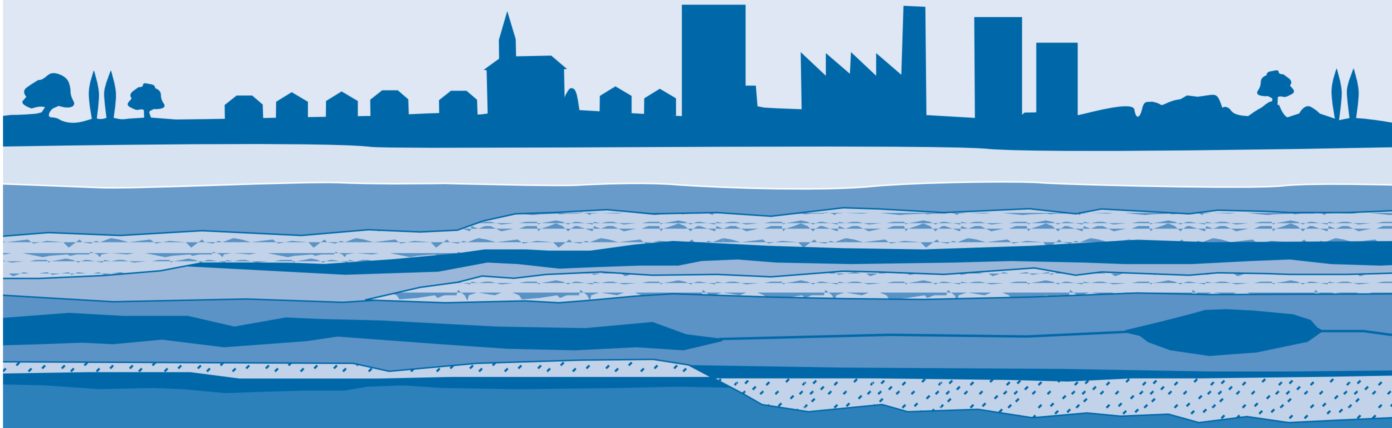
Environment Agency

underground, under threat



Groundwater protection: policy and practice

Part 2 – technical framework

Contents

Part 1 – Overview
• Our overall position at the Environment Agency on the management and protection of groundwater
• An overview that identifies our goals
Part 2 – Technical Framework
• A basic introduction to groundwater and its place in the water cycle
• Key principles and concepts
• Description of the threats from human activities
Part 3 – Tools
• Introduction to the tools available for analysing and assessing the risks to groundwater
• A brief overview of the use and application of each tool and where to obtain it
Part 4 – Position Statements
• Key groundwater legislation and how we interpret it
• Position Statements on activities that pose a risk to groundwater and how we plan to deal with them

1. Introduction

1.1. The importance of groundwater and its protection and management

1.1.1. A hidden asset

Groundwater is an essential part of the natural water cycle (Figure 1-1). It is present practically everywhere beneath our feet. It forms the largest available store of fresh water in England and Wales – in fact there is far more groundwater than there is fresh surface water. However, it is a hidden asset, out of sight and all too often out of mind. This store of groundwater comes mostly from rainfall that has filtered down through the ground. Providing it is not pumped directly out of the ground, for example, for public water supply, most groundwater eventually discharges into surface waters. Here it supports river flows, and maintains ecosystems. It is the primary source of water for rivers and lakes in summer or at times of drought. Groundwater is therefore important to wildlife.

Groundwater is an important strategic resource. Three-quarters of all the groundwater pumped from boreholes or taken from springs is used for mains water supply. It directly supplies nearly a third of the drinking water in England and Wales. In some areas it is the only available drinking water resource. It also supplies nearly all those who do not have mains water. Groundwater is not just for private domestic use: many hospitals, bottling and food processing plants also rely on their own groundwater supplies, as do major manufacturing and other industries. There are advantages in using groundwater for both public and private supplies: compared to surface water, it is of relatively high quality and usually requires less treatment prior to use, even for drinking and other potable purposes.

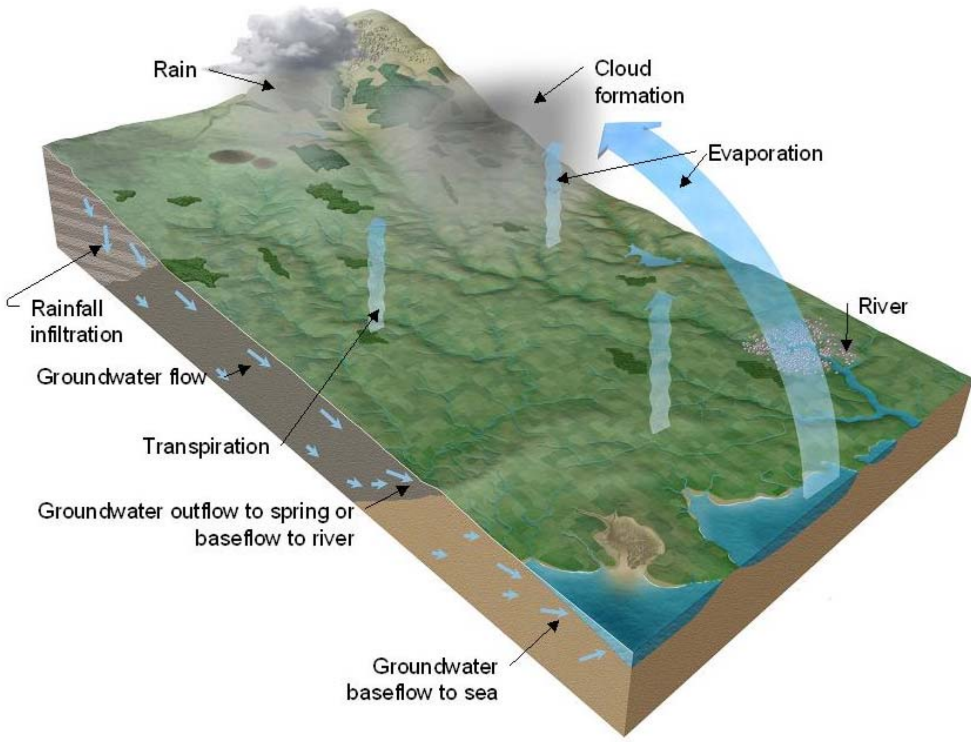


Figure 1-1 Groundwater in the hydrological cycle
(**Sniffer 2005, www.wfdvisual.com**)

1.1.2. Links to other elements of the water cycle

Groundwater is an integral part of the water cycle. For example, if you abstract or divert groundwater, this can affect river flow and surface water levels – and consequently the associated habitats and ecology.

The need to protect groundwater resources from the effects of human activity is just one element of environmental protection as a whole. For example, a reduction in either the quantity or the quality of the groundwater may prevent associated surface water from achieving good status, as required by the Water Framework Directive.

1.1.3. Protection and restoration

Compared to surface water, groundwater is often relatively well protected from pollution by the overlying layers of soil and rock. Water passing through these layers is naturally filtered and many pollutants are degraded during the slow passage to the water table. This helps to maintain the relatively good quality of groundwater. This is important both for water-dependent flora and fauna, and for the use of groundwater as a source of drinking water.

The widespread presence of groundwater means that any material spilt on or applied to the ground has the potential to reach the water table. Whether it will or not depends on the material involved and the ground conditions at that site. Pollutants introduced by people can overwhelm the natural capacity of the ground to deal with them. If human activities do pollute groundwater, it is very difficult to return it to its original condition. Processes that take days or weeks in surface water systems may take decades to centuries in groundwater. This is because of the relatively slow rates of groundwater flow and the reduced microbiological activity below the soil zone (due to the general lack of oxygen and nutrients).

Protecting groundwater is essential. The subsurface environment is inaccessible and complex. Groundwater pollution can be very difficult to detect and may not become evident until a water supply or spring is affected. Pollutants may take months or years to migrate from the source to a receptor or to a point where they can be detected.

We must all work together to reduce the risk and therefore the occurrence of groundwater contamination. Trying to clean up groundwater is technically difficult and attempting to do so may even make matters worse. The problems of access to groundwater and the technical difficulty mean costs are very high indeed (**EA (1999a)**) – they will be met not just by polluters but by users such as water companies, and through their bills, householders and those in industry. Prevention is far better than cure!

The growing population, intensive agriculture, waste disposal and the use of new chemicals have significantly increased the risk to groundwater over the past 60 years. Some of these potential sources are illustrated in Figure 1-2.

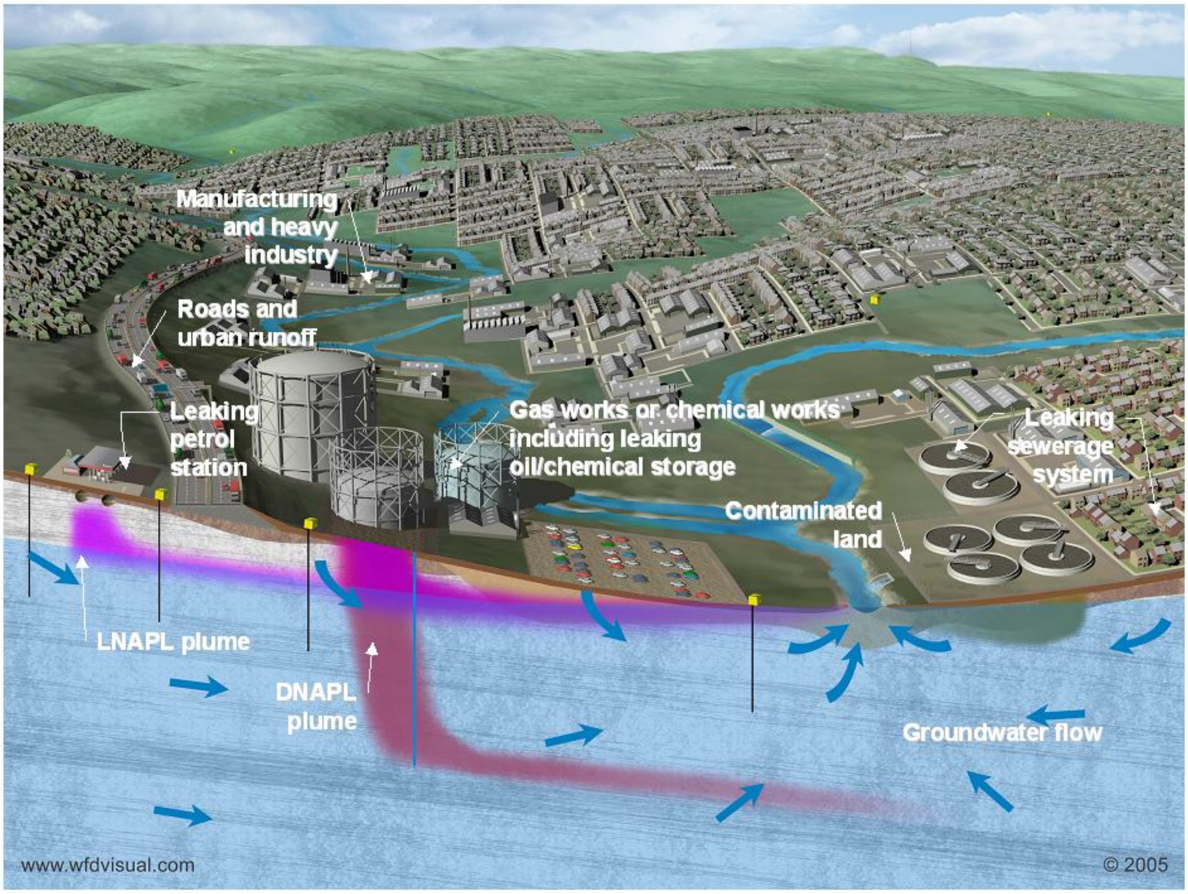


Figure 1-2 Potential threats to groundwater from the urban environment (Sniffer 2005) www.wfdvisual.com)

The Government, industry, regulators and others have put extensive legislative and voluntary measures in place to protect the environment. However, the legacy of the past is often evident in groundwater quality. Groundwater is now particularly at risk from distributed or 'diffuse' sources of pollution. These pollutants can affect wide areas and accumulate over many years. They are even more difficult to control and clean up than 'point' sources, such as leaking underground tanks.

