local basis in connection with a Nitrate Vulnerable Zone. We are seeking the co-operation of all stakeholders at each stage of developing and implementing the framework so that all their requirements can be taken into account to develop the most efficient, effective and economic system possible. The involvement of stakeholders throughout this process is seen as being of fundamental importance to its successful implementation.

Stage 1 – Objectives

The first stage is to define clear objectives for the groundwater monitoring framework. To a large extent we have already done this, in that the framework takes full account of the legal requirements and also fits in with our overall environmental monitoring programmes. The most important aspect will be identifying the needs of all the stakeholders through consultation and dialogue. This process will also allow any opportunities for collaboration through the use of shared information to be identified. The monitoring network will make use of existing boreholes and other sampling points, as well as any opportunities to use established sampling programmes to ensure the maximum cost-effectiveness.

The Agency has set out the key objectives for groundwater monitoring as follows:

- to comply with UK and European legislation;
- to comply with other non-statutory commitments;
- to protect the quality of groundwater;
- to provide groundwater quality data across England and Wales on a common basis;
- to define the baseline conditions in all aquifers;

- to determine trends in groundwater quality;
- to provide an early warning system of groundwater pollution;
- to identify hydraulic and geochemical links between groundwater and both surface waters and the terrestrial environment.

Stage 2 – Planning

The second stage is to build on the information needs identified in Stage 1 and produce a detailed plan of the monitoring framework. An important feature is to ensure consistency across all Agency Regions to produce a common standard for a national groundwater quality database.

Implementing the WFD will require us to develop a series of River Basin Management Plans for each River Basin District. As part of this work, all significant bodies of groundwater will be identified. A groundwater body is a distinct volume of groundwater within an aquifer defined to enable effective management and protection of groundwater and associated surface waters and ecosystems. The monitoring framework will be developed to provide groundwater quality data required for these groundwater bodies.

The Agency's implementation of the long-term monitoring plan will be priority-based, allocating resources to those groundwater bodies that:

- are most vulnerable to pollution;
- support important water supplies or have significant resource development potential;
- support river baseflows or important water-dependent habitats;
- are subject to measures under the Water Framework Directive to return the body to good status.

To ensure a common approach across England and Wales, we will also develop technical guidance and standards for operational procedures covering all aspects of the monitoring process. The guidance notes and standards will cover:

- the design, construction and maintenance of monitoring points;
- identification of the staff and technical resource requirements;
- procuring laboratory services;
- data processing and storage, and the associated Information Technology resources and reporting systems.

The framework for groundwater quality monitoring will be implemented by the Agency's Regions through a series of local implementation plans. Each plan will include a list of groundwater bodies in that Region, giving priority on the basis of vulnerability, water use and environmental significance. It will also identify the specific data requirements of the Agency and local stakeholders. Each element of the groundwater quality monitoring framework will be implemented and operated at local level but will be co-ordinated nationally to ensure that our overall requirements are met.

Stage 3 – Implementation

The details of the hydrogeology will be described for each groundwater body that is to be included in the monitoring framework. Hydrogeologists call this type of description a conceptual model. Each one will define important features of the groundwater body such as:

- the geology and how groundwater flows through the system;
- existing information on the groundwater quality;
- information on land use that may influence the groundwater quality;
- interactions between groundwater and surface water and aquatic ecosystems;
- existing abstractions and the potential for future resource development.

The conceptual model will enable us to identify the detailed monitoring requirements, such as the location and density of monitoring points, the chemical parameters to be measured and the sampling frequency.

Data analysis and reporting

The end product of the groundwater quality monitoring system will be reliable, quality assured data. It is important that these data are readily available in a user-friendly format for all the stakeholders.

Reports will be produced for each groundwater body and monitored hydrogeological unit in a format that meets statutory requirements, such as the WFD. They will provide information on the hydrogeological setting and conceptual understanding of the groundwater system, and these reports will be updated every six years. They will describe the groundwater quality for each unit in the context of the water resources and habitat significance. Regional and national summaries will also be produced, with all reports made available through a wide range of media, including electronic formats and the internet to make the information as accessible as possible.

Both the information needs and the data themselves will be reviewed periodically to identify any future modifications to the monitoring network or monitoring procedures that may be required.

Benefits of monitoring

The information on groundwater quality from the monitoring framework will be invaluable to the Agency in ensuring the sustainable use of groundwater resources. A nationally consistent method of obtaining groundwater quality information will enable both us and the Government to comply with national and EU legislation, and make meaningful comparisons between all the groundwater bodies across England and Wales.

The main benefits are seen as:

- providing a reliable database leading to a better understanding of the natural processes that affect groundwater quality and the impacts of pollution, including predicting future potential problems;

- establishing a consistent monitoring programme across England and Wales as the basis for all groundwater quality monitoring needs;
- optimising the use of existing monitoring systems for maximum cost-efficiency;
- greater availability of reliable data for all stakeholders, using a wide range of reporting media;
- supporting the Agency's Vision for a better environment by contributing to a better quality of life for the whole community, an enhanced environment for wildlife, improved and protected inland and coastal waters, and a wiser, sustainable use of natural resources.

References

UK Groundwater Forum, compiled by R. A. Downing, 1998
Groundwater: Our Hidden Asset.
Natural Environment Research Council ISBN 0-85-272304-0

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The National Groundwater and Contaminated Land Centre's Vision is:
an improved groundwater and land environment for present and future generations.

Further National Centre reports and other booklets in this series are available from the Agency website: **http://www.environment-agency.gov.uk.**

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