An example of a diffuse pollution source is nitrate. About 60 years ago there was a move to intensive agriculture and the use of chemical (rather than organic) nitrate fertiliser. It took decades, however, to fully appreciate the problems of the increasing nitrate in groundwater. Monitoring and research show that nitrate concentrations are still increasing over much of the country and will continue to do so for many years to come. We predict a continuing rise due to the storage of nitrate in the subsurface and its inevitable slow downward movement through the unsaturated subsurface towards the water table. This will happen even where the original activity that gave rise to the pollution has been stopped. Other potential rural sources of pollution are illustrated in Figure 1-3.

1.1.4. Management principles

At the Environment Agency, we recognise that:

- Groundwater is a natural resource that has both ecological and economic value. It is vitally important for sustaining life, health, agriculture and the integrity of ecosystems.
- It is essential to protect groundwater resources from over-exploitation; from human activities that can cause adverse changes in hydrological systems; and from pollution – many forms of which can produce irreversible damage.
- As with surface water, groundwater reacts to events such as droughts and floods. However, it does so over a longer time period. It can therefore be a good indicator of climate change.
- Though large, our groundwater resources are finite. As a society, we should manage and protect them on a sustainable basis. Groundwater will become more important as the effects of climate change become apparent.
- As regulators and users of water, we should manage surface water and groundwater as a whole. We need to pay equal attention to quality and quantity, and take into account all interactions with the soil and atmosphere.
- We need to integrate water management policies within the wider environmental framework. There must be links with other policies that deal with human activities such as agriculture, industry, energy, transport, urbanisation, and tourism.
- The groundwater environment and its relationships with other parts of the water cycle are complex. We need to underpin our work with sound science and a good conceptual understanding. We must also ensure that we refine that understanding as new data come to light.

An integrated water management framework, such as this Groundwater Protection: Policy and Practice (GP3) document, has to balance many different considerations. As groundwater resources are hidden, there is always the risk that they will be overlooked when decisions are made on land-use management. There is a general lack of awareness of the importance of groundwater protection. This extends even to those working in the field of water and environmental management. We will, with other initiatives, use the GP3 for groundwater protection and management and to educate society about the risks to groundwater and the ways of reducing these to acceptable levels.

1.1.5. Supporting tools

Published alongside the original *Policy and Practice for the Protection of Groundwater* (Environment Agency 1998 (**EA (1998)**, National Rivers Authority 1992) were groundwater vulnerability maps and source protection zones. A much wider variety of tools are now available. These include risk screening and risk assessment tools. There is a brief guide to these in Part 3 of the GP3. This describes the tools and methodologies that are already available or are being developed. We, and many other people and organisations, use these to assess the impact on groundwater of the hazards described in this Part of the GP3.

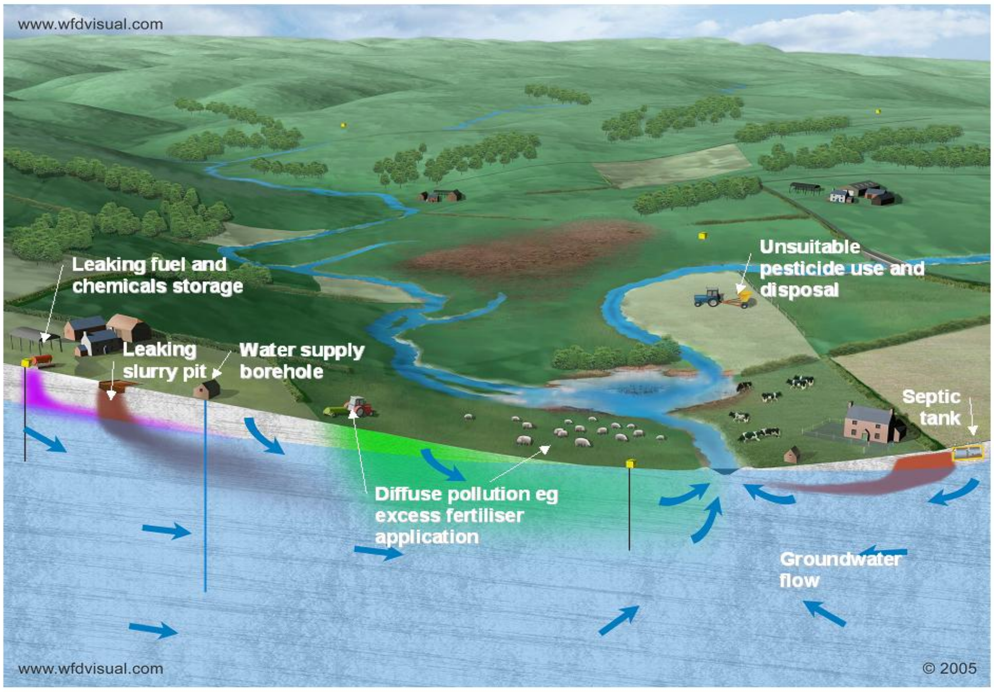


Figure 1-3 Potential threats to groundwater from rural sources (Sniffer (2005) www.wfdvisual.com/)

2. Groundwater – An introduction

2.1. Basic groundwater flow concepts

2.1.1. Where does groundwater come from?

The vast majority of groundwater originates as rainfall. However, not all rainfall ends up as groundwater. Some runs off directly into surface water. Some evaporates. The rest soaks into the ground, but has to pass through the soil, and underlying strata before it reaches the water table. The ground above the water table is called the unsaturated zone. In this zone some water can be held in storage around soil particles, some flows into drains and into surface water, and some is taken up by plants. The remaining infiltration, known as recharge, eventually reaches the water table and becomes groundwater. There can be a considerable time lag between the fall of rain and recharge to groundwater.

Definitions

Groundwater – all water which is below the surface of the ground in the saturation zone *(below the water table)* and in direct contact with the ground or subsoil (Groundwater Directive, 1980 and Water Framework Directive, 2000).

Aquifer – 'a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater' (Water Framework Directive, 2000).

2.1.2. Where is groundwater found?

Most groundwater is found within *aquifers*, where it can be exploited via boreholes, wells or springs, or it can support other ecosystems such as rivers and wetlands. *Unproductive strata* may also contain groundwater (see 5.3.3) but here the groundwater flow is not significant in terms of water supply or ecosystems support.

2.1.3. How does groundwater flow?

Gravity is the main force behind groundwater flow. However, there is a common misperception that groundwater flows in large subterranean channels, such as in the cave systems within the limestone of the Mendip Hills. In fact, such channels are the exception rather than the rule. Groundwater flows mostly through the interconnected voids in rock. These may be the pore spaces between the grains in a rock, or cracks and fissures.
The total volume of the pore space is known as the *porosity*. This represents the total volume of water that the rock can store. For the rock to be *permeable*, the void spaces must be interconnected, so that water can flow between them.

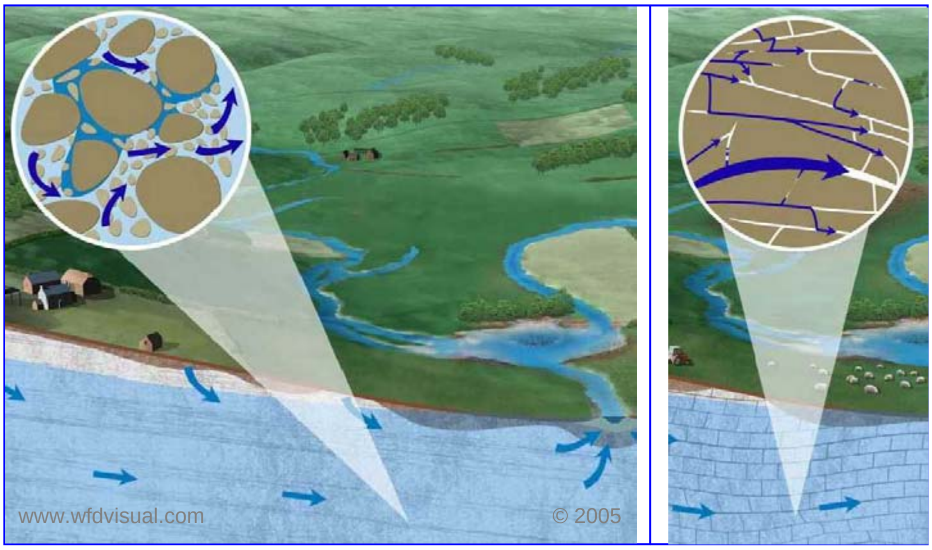


Figure 2-1 Intergranular groundwater flow (left) and fissure flow (right) (Sniffer (2005) www.wfdvisual.com)

Groundwater can flow in different ways depending on the type and structure of the rock. The rate of groundwater flow, from springs or into boreholes, depends partly on the type of rock making up the aquifer. Flows can range from a tiny trickle out of a sandy clay, for example, to thousands of cubic metres a day from some limestone aquifers. For more information see the Groundwater flow concepts box.

Intergranular flow occurs when water moves between the grains in rock, for example, in a sand or a sandstone. This is usually fairly slow. However, in limestones, cemented sandstones and many 'hard' rocks such as granites, most flow is along cracks and fissures. This is called *fissure flow* and is usually significantly faster than intergranular flow. In many aquifers there is no simple division between intergranular and fissure flow. Both flow mechanisms can be present and play a greater or lesser part in overall groundwater flow (Figure 2-1). In *dual porosity aquifers,* such as the Chalk, the rock mass between the larger fissures can hold considerable volumes of water. Water flows quickly in the fissures between the rock mass, but intergranular flow in the matrix is relatively slow. During abstraction this gives rise to a phenomenon known as *delayed yield*, where the water in the matrix is released from storage after the water in the fissures.

2.1.4. Interaction between groundwater and surface water

Traditionally people studied groundwater and surface water separately. However, groundwater, rainfall and surface water are intimately connected. It is now widely accepted that they should be managed in an integrated way. Most rivers derive their flows from both surface run-off and groundwater discharge. The highest river flows and the short-term peaks occurring after rainfall are mostly due to surface run-off, particularly in winter when evaporation is low. Over the spring and summer, as evaporation and transpiration rises, and soil becomes dryer, runoff decreases and the overall river flow declines. During this period groundwater becomes increasingly important in maintaining river flow. At these times much of this *baseflow* is derived from groundwater.

Some rivers, such as those on the Chalk downlands of Southern England, drain areas that consist entirely of permeable rocks. They obtain virtually all their water from groundwater. Flows are at their highest at the end of winter or in early spring, when groundwater levels are high. They decline progressively from late spring to autumn. As the water table falls in aquifers such as the Chalk, streams may dry up. This is because the point at which the groundwater discharges moves downstream (downhill). Such streams, referred to as winterbournes (or simply bournes), may remain dry for extended periods during droughts.

These are natural seasonal variations. River flow can also be affected by groundwater abstraction. The relationship between the volume and timing of groundwater abstraction and river flows is complex. Inputs to surface water from urban runoff and sewage treatment works further complicate the situation and can hide natural inputs from groundwater. Sewage discharges can also hide inter-catchment transfers of groundwater (water in the discharge may be abstracted from a different catchment).

Groundwater flow concepts

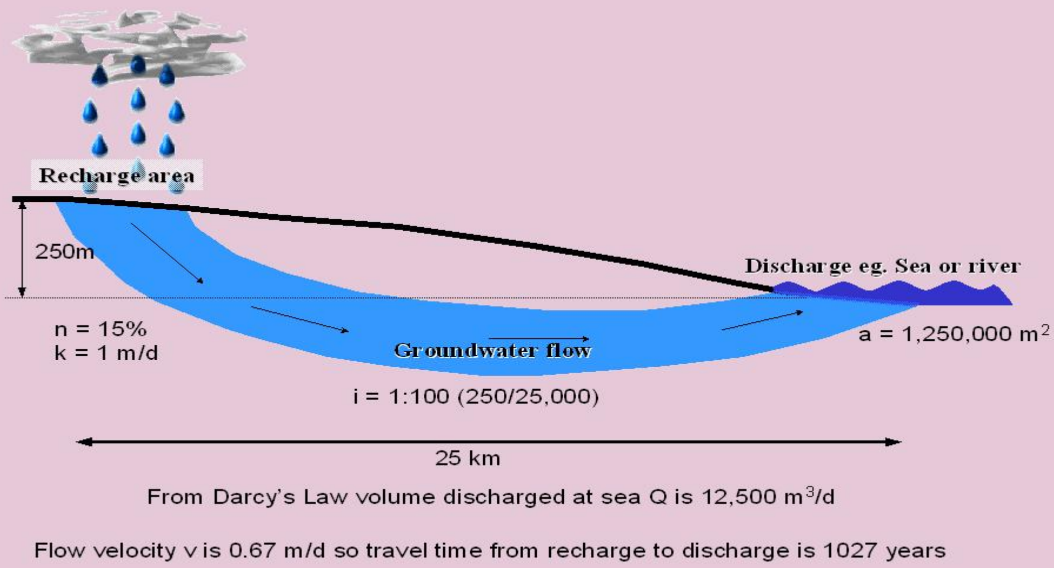
The hydraulic gradient is the slope of the water table. It governs the direction of groundwater flow. The volume of flow through an aquifer is related to the hydraulic gradient and the *hydraulic conductivity* or permeability of the rock (a measure of how well pore spaces are interconnected). The speed of flow (Flow Velocity) is related to hydraulic conductivity, hydraulic gradient and *effective porosity* (the connected void space in the rock).
In most aquifers, groundwater flow is slow. Speeds range from one metre per year to one metre per day. Occasionally, for example in highly fissured or *karstic* limestones, flow rates can be similar to those in rivers – in the order of kilometres a day.

More details of these and related hydrogeological concepts are available – see **BGS (1998)**.

Darcy's Law relates the volume of discharge through an aquifer to the *hydraulic gradient* and the *hydraulic conductivity:*
Q = k i a
Q = discharge (m^3/d), k = hydraulic conductivity (m/d), i = hydraulic gradient,
a = cross sectional area of flow (m^2).

Flow velocity

v = k i /n
v = velocity in m/d
n = effective porosity.



Around a watercourse is a zone where surface water and groundwater interact. This is known as *the hyporheic zone* (Figure 2-2). This is a zone where biological and geochemical activity are often enhanced and where some pollutants may be attenuated.

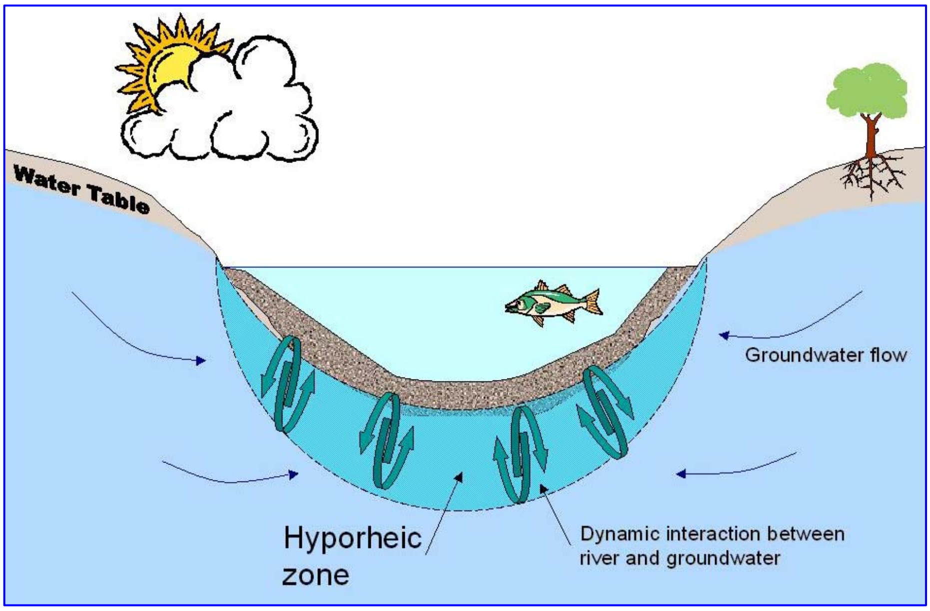


Figure 2-2 Hyporheic zone – a complex area of enhanced biological and geochemical activity at the interface between groundwater and surface water

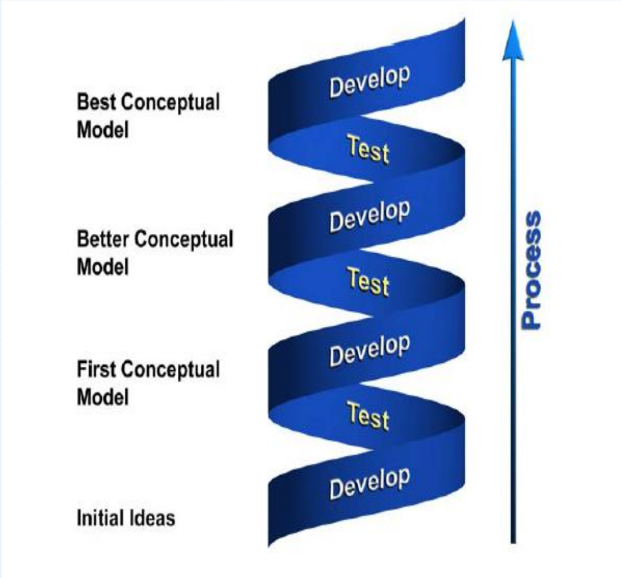
Most wetlands are also heavily dependent on groundwater. They are generally formed in valley floors by flows of groundwater from springs and seepages. Wetland habitats often rely on a complex balance between inflows and outflows to maintain water levels throughout the year. Water quality is also very important, and different plant communities may develop in different parts of the same wetland. For example, in Suffolk, some parts of the Redgrave and Lopham Fen are an acid wet heath and depend on acidic rainfall. Other parts of the fen depend on lime-rich groundwater from the underlying Chalk.

2.2. Conceptual understanding and models

A conceptual understanding – often referred to as a conceptual model – is the key to comprehending and managing groundwater systems. This is true for all assessments regardless of scale. It could be the investigation of a pollution incident at a petrol station or the development of a new farm borehole, or it could be the assessment of the water resources in a body of groundwater covering tens of square kilometres.

A conceptual model is a simplified representation or working description of what we believe to be the physical, chemical and biological processes operating at a site or study area. It can be thought of as an annotated picture of the system, with supporting text. It shows geology, flow paths, pollution sources, abstractions and receptors. It should include both qualitative and quantitative information that people can use to test the model and its assumptions to see if it is correct. Conceptual modelling is an iterative process of development, testing, and refinement as more information is obtained or a better understanding is gained (see Figure 2-3). This gives us improved confidence in model predictions.

The development and testing of conceptual models



Key points are:

- the model should not be overcomplicated;
- assumptions will have been made in developing the model – these may be wrong;
- assumptions and uncertainties must be clearly stated and understood;
- the information used and therefore the model will always be incomplete (it is, after all, a simplified representation);
- some information may be conflicting; the processes being described may be poorly understood.

Figure 2-3 The development and testing of conceptual models

2.3. Use of mathematical, analytical and numerical models

Models (conceptual, mathematical, analytical, and numerical) are increasingly used to study hydrogeological systems. These models have many purposes including:

- predicting the behaviour of contaminant plumes;
- estimating the resources of an aquifer block, ie a defined area of aquifer;
- assessing the impact of groundwater abstraction on rivers, wetlands, or other abstractions;
- Undertaking hydrological impact assessments of, for example, quarrying.

Any numerical model must be based on a good conceptual model. Without a basic conceptual understanding of how the system works, the results of numerical models can be at best misleading. Just as a conceptual model is a precursor to a groundwater flow model, then an accurate flow model is an essential precursor to a groundwater quality/contaminant transport model.

The development of the numerical model can help with overall understanding of the system. For example, it may reveal false assumptions in the conceptual model. The model will then be refined. Numerical models must be used with caution as they:

- are based on assumptions;
- rely on the input of good quality data;
- are time-consuming and expensive to produce;
- can provide compelling, but inaccurate, visual output.

In the right circumstances, however, numerical models are very valuable tools for investigating, managing and protecting groundwater.

Mathematical models
These are the mathematical expressions or governing equations which approximate the observed relationships between the inputs (rainfall, abstraction from wells, aquifer properties, etc) and the outputs (level of the water table, river flows, etc). These governing equations may be solved using analytical or numerical techniques.

Analytical models give exact mathematical solutions of the flow and/or transport equation for all points in time and space. In order to produce these exact solutions for groundwater systems, the flow/transport equations have to be considerably simplified (e.g. very limited, if any, representation of the spatial and temporal variation of the real system). To give a better idea of uncertainty, some analytical models such as LandSim and ConSim work on inputs expressed as ranges or probabilities. The exact solutions to the equations are calculated hundreds of times using different permutations of the input data. This allows the answers to be presented in a probability distribution.

Numerical models use numerical approximations to solve the water flow and/or chemical transport equations. Inputs are made at certain points in time and space. This allows for a more realistic variation of parameters and results than in an analytical model. However, outputs are also produced only at these same specified points in time and space.

You will find additional information, including how to obtain some models, in Part 3: Tools.

2.4. Groundwater quality

Groundwater can be *contaminated* by a wide range of naturally occurring substances as well as by human activities. *Pollution* only occurs when contamination arising from human activities (by substances or heat) actually harms ecosystems, human health, material property, amenities or other legitimate uses of the environment.

Pollutants are substances that can either occur naturally but are concentrated by human activities, or they can be substances that are synthesised by humans and do not normally occur in nature. *Pollution* as such is always caused by human action (see box). It may be due to the deliberate or accidental release of a pollutant. Or it may be due to an activity that moves a pollutant so that it becomes a problem. The following sections and Annex 1 describe typical groundwater pollutants, their causes and their significance for groundwater resources.

Definitions
Pollutant – any substance liable to cause pollution.

Pollution – the direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems, which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment.

These definitions are taken from the Water Framework Directive (2000/60/EC).

2.4.1. Pollutant phases

Polluting substances can occur in different phases – for example, in gaseous and aqueous phases, or as non-aqueous phase liquids (*NAPLs*). Methane, often derived from degrading organic matter, is an example of a gaseous pollutant that may be present both in the unsaturated zone and below the water table – where it is dissolved in and therefore potentially moves with groundwater. The methane can be released some distance from the source where it can mix with air. This may result in an explosion, especially in confined spaces below ground.

Aqueous pollutants include substances that dissolve readily in water. Examples are MTBE (the anti-knock ingredient of unleaded petrol), bromate, nitrate or ammonium. Although they are generally only easily soluble under acidic conditions, metals such as lead and zinc fall into this category.

What happens to NAPLs below the ground?

The behaviour of these substances in groundwater is complex and not always what you might expect. The lighter substances, LNAPLs, may float on the water table. However, the DNAPLs may sink through the aquifer until they reach an impermeable layer. They may then move in a different direction to groundwater flow. In both cases the slowly dissolving pollutant may form a plume of dissolved contamination which moves with the groundwater flow. These substances also present a hidden risk due to the release of toxic gases from the pollution plume.

Non-aqueous phase liquids (NAPLs), many of which are highly toxic, are not readily soluble in water. They can however move through the ground as liquids in their own right and enough may dissolve in water to produce a pollutant plume. NAPLs behave differently depending on whether they are lighter or heavier than water – see box above. Cleaning up NAPL pollution is expensive and technically challenging. Clean-up techniques can deal successfully with some of the lighter liquids, whilst cleaning up pollution from DNAPLs is rarely a practical option.

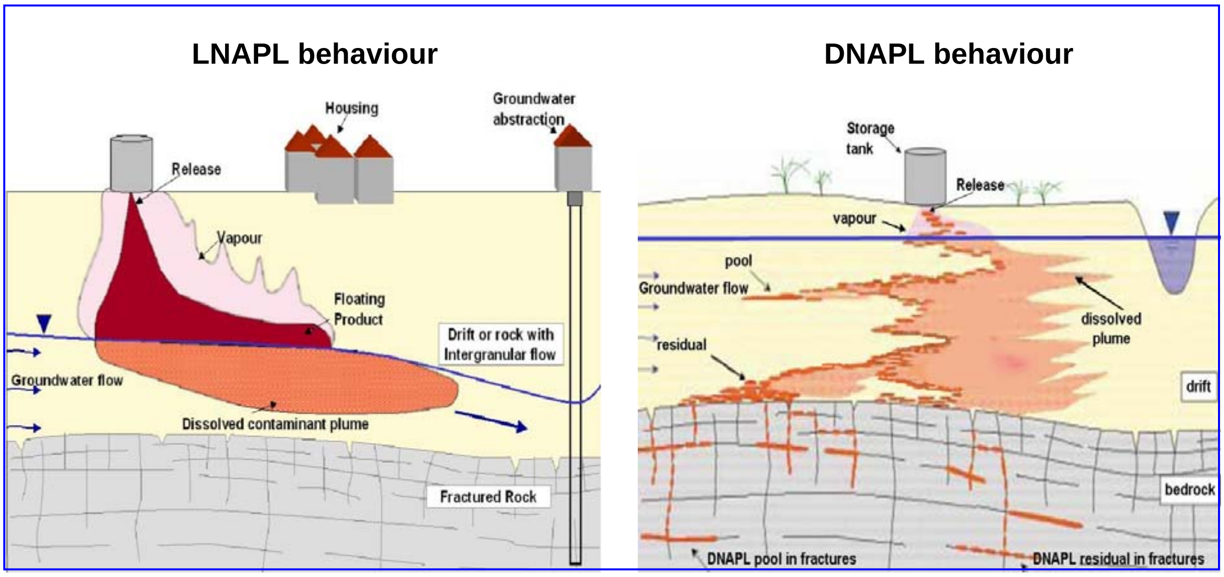


Figure 2-4 Behaviour of different classes of non-aqueous phase liquids in groundwater (after Environment Agency 2004)

2.4.2. Vulnerability

The risks of pollution from a given activity vary from place to place. They depend on the physical, chemical and biological properties of the underlying soil and rocks. These make the groundwater in different areas more or less vulnerable to pollution. Note that our assessment of vulnerability looks only at the protection afforded by the materials above the water table.

Vulnerability is discussed in more detail in section 5.3 of this Technical Framework.

2.4.3. Attenuation

Soils and aquifers can do much to purify polluted groundwater. A growing body of evidence shows that naturally occurring subsurface processes can reduce the mass, toxicity, volume or concentration of organic and inorganic contaminants in both the unsaturated and saturated zones. Specialists often refer to this as *natural attenuation.* It is often applied in the context of restoring groundwater quality. An assessment of the vulnerability of groundwater at a specific site can take account of these processes in the unsaturated zone.

A technique called Monitored Natural Attenuation (MNA) is increasingly accepted as a viable, cost-effective option for managing the risks from contaminated groundwater (see box below). MNA needs to achieve remedial objectives in a reasonable time. If it does not, then we may fail in our duty to contribute to sustainable development. Further information on natural attenuation can be found in our Environment Agency guidance (EA (2000b)).

Natural attenuation in groundwater – refers to the naturally occurring physical, chemical and biological processes, or combinations of these processes, which reduce the load, concentration, flux or toxicity of polluting substances in groundwater. For natural attenuation to be effective, the rate at which these processes occur must be sufficient to prevent polluting substances from entering identified receptors, and to minimise expansion of pollutant plumes into currently unpolluted groundwater. Dilution within a receptor, such as in a river or borehole, is not natural attenuation.

Monitored Natural Attenuation (MNA) – this remedial technique monitors groundwater to confirm whether natural attenuation processes are operating. The monitoring must also demonstrate that natural attenuation is acting at a rate that ensures the wider environment is unaffected and that remedial objectives will be achieved within a reasonable timescale. This will typically be within one generation or less than 30 years.

2.4.4. Baseline groundwater quality

Before the Industrial Revolution, the chemical composition of groundwater was largely the result of natural processes. Groundwater begins as rainfall – this is a dilute slightly acidic chemical solution and its composition reflects the contents of the atmosphere at the time the rain fell. As rain soaks in and travels through the soil and rock, it is subject to a number of processes. The water is filtered, often removing bacteria, and minerals dissolve from the rock. The concentration of dissolved substances generally increases the longer groundwater remains in contact with the rock. It is this process that gives groundwater its natural or *baseline quality*. This tends to be characteristic of a particular area and aquifer.

The Industrial Revolution saw the advent of large-scale manufacturing and energy generation. Later came the intensification of agriculture, the production of synthetic chemicals and increased demand for water. All these changes have affected groundwater quality, moving it away from its natural baseline. It is important to recognise that for some substances it may be difficult to distinguish between the effects of long-term diffuse sources of contamination and the natural baseline. This is a particular problem in areas affected by mining since this activity tends to accelerate the release of contaminants from rocks.

However, such areas may already have elevated contaminant concentrations in groundwater and surface waters as a result of the natural weathering of minerals.

We have worked with the British Geological Survey to gather data on and assess natural baseline quality in a variety of aquifers in England and Wales. These data are being made available in a series of research reports (BGS/EA (1998-2004)). We will need the baseline data to assess:

- the relative impacts of natural and human activities;
- the implications of applying water quality standards;
- the constraints on meeting the objectives of the Water Framework Directive.

3. The Management Framework

3.1. Sustainable development

In May 1999, the Government published *A better quality of life: a strategy for sustainable development for the United Kingdom* (Department of the Environment, Transport and the Regions (DETR (1999a)). This says that at the heart of sustainable development is the simple idea of ensuring a better quality of life for everyone, now and for generations to come. It has four objectives:

- social progress which recognises the needs of everyone;
- effective protection of the environment;
- prudent use of natural resources;
- maintenance of high and stable levels of economic growth and employment.

At the Environment Agency, we have a legal duty to contribute to the goal of sustainable development. In our Water Resources Strategy for England and Wales (EA (2001a)) we used a technique known as sustainability appraisal to measure the contribution of that Strategy to sustainable development.

Many of the factors that affect the management and protection of groundwater are subject to uncertainty. This uncertainty arises from physical characteristics and also social values, systems of governance and climate change. Where appropriate, we apply *the precautionary principle*. This means that, if there is uncertainty about the consequences of a decision **and** there is potential for serious or irreversible harm, we should err on the side of caution and try to clarify the situation. In water resources management for example, if a proposed abstraction may cause serious environmental damage, our decision on the abstraction should ensure the environment is protected. A precautionary approach may also be warranted if there is a risk of failure to a public water supply – this failure may be unacceptable in terms of its social and economic impacts.

Over-abstraction from surface water can damage the environment, but it is often relatively straightforward to reverse – levels and flows will often return to normal in a matter of months or a few years. As described in Section 1.1, once groundwater is polluted, it takes many years, decades or even longer for natural processes to clean-up the groundwater. Human intervention may not reduce these timescales very much. Damage may be serious and perhaps irreversible. For this reason, it is essential to follow the precautionary principle in protecting groundwater quality. We will ensure that we maintain a balance between the precautionary principle and meeting the socio-economic objectives of sustainable development, by taking account of the uncertainties, risks, the potential consequences, and the costs and benefits (EA (2000e)).

3.2. Groundwater Management Issues

3.2.1. Pollution

Pollutants and pollution are defined in terms of the risk of harm to humans and the environment. The risk presented by a pollutant relates not only to its use but also to how it enters groundwater, the degree of harm it may cause, its persistence, our ability to detect it, and the statutory requirements.

In most circumstances, the overlying soils and rocks naturally protect aquifers. However when groundwater pollution does occur it can go unnoticed for long periods. This is because the pollutants soak into the ground and disappear from view.

Pollution may only become apparent much later – when, for example, the groundwater quality at an abstraction borehole is affected, or when contaminated baseflow has a noticeable effect on the chemical quality or ecology of a watercourse. Because of this time lag, a large volume of aquifer may become polluted before the impacts are readily noticeable. The potential for groundwater pollution increases greatly if the overlying layers are removed or bypassed, for example, by quarrying or sinking a poorly constructed borehole for private water supply (EA (2001b)). The vulnerability of groundwater is discussed in section 5.3 and the key pollutants are described in Annex 1.

Poorly stored drums are a groundwater pollution risk

Once groundwater has become polluted, it is very difficult to clean up. Reasons for this include:

- the inaccessibility of the pollutants;
- the difficulties of defining the exact nature and extent of the pollution;
- the retention of the pollutants within the rock matrix;
- the difficulties of controlling the spread of the pollution.

3.2.2. Diffuse and point sources

Risk of point source pollution from an accident

Groundwater is at risk from pollution from a wide range of human activities. Some pollution originates from discrete point sources, such as underground storage tanks, septic tanks, landfill sites and many types of industrial activity. Other pollution originates from the wider, more diffuse use of substances such as fertilisers and pesticides, and the spreading of waste on land.

Point sources are relatively easy to visualise and identify: they are discrete and well-defined events or activities. Examples include, leaking underground fuel storage tanks and accidental spillages from the handling of chemicals. Most point sources arise from activities we control by permits or can be influenced by the use of Codes of Practice.

Diffuse sources tend to be spread over larger areas and time periods. They cause pollution by:

- The spread of pollutants over an area: examples are the deposition of atmospheric pollutants and the leaching to groundwater of fertilisers and pesticides.
- The cumulative effect of many individual and ill-defined events: examples are the combined effects within a catchment of poor land management practices, such as the handling of farm wastes or leaks from the sewerage system. Individually these may be small and hard to detect. Together they have a significant impact on water quality.

In both these examples of diffuse pollution it is difficult to relate cause to effect, i.e. the pollution source to the impact on groundwater.

A potential source of diffuse pollution

There is an extensive 'grey area' between point source and diffuse source pollution. The distinction can depend on the scale at which you are looking at the problem. For example, wastewater leaking from many small breaks in a sewerage network over many square kilometres can be regarded as a diffuse source. However, at the street scale a leak in a sewer represents a point source.

Diffuse pollution is a particular problem for groundwater because of its distributed nature. It is also difficult to regulate activities where a particular source cannot be easily related to a specific impact. As a result, potentially large volumes of pollutants may enter the subsurface and be stored in the unsaturated zone or within the aquifer before the pollution has been detected, linked to a particular activity and made subject to controls. Even after we have dealt with the source of the diffuse pollution, it may then take decades to restore groundwater quality. This is because of the long time that groundwater stays in aquifers. The diffuse pollution of groundwater may also affect surface water, for example, through the baseflow to rivers. In such cases, there is often a considerable time lag between the source activity and the pollution – and an even less obvious connection between cause and effect.

Currently, one of the most pressing problems for groundwater quality in England and Wales is the rising concentration of nitrate. This largely arises from agricultural activities. Although nitrate is not controlled by the Groundwater Directive (it is not a listed substance), nitrate from agricultural sources comes within the scope of the Nitrates Directive.

The Water Framework Directive sets new objectives to reduce diffuse pollution and extends the scope of "prevent or limit" requirements to **all** inputs of pollutants. However, given the difficulties already described, it will be hard to meet these objectives. An effective combination of regulatory and non-regulatory measures will be needed over a considerable period of time.

3.2.3. Land contamination

Land contamination arises when there are substances in, on or under the land which threaten human health and the environment. This may result from previous polluting activities, such as industrial processes, mining and waste disposal, or from pollution incidents such as leaks and spills. However, it can also arise due to the presence of high levels of naturally occurring substances which can be mobilised by human activities. When contaminants are leached from the land to the water table, groundwater may be polluted. Once this has happened, groundwater can be difficult and expensive to clean up. What is more, it may take many years before any clean-up operation takes effect. This can become a greater problem when a concentration of many small areas of land contamination creates diffuse pollution affecting groundwater on a large scale.

Land contamination normally only presents a risk to groundwater if the contaminants are mobile or present in a readily leachable form. In some situations, contaminants may be relatively immobile and only become a risk to groundwater when they are disturbed, for example during site redevelopment. Even then, groundwater may not be at risk if there is protection from overlying low permeability strata or a deep unsaturated zone.

Our priority is to prevent new land contamination. As a regulator, we control activities that could cause pollution through a system of permits (such as those issued under the Groundwater Regulations and Pollution Prevention and Control (PPC) Regulations). We also use our discretionary powers to serve Notices.

Existing contamination is tackled in a different way. When a developer is seeking planning permission to redevelop land where contamination is known or suspected, planning legislation requires appropriate site investigation and clean up. Local authorities also have responsibilities under the Environmental Protection Act (EPA)1990, Part IIa (see Part 4 of the GP3 for more information). This requires them to examine their areas and determine land as Contaminated Land where there is, or is likely to be significant pollution of controlled waters (see definitions box in 2.1.1). The local authority may then serve remediation notices to ensure the necessary level of clean up. In some cases the local authority may consult with us and designate land as a ‘special site’ in which case the Environment Agency takes over as regulator.

The risks from a given level of contamination will vary greatly, according to the use of the land and a wide range of other factors including the underlying geology of the site. These factors may be more critical in determining risk than the total concentration of contaminants. Landholders and developers should therefore assess risks on a site-specific basis adopting a ‘suitable for use’ approach for the clean-up of contamination. We, or the local authority, will then consider the risk assessment to see that it, and the proposed remediation are acceptable. This approach limits clean-up work to what is necessary to prevent unacceptable risks to human health and the environment. Additional work may be needed to protect controlled waters and comply with legislation. All of those involved in this work should adopt appropriate technical solutions to deal with the risks in a sustainable way. See also Section 3.2.6 overleaf on 'Physical interference to groundwater flow'.

3.2.4. Over abstraction

Groundwater stored in aquifers may be depleted by what is sometimes called ‘mining’. This refers to the pumping out of more water than is replenished by recharge. The effects can be reduced river flows, dried-up boreholes and damage to the aquifer system. Our use of CAMS will help to prevent this occurring in the future and identify solutions where problems already exist.

3.2.5. Saline and other intrusions of poor quality water

The intrusion of saline groundwater can occur naturally where aquifers meet the coast. The discharging fresh waters ride over a wedge of denser, salty water (see Figure 3-1). Ancient saline groundwater is also present in certain deep aquifers. This saline groundwater is unrelated to coastal intrusion and in some cases is many times more salty than the sea. The balance between the lighter fresh water and the denser saline water is a delicate one. It is highly dependent upon the local groundwater flow regime and the geology.

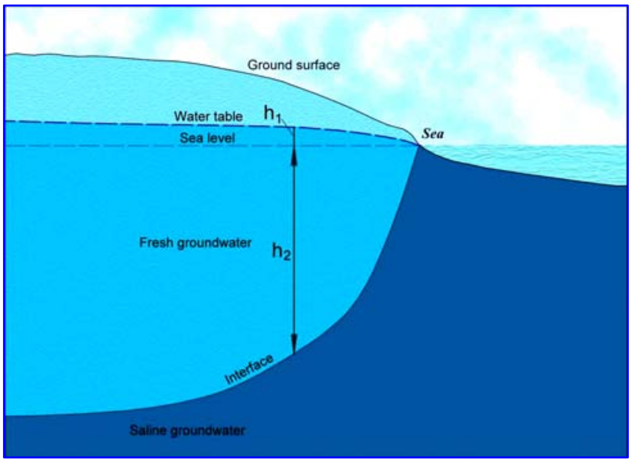


Figure 3-1 Relationship between fresh and saline groundwater in a coastal aquifer

Abstraction from the overlying fresh waters can cause saline waters to intrude further into the aquifer. In sandstones – where the flow is mainly intergranular – saline intrusion moves more slowly and on a broader front. In fractured aquifers, such as the Chalk, intrusion can move rapidly and extend inland for a considerable distance.

Some abstractors have developed practices to control saline intrusion. These practices allow abstractors to make the optimal use of the groundwater resource. However, in some cases, excessive abstraction has resulted in the progressive migration of saline fronts inland or upwards from depth. This threatens high-quality groundwater resources.

Saline intrusion is complex and unpredictable. As a regulator, we need to act with caution when we consider new, increased or changed abstraction regimes in estuarial or coastal settings, or in inland areas where deep saline groundwater is present.

Some areas have had saline groundwater for a long time. This does not mean that the groundwater has no potential use. It is possible to utilise brackish groundwater for industrial and manufacturing purposes. With the increased focus on the effective use of water resources, more companies are using these waters. Also, suitable treatment enables brackish groundwater to be used for higher-grade purposes. This use of poorer quality groundwater can reduce the pressure to abstract more environmentally sensitive groundwater and surface water.

3.2.6. Physical interference to groundwater flow

Engineering activities in the ground, such as the construction of large basements or piles, can impede the natural flow of groundwater. It can affect springs and river flows or raise groundwater levels behind the obstructions. This may cause surface water-logging, the unexpected appearance of springs or, in extreme cases, flooding. Mines and quarries often cut across the water table and water may be pumped out to prevent interference with the extraction activities. As a result of the Water Act 2003, these activities will require a transfer licence (see Part 4 of the GP3 for more information). The pumping may affect nearby groundwater supplies or rivers and wetlands. In addition, the discharge of the pumped water may change the flow characteristics or chemistry of the receiving stream or river. Some civil engineering activities, such as the construction of roads and tunnels, are also likely to intercept groundwater. Drainage to prevent interference with construction activities may also have an impact on the groundwater regime.

As well as interfering with flow, these engineering, mining and construction activities may increase the risk to groundwater quality. The removal of overburden in a quarry or the introduction of drains in a tunnel or cutting can provide rapid pathways to the water table. By removing or bypassing the overlying protective layers, pollutants are not attenuated – they may discharge at much higher concentrations into groundwater. Chemicals used in the construction of some engineering structures can also leak into and pollute groundwater. Piling activities as well as threatening groundwater flow can also put groundwater quality at risk. Additional information on this subject is available in a booklet 'Piling into contaminated sites' (300kb, PDF) and in the report 'Piling and Penetrative Ground Improvement Methods on Land Affected by Contamination: Guidance on Pollution Prevention (600kb, PDF).

3.2.7. Groundwater flooding

Groundwater flooding is a significant but localised issue. In recent years, there has been considerable concern about the risk of flooding from groundwater.

There are a number of situations where groundwater levels can rise close to, or above, ground level. This potentially affects property and infrastructure. These situations include:

- natural exceptional rises in groundwater levels, reactivating springs and ephemeral watercourses (often referred to as clearwater flooding);
- rising groundwater (rebound) following reductions in previous levels of abstraction;
- mine-water recovery;
- local shallow drainage/flooding problems unrelated to deep groundwater responses.

Groundwater flooding is a problem partly because it happens very infrequently. Memories or information about previous floods may have been lost. Developments may have taken place in areas susceptible to the break-out of new springs or the appearance of lakes fed by groundwater. These 'new' groundwater features can flood property and land for many weeks because of the large storage potential of groundwater. Rising groundwater can also inundate sewers. This can cause serious problems for sewage treatment works, overloading their flow capacity and polluting surface water.

3.3. Approach to groundwater management

3.3.1. Groundwater resources

We use a series of guiding principles to ensure a consistent approach to the assessment and management of groundwater. These are:

- To secure the proper use of water resources for all purposes, including environmental need.
- To protect the environment by:
  - identifying a minimum flow or groundwater level below which abstraction may be curtailed or flows augmented;
  - protecting flow and water-level variability across the full range of seasonal regimes from low to high water flow/level conditions;
  - protecting the critical aspects of the water environment including, where relevant, habitats that are dependent upon river flows or water levels;
  - recognising that some watercourses or wetlands are more sensitive than others to the impact of flow or level changes.
- To ensure no reduction in existing protected rights.

- To protect the interests of other legitimate water users.
- To take account of existing and future local requirements that are currently not considered. These could be protecting or changing flows from rivers into estuaries in order to provide protection for the estuarine environment.
- To take account of water quality considerations throughout the catchment in both surface waters and groundwater.

To assess the current state of water resources, we have produced a Water Resources Strategy (EA (2001a)). This forecasts the likely pressures over the next 20 years and the ways we may be able to satisfy future demand. We look for:

- development of new sources, coupled with reduction in demand and losses;
- risk-based water resources management;
- maximisation of existing sources before the development of new ones;
- where possible, development of local supplies.

Mapping the future

Foresight Scenarios are used to investigate how social attitudes and systems of governance might change and how this may affect water resources. There are four scenarios:

- World Markets: high growth, low social equity;
- Global Sustainability: social and environmental problems resolved globally;
- Local Stewardship: local government and collective action dominant;
- Provincial Enterprises: low growth, low social equity.

To get a clearer picture of what the future may have in store, we have also drawn on the Department of Trade and Industry foresight scenarios (DTI1999). These scenarios look at the impact of climate change together with changes in agriculture, industry and domestic use. Annexes to the plans consider the options available to water companies.

3.3.2. Groundwater quality

Groundwater quality is difficult to control – the potential sources of pollution are many and varied, reflecting land use. In England and Wales there are extensive areas of high population density, industry and intensive agricultural use. The hydrogeology is highly variable adding to the complexity of the system.

Preventing pollution is by far the most sustainable and cost-effective way of maintaining good groundwater quality. For this reason we are committed to protecting groundwater and in particular the “prevent or limit” approach, reflected in EU and domestic legislation and described in detail in Part 4 of the GP3.

Our existing approach to groundwater quality protection reflects the requirements of EU legislation, such as the Groundwater, Nitrates and Plants Protection Products Directives.

The Groundwater Directive (80/68/EEC) lists two broad categories or groups of substances (List I and List II) that can be regarded as pollutants: we must control their entry into groundwater in performing regulatory duties. List I substances (the most hazardous) must be prevented from entering groundwater and List II substances must be controlled to prevent pollution of groundwater. The Joint Agency Groundwater Directive Advisory Group (JAGDAG) publishes a list of substances whose listed status is confirmed.

Various pieces of domestic legislation implement these EU requirements. As a regulator, we operate a system of permits for intentional discharges and disposals, and control other potentially polluting activities by measures such as Notices and Codes of Good Practice.

Nitrate is not a listed substance under the Groundwater Directive. However, the Nitrates Directive (91/676/EEC) controls nitrate pollution from agricultural sources. In England and Wales we identify Nitrate Vulnerable Zones where action plans are used to limit the amount of fertiliser, manure and slurry that farmers can apply.

The Biocides (98/9/EC) and Plant Protection Products Directives (91/414/EEC) restrict the marketing and use of substances such as pesticides and herbicides. As existing and new products are reviewed for their pollution risks, this is becoming an increasingly effective way of protecting groundwater.

Wherever possible, we use risk-based methods to control releases of pollutants.
A combination of legislative controls and influencing measures has been and will be necessary to achieve our objectives.

Further details of the legislation governing groundwater management and protection, and how we implement and interpret this, are given in Part 4 of the GP3.

3.4. The Water Framework Directive

The Water Framework Directive (2000/60/EC) (**EC (2000)**) was agreed in December 2000. The Directive is a radical improvement on previous water legislation. It will change the way we protect and manage water. It establishes a new, integrated approach to the protection, improvement and sustainable use of Europe’s rivers, lakes, estuaries, coastal waters and groundwater. The underlying philosophy and requirements of the Directive are in line with our own Vision for the environment (**EA (2000a)**). The Directive emphasises the need for sustainable development, and encourages the development of sustainable solutions to water management through the active involvement of everyone involved in both technical interpretation and implementation.

The Water Framework Directive (WFD) widens the requirement for pollution control to all inputs of pollutants, but also lists broad groups of substances that are called Main Pollutants, a list similar to the combined lists of the Groundwater Directive. The WFD also identifies the chemicals that are most hazardous for the water environment, called Priority and Priority Hazardous substances. There will be strict controls on the release of these substances to the environment as a whole.

We will implement the Directive in phases, leading up to the publication of the first River Basin Management Plans (RBMP) in December 2009. The Directive introduces two key changes to the way the water environment must be managed.

Firstly, it aims to:

- protect the water environment and water users from the effects of pollution from dangerous substances;
- introduce new, broader ecological objectives.

These objectives are designed to protect and restore aquatic ecosystems – and thereby safeguard the sustainable use of water resources.

Secondly, the Directive introduces a river basin management planning system. This will ensure the integrated management of groundwater and surface waters. It provides a decision-making framework within which costs and benefits can be properly taken into account when setting environmental objectives. It will also allow the design and implementation of measures which are proportionate and cost-effective.

The Directive requires us to define management units in the form of River Basin Districts and their associated water bodies. To set the boundaries for bodies of groundwater, we will need to understand the flow behaviour of aquifer systems, including hydraulic boundaries, water balances, groundwater/surface water interactions, and water quality. Developing a conceptual model is key to this process.

A key element in the Directive is the requirement to set up Drinking Water Protected Areas (DWPAs). The purpose is to provide any necessary protection with the aim of preventing deterioration in water quality that could increase the treatment of water abstracted for human consumption. DWPAs are whole water bodies. Most groundwater bodies in England and Wales will be DWPAs.

More details about the Water Framework Directive are in Part 4 of the GP3 and on our website.

3.5. Climate change

There is mounting evidence that our climate is changing as a result of man-made atmospheric emissions. DEFRA's UK Climate Impacts Programme has reported that UK temperatures have increased by about 0.7°C over the last 300 years, with about 0.5°C of warming during the twentieth century (EA (2001a)). This is part of a world picture of warming. Globally, 1998 was the hottest year since records began in the middle of the nineteenth century, and the 1990s was the warmest decade of the last millennium. There is more confidence in some aspects of climate change prediction – for example, in the amount of sea level rise and global temperature increases for a given change in carbon dioxide concentrations. However, it is more difficult to predict the precise impact on the climate of changes in greenhouse gas composition in the atmosphere. Climate change could affect both demand for water and its availability, as well as having an impact on water-dependent ecology.

Changes in climate will affect groundwater and river flow regimes. They will therefore affect the availability of water for abstraction. Groundwater has a long 'memory' of past rainfall and recharge because of its slow flow. This 'memory' may be a useful indicator of the effects of previous climate change. It may also help us to predict the impacts of future changes. Current estimates of climate change suggest that by the 2020s throughout southern and central England there will be on average more winter rainfall and less summer rainfall. Northern England will receive more winter rainfall and about the same volume in summer. Across the UK, the year-to-year variability of rainfall will increase. Effectively, this means that the climate will be less predictable, with more dry years and more wet years. This in turn means that both low flows and flood flows in rivers will probably occur more often.

All this is likely to place additional demands on water resources. This makes an integrated approach to water management and protection even more important.

3.6. Catchment Abstraction Management Strategies – CAMS

The Government proposed changes to the abstraction licensing system in 1999 (DETR (1999b)). The Environment Agency consulted upon detailed proposals for the production of Catchment Abstraction Management Strategies (CAMS) and the management of time-limited licences. We have now produced a national document that supports the development of CAMS at a local level (EA (2001c)). This sets out the policy and regulatory framework, the development process, and provides information on the structure and content of CAMS. CAMS operate on a six-year review cycle, and implementation of the Water Framework Directive may necessitate a re-evaluation of relevant CAMS within the first one or two review cycles.

The objectives for CAMS are:

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

We divided England and Wales into 126 CAMS areas, and added three major rivers as 'corridor CAMS' – the Thames, Severn and Trent (see Figure 3-2).

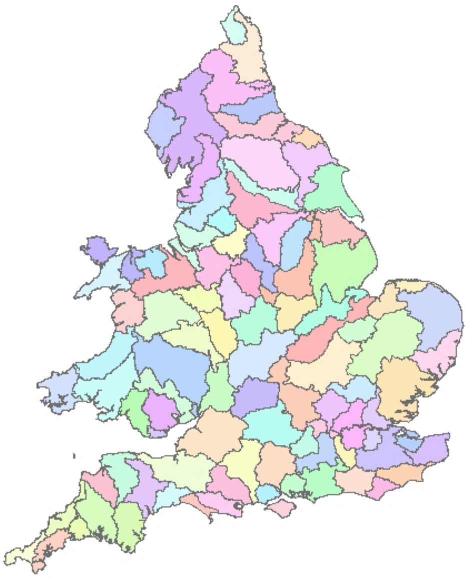


Figure 3-2 Map of CAMS areas

In order to implement CAMS, we have developed a tool called the Resource Assessment and Management (RAM) Framework. This feeds information on ecology, river flows and artificial influences into CAMS. This is then used to set target flows that balance abstraction with the needs of the rivers' ecology. See Part 3 of the GP3 for a more detailed description of the RAM framework.

In areas where major aquifers have been over-abstracted, we may seek to reduce groundwater abstraction. However, in some cases rising groundwater (rebound) is such that it could potentially affect property and infrastructure. Then the CAMS process may lead us to adopt a licensing strategy that encourages new abstraction. This is consistent with the Water Framework Directive. We may also encourage more sustainable local groundwater use where rising levels may adversely affect people or property. The aim is to achieve a 'good quantitative status' in all groundwater bodies. We may set less stringent objectives in cases where it is not technically feasible or where it would be disproportionately expensive to achieve good status. For example, we are unlikely to set a groundwater level so high that it adversely affects building foundations or causes tunnel flooding. In the case of mine water rebound, allowing groundwater levels to recover so that good quantitative status is achieved might threaten the good chemical or ecological status of water bodies. In this case a balance between competing demands must be struck.

3.7. Options for developing resources

To manage groundwater effectively, we need to balance abstraction for water supply with the needs of the environment, for example maintaining adequate river flows. Our 'Water Resources Strategy' (EA (2001a)) therefore considers a wide range of options which combine resource development and demand management. (see Table 3.1)

Table 3.1. Examples of water resource management options considered

Resource development	**Demand management**
New reservoirs or raising existing reservoirs	Improved leakage control
Winter storage reservoirs	Rainwater use (new development, non-potable)
Surface water abstraction	Grey water use (new development, non-potable)
Groundwater abstraction or enhancement	Waste minimisation (industrial/commercial)
Desalination	White goods subsidies
Wastewater re-use	Retrofit of toilets to dual flush
Aquifer artificial recharge and recovery	Increased household metering
Canal, river, and pipeline transfers	Tariffs for measured charges

3.8. Storage and joint use with surface water

Groundwater storage is more difficult and sometimes more costly to access than surface water. However, the potential storage is vast and there may be cost, technical and political advantages in using groundwater storage rather than building a major reservoir.

There is a useful relationship between the recharge of surface and groundwater 'reservoirs' due to the time lag between rainfall filling conventional reservoirs and the recharge to aquifers. Surface water resources are often plentiful in the spring and early summer. In contrast, plentiful groundwater supplies may be available during late summer and early autumn, when rainfall and surface water flows are low. The lag time in groundwater systems usually means that groundwater resources are lowest in late autumn or early winter. Recharge is usually at a maximum in winter and groundwater levels peak in the spring. The different storage characteristics for groundwater and surface water reservoirs are also helpful – for example, groundwater abstraction in summer may only impact on a river in winter when surface flows are higher. Using both groundwater and surface water sources can therefore be an efficient use of the overall resource.

In some places, operators – usually water companies – make use of aquifers for water storage. This technique is used in the North London Artificial Recharge Scheme. During periods of surplus, water treated ready for supply to customers is instead recharged to the Chalk aquifer via wells and boreholes. The water is then stored in the rock for later abstraction. A different approach is Aquifer Storage and Recovery (ASR). This is a more localised scheme: excess surface water is taken and injected into an aquifer, often where the groundwater quality is naturally poor. This technique uses the storage capacity of the aquifer to store good quality water by displacing the natural poor quality water. The stored water is re-abstracted when surface water flows are low. This can help to reduce the demands on surface water systems when the environment is most stressed. It therefore reduces damage to ecosystems.

In certain parts of the country, ***river augmentation*** schemes pump groundwater into surface watercourses to enhance flow. There are two main reasons for river augmentation:

- either to support surface water abstractions further downstream; or
- for environmental protection (to alleviate low flow for example).

The variation in the size of augmentation schemes is large. Small schemes may use a single borehole to maintain flow in a small stream with a high amenity or ecological value. The largest schemes may have 20 or more boreholes supporting large-scale downstream surface water abstraction for public water supply.

There are over 50 such river augmentation schemes in England and Wales. The Shropshire Groundwater Scheme is a well known example. We in the Environment Agency run many of them, but others are the responsibility of water companies or other abstractors, such as where licensed abstractions are considered to affect river flows.

The design of river augmentation schemes is often complex. Designers have to consider many things including:

- the effects of the groundwater abstraction itself on river flows, and the net gains to flow which will result;
- the effects of the abstraction on groundwater levels, other groundwater abstractions, and the environment;
- the compatibility of the quality of the groundwater with the receiving surface water quality;
- the costs of installation, including boreholes, pumps, pipelines and discharge points;
- the costs of operation and maintenance; and
- the operating rules governing when the scheme will be used.

A well-designed river augmentation scheme may be the most sustainable option for restoring or maintaining flows in rivers. This accords with the Government's approach to sustainable development. Such schemes may well form important components of River Basin Management Plans developed under the Water Framework Directive. They enable the overall development of groundwater resources to fulfil economic and social needs, whilst still affording adequate protection to the water environment.

4. Groundwater monitoring

4.1. The reasons for monitoring

We have to monitor groundwater to know how human activities affect groundwater. We need this information to fulfil our statutory duties, to detect resource problems and to identify pollution in good time. It is our job to protect public water supplies and ecosystems. Monitoring is the only way to get this information and is therefore an essential part of protecting groundwater and its dependent surface ecosystems. As illustrated in Figure 4-1, groundwater monitoring is only part of the monitoring regime for water, just as groundwater is only part of the water cycle.

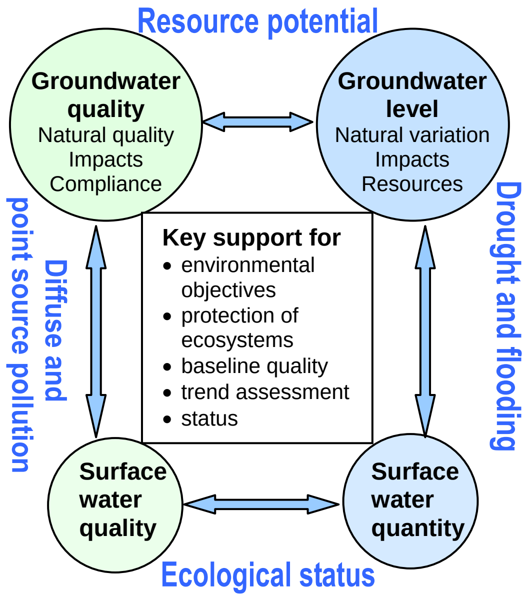


Figure 4-1 Groundwater monitoring objectives and relationships with surface water monitoring

As we discussed in the Introduction, groundwater is found nearly everywhere beneath our feet. It is relatively inaccessible and has complex relationships with other parts of the water cycle. This all makes it more difficult and expensive to monitor groundwater than surface water. It is thus essential that monitoring activity is supported by a good conceptual understanding of the hydrogeological conditions and of the identified pressures on groundwater. The monitoring in turn informs our conceptual understanding.

This approach enables us to make better decisions on:

- the appropriate number and distribution of monitoring points within each groundwater body;
- the frequency of monitoring;
- the range of parameters of groundwater quality to monitor.

One of the most important factors in these decisions is the variability in groundwater conditions.

We carry out groundwater monitoring as part of our:

1) General statutory duties: we carry out monitoring to determine the chemical and quantitative status of groundwater bodies under the Water Framework Directive. It also underpins the designation of Nitrate Vulnerable Zones, under the Nitrates Directive, and our assessment of available resources for the Water Resources Act 1991.

2) Specific statutory requirements: the Groundwater Directive requires us to assess the overall impact on groundwater of discharges from the activities which we license.

3) Monitoring to support national and/or European non-statutory commitments, or environmental initiatives – such as our Vision for improved and protected inland waters and Eurowaternet (proposals for pan-European reporting of water quality).

At the Environment Agency, our overall aims in monitoring groundwater are to meet domestic and European legislative requirements and to contribute to the protection of groundwater and its uses (including direct abstraction and surface ecosystems dependent on groundwater).


Drilling a borehole

There are two main types of groundwater monitoring:

- **Strategic monitoring** – to gain an understanding of the overall conditions within a groundwater body.
- **Defensive monitoring** – to assess the impact of specific activities on the local groundwater environment. It is usually done to determine compliance with regulatory permits we have issued, such as discharge consents and abstraction licences.

Our approach to groundwater monitoring at the Environment Agency is based on risk. This allows us to target resources where there is most need and pressures are greatest, while still fulfilling our general duties. We will focus our strategic monitoring on those groundwater bodies which we believe are most likely to fall short of the environmental objectives in the Water Framework Directive. Defensive monitoring will be focused on licensed activities where non-compliance with permits would result in the greatest risk to the environment.

The final and key steps in the groundwater monitoring process are data analysis and reporting. We use our analysis, and interpretation of the reported data to communicate information on groundwater quality to all interested parties. This also enables us to get the feedback that improves our conceptual understanding of the groundwater body.

We have traditionally operated separate networks for groundwater quality and levels. Occasionally one borehole is used for both purposes, but the specific technical requirements for quality and level boreholes often conflict and it is difficult to obtain good data for both purposes from the same monitoring installation.

4.2. Monitoring of groundwater quality

It is our job to monitor groundwater quality so that we can protect the environment and drinking water supplies from pollution. In many places, the impact of people's activities has moved groundwater quality from the natural background or baseline quality (see BGS/EA (1998-2004)). Groundwater may also naturally contain toxic substances, such as arsenic.

To meet the challenges of the Water Framework Directive, we have continued to develop our Strategic Groundwater Quality Monitoring Programme. This consists of more than 3,000 monitoring points that we sample on a regular basis for a wide variety of parameters. Our analytical techniques are at the forefront of this type of work. We can now detect a huge range of substances in a short time. These include a large number of metals, non-metal anions such as chloride and nitrate, and more than 100 organic chemicals (including pesticides and solvents). We also carry out physical and, where appropriate, microbiological analyses. We will use this strategic network to establish the status of groundwater bodies and assess overall trends in groundwater quality. This information helps us to determine how we can reverse declining trends in quality. This will help us to meet the environmental objectives set for groundwater.

The defensive monitoring needed to ensure compliance with water quality permits is normally quite separate from the strategic network. It focuses on more localised quality issues. We also do investigative quality monitoring to assess the impact of pollution incidents and land contamination.

In all cases our assessment of the monitoring results relies on the conceptual model/understanding of the site or aquifer.

4.3. Monitoring of groundwater levels

Monitoring groundwater levels is essential for the responsible management of groundwater resources. It is not possible to measure groundwater quantity directly because it is dependent on variable aquifer factors, such as porosity, yield etc. The boreholes used to monitor groundwater *quantity* are actually measuring groundwater *level*. With a good conceptual model of the aquifer, we can relate changes in level to the balance between recharge, abstraction, baseflow to surface water, etc. A groundwater-monitoring network can have a number of objectives. A summary of these is given in Table 4.1 (from BGS (1994)).

At the Environment Agency, we maintain an extensive network of boreholes for monitoring groundwater levels. This is managed by our Regional and Area offices within a three-tier hierarchy:

- **National network:** boreholes with data of the highest quality, where monitoring provides the detailed long-term records which are essential for resource studies of aquifers or groundwater bodies.
- **Regional network:** boreholes which provide groundwater level data on a regional basis. These meet most of the demands from people who need information on water levels and allow us to monitor and report variations in the resources available.
- **Local network:** project-orientated, monitoring boreholes. These are for long-term regional projects over wide areas, and also address more local issues such as the monitoring of individual abstraction licences or wetlands.

Table 4.1 Objectives of groundwater level measurement

Objective	Information output
Spatial distribution	Maps of groundwater level. Quantitative data on the hydraulic behaviour of aquifers. Identification of areas of recharge and discharge.
Trends	Monitoring of recharge, recession and natural groundwater level fluctuations. Monitoring impact of local and regional groundwater abstraction.
Early warning	Information to allow assessments of resources during periods of groundwater stress. Data for drought action monitoring or flood warning.
Baseline for future issues	Provision of data to support groundwater modelling, and for water resources investigation.
Industrial and urban impacts	Mine water and pollution incidents. Monitoring areas of rising groundwater levels.
Surface water/groundwater interaction	Data to assess the impact of recharge or abstraction on streamflow.
Licensing and operational control	Data to control the monitoring and licensing of groundwater abstraction on a regional and local scale. Data for the operational control of abstraction/recharge works.
Support to water quality studies	Aquifer protection associated with major developments. Water quality monitoring and control.

In addition, individual monitoring boreholes can be assigned to one or more of the functional classifications shown in Table 4.2.

Table 4.2 Functional classification of monitoring boreholes

Function	Description
Basic resources	Definition of the availability of groundwater resources, seasonal variation, and the interaction with river and spring flows.
Sustainable resources	Evaluation of the long-term sustainability of groundwater resources from long-term groundwater trends, and to provide information for periodical assessment of the national situation.
Groundwater abstraction	Monitoring of the impact of existing groundwater abstraction on groundwater flow patterns and storage, and to provide basic information to derive groundwater protection zones.
Environmental needs	Monitoring of changes in groundwater availability to sites of recognised conservation value. Monitoring rising groundwater levels.
Quality	Monitoring required for input into water quality investigations and/or control measures (see previous section).

Our observation borehole networks provide a broad spatial record of long-term and seasonal groundwater trends in the major bedrock aquifers of England and Wales (principally the Chalk and Permo-Triassic sandstones). In general the network is not designed, or does not have the necessary instrumentation, for ‘real-time’ groundwater flood warning.

In certain high-risk ‘main river’ floodplains, we may monitor and predict shallow groundwater responses to surface-water flood events. This is part of our real-time surface-water flood warning systems. However, we do not routinely monitor groundwater levels in shallow or minor aquifers for flood warning purposes. The cost for this would not reflect the risk. Also, due to the layered and discontinuous nature of many of these aquifers the information from monitoring boreholes may not help in predicting the occurrence or location of flooding.

5. Risk assessment

5.1. Approach to risk assessment

Wherever groundwater is present there is the potential for human activity to affect it. No soil or rock is completely impermeable, no pollutant completely immobile. We are usually forced to use incomplete or uncertain information when we are deciding whether a threat from an activity will impact on the environment. This is a particular issue for groundwater. Subsurface processes are complex and inaccessible and it is costly to obtain data to confirm our conceptual understanding. This introduces a degree of uncertainty that most non-specialists find difficult to accept. We use risk assessment as the formal mechanism or framework to deal with these uncertainties.

At the Environment Agency, our overall approach to risk assessment follows the Government's Guidelines for Environmental Risk Assessment and Management (DETR (2000)). This explains in more detail the risk assessment framework within which we operate and the associated terminology. (See box for a summary of some of these terms.) The tools we use in groundwater risk assessment are described in Part 3 of the GP3.

Definitions

Hazard – a property or situation that could lead to harm. *Harm* may include damage to the health of living organisms or other interference with the ecological systems of which they form part and, in the case of man, includes damage to property. In some cases, definitions of environmental damage are laid down in legislation. In others, we must select appropriate criteria on the basis of scientific and social judgements. (See also the definition of pollution in Section 2.)

Risk – the chance that a defined hazard may occur multiplied by (combined with) the magnitude of the consequences of this occurrence. In the context of groundwater protection, risk arises when an activity is proposed, or is already taking place at a given location. We assess risk to groundwater by taking account of:
- the nature of the hazard;
- the natural vulnerability of the groundwater;
- any preventative measures proposed.

Uncertainty – is a measure of how far the result of an assessment is likely to be from the actual situation. Dealing with uncertainty is an important part of risk assessment and management. It affects all stages of the risk process. Analysing the sources and magnitudes of uncertainties can help to focus discussion, identify gaps in our knowledge and support decision-making.

In order to visualise the factors involved in groundwater protection we use the 'source-pathway-receptor' concept. In Figure 5-1, the 'source' equates to the hazard as defined above. The 'receptor' is groundwater, and the 'pathway' represents the means by which the receptor could be exposed to the hazard. For harm (groundwater pollution) to occur there must be a source and an active pathway. Groundwater can be protected by:
- removing the source – for example, by removing contaminated soil;
- breaking the linkage between source and receptor– that is, by blocking the potential pathways. An example would be using an engineered lining system under a landfill.

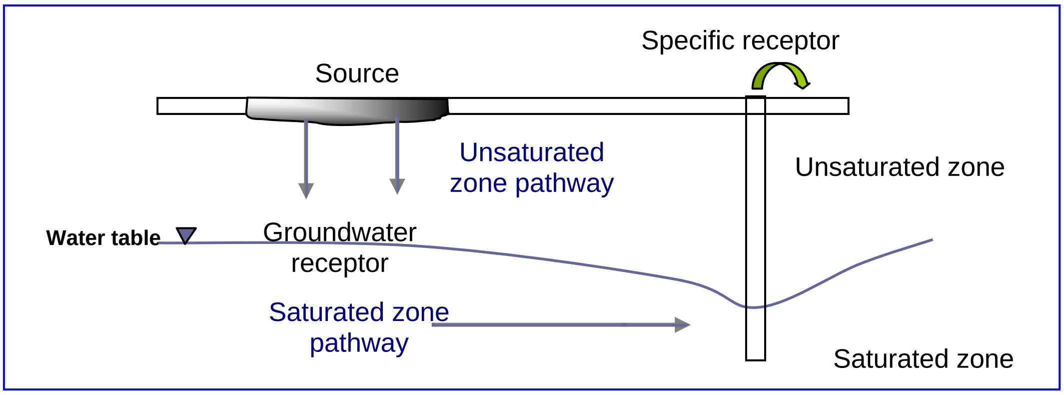


Figure 5-1 The concept of source-pathway-receptor

Sensitivity analysis is an important tool in risk assessment. It looks at how the parameters used in the risk assessment are likely to vary. These parameters could be ranges in water levels, chemical concentrations of source pollutants, aquifer properties etc. Such analysis allows us to understand how different sources of uncertainty contribute to the overall variability of the final risk estimates used. It gives a credible basis for decision-making.

Because of the complexity of the natural environment, conducting a full risk assessment can often be very time-consuming. A pragmatic approach to environmental risk assessment can turn an extremely detailed, complex and resource-intensive process into a practical aid for decision-making.

5.2. Tiered approach

The Guidelines for Environmental Risk Assessment and Management (DETR (2000)) provide a framework for a tiered approach to environmental risk assessment and management. This balances the cost, time and effort in conducting risk assessment with the cost, time and effort of measures to make the risk acceptable. The framework is built around three tiers of increasing complexity. It starts with risk screening in Tier 1, proceeds to generic quantitative risk assessment in Tier 2, and, if necessary, goes on to detailed quantitative risk assessment in Tier 3. Many of the risk assessment tools described in Part 3 of the GP3 adopt a tiered approach.

Within each tier of risk assessment, there should be five key stages, as follows:

Stage 1: Hazard identification. The identification of hazards has an important bearing on the breadth of the overall assessment and the credibility of the final output.

Stage 2: Identification of the consequences. Those carrying out the monitoring must consider the full range of potential consequences, before making judgements on their magnitude, probability and significance. A broad look at the environmental damage that may occur is essential, if only to be clear as to why some potential consequences are not assessed further.

Stage 3: Estimation of the magnitude of the consequences: this can be determined differently at different tiers, but should consider the scale of the consequences over time and area, as well as the time until the consequences become apparent. For example, a single small spill of a solvent on porous ground may have less impact than a slow leak over an extended period of time. In both cases the spillage may not result in an impact on the underlying aquifer for many years.

Stage 4: Estimation of the probability of the consequences. This has three components: the probability of the hazard occurring; the probability of the receptors being exposed to the hazard; and the probability of harm resulting from exposure to the hazard. At a screening level, the estimation of the probabilities may be as simple as allocating, on the basis of experience or professional judgement, a score on a scale of 1 to 5. At higher tiers of risk assessment, if enough data is available, the estimation may take the form of full statistical analyses and the combination of individual probabilities.

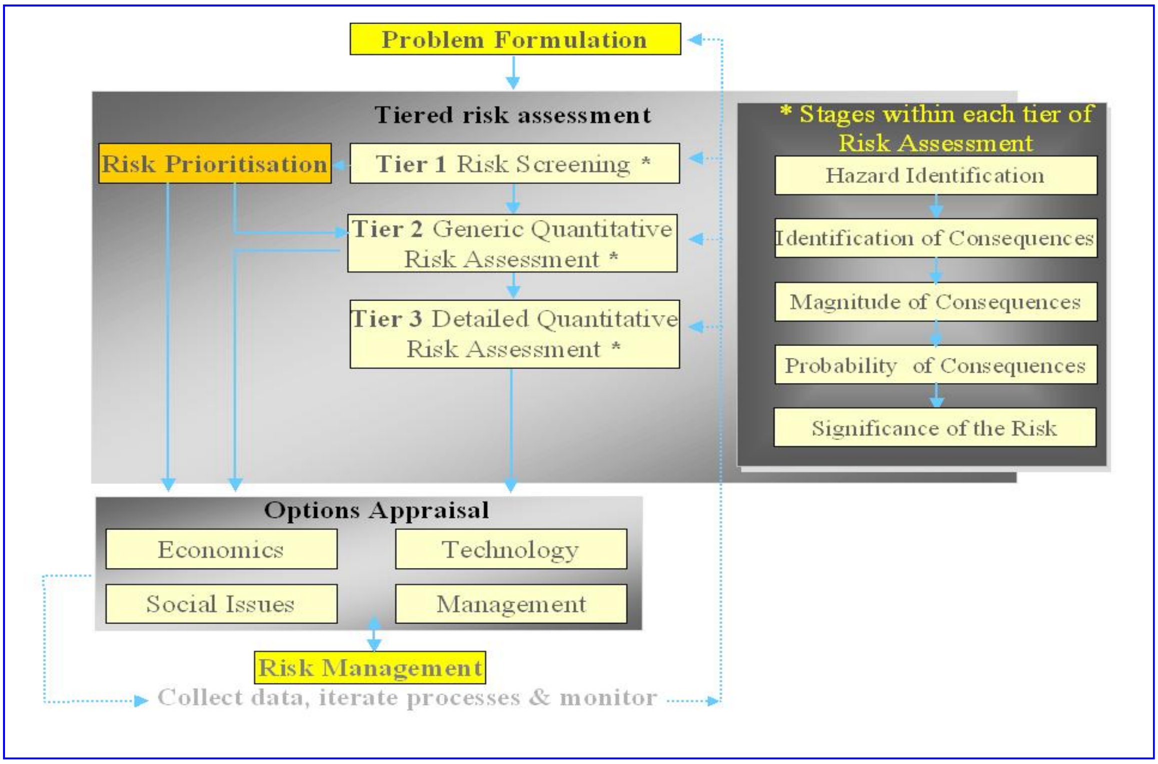


Figure 5-2 Our approach at the Environment Agency to tiered risk assessment based on DETR EA, IEH 'Guidelines for environmental risk assessment and management'

Stage 5: Evaluating the significance of the risk. It is important to place the probability and magnitude of the consequences in some sort of context. Value judgements may have to be made. These might refer to some pre-existing measure – such as a toxicological threshold or environmental quality standard. Alternatively, they could refer to social, ethical, or political standards.

Once the risk assessment is completed, the next step is to identify and evaluate options for risk management. The options will usually be along the following lines:

- Exploring with interested parties the acceptability or otherwise of the risk. This may involve rejecting unacceptable risks altogether, or accepting the risk being imposed.
- Reducing the hazard, for example by taking engineering measures or using alternative, less hazardous materials.
- Mitigating the effects, through improved environmental management techniques.

The decision on which option or combination of options to choose will take account of risk reduction, costs, benefits and social considerations.

5.3. Groundwater vulnerability

5.3.1. Concept of groundwater vulnerability

When we assess groundwater vulnerability, our aim is to evaluate how susceptible groundwater resources are to pollution from various activities. The pollution hazard from an activity will be greater in certain hydrological, geological and soil situations than in others. When we look at the level of risk from any given activity and want to make judgements about its acceptability, we have to assess the total exposure of the groundwater system to that hazard. Vulnerability is usually a significant element of the risk assessment. There are two types of vulnerability that we can consider.

The *intrinsic vulnerability* of a location depends on a number of factors, including the soil type, presence of drift, and the characteristics of the rock (See Figure 5-3). This can be mapped with varying precision depending on the availability of relevant data (soil and geological maps, borehole information etc).

The *specific vulnerability* of a location takes into account additional factors. These include the nature of the activity under scrutiny and the characteristics of the contaminant that is posing a threat to groundwater. In this case we may also consider the removal or bypass of soil or drift and the unsaturated zone.

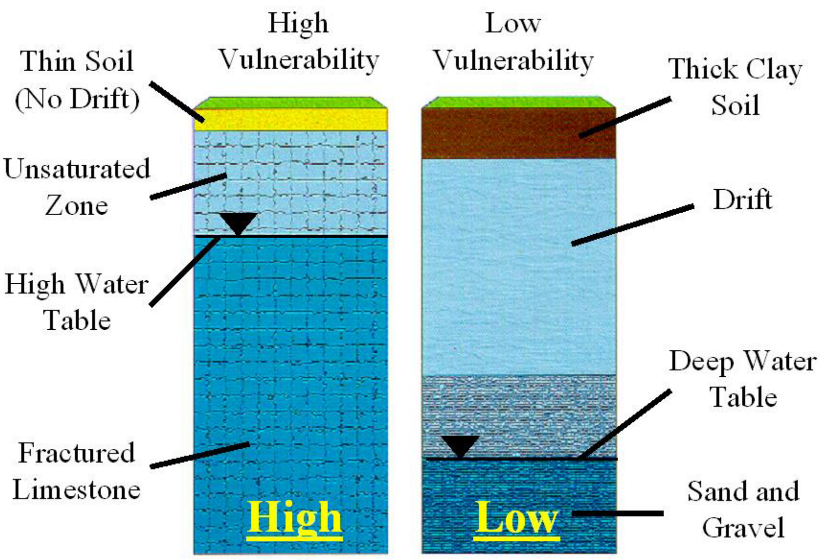


Figure 5-3 Illustrated vulnerability
(UK Groundwater Forum)

In sumary the key factors that define the vulnerability of groundwater are:

- the presence and nature of overlying soil;
- the presence and nature of drift;
- the nature of the geological strata;
- the depth of the unsaturated zone.

5.3.2. Existing maps of groundwater vulnerability

We produce digital maps of groundwater vulnerability. These are based on printed maps originally developed for strategic land use planning. The maps use existing geological and soil maps and databases held by the British Geological Survey and the National Soil Research Institute.

One of the main purposes of the maps was to increase general public awareness of the location of the groundwater resources at risk. The current version of the maps are available only as digital files. They cover England and Wales at a scale of 1:100,000 (See Figure 5-4).

We produced the groundwater vulnerability maps to aid developers who were planning new activities, and planners who were assessing new proposals or drawing up development plans. However, the maps are only a screening tool. Site-specific studies will *always* be needed for the assessment of detailed proposals beyond the screening stage.

The maps relate mostly to activities taking place on the surface. Many development activities result in the partial or total removal of the soil layer. In these cases the vulnerability classification on the published maps is irrelevant. Quarrying, landfill, road building, large scale building works, and mining are examples of activities that may invalidate the vulnerability shown on these maps. If you are using the maps, you should assume that the contaminant is relatively conservative i.e. not rapidly neutralised or absorbed onto soil or rock, and that it will only be attenuated to a limited extent in the unsaturated zone. There is a guide to the use of these vulnerability maps which has more information (NRA (1995a)).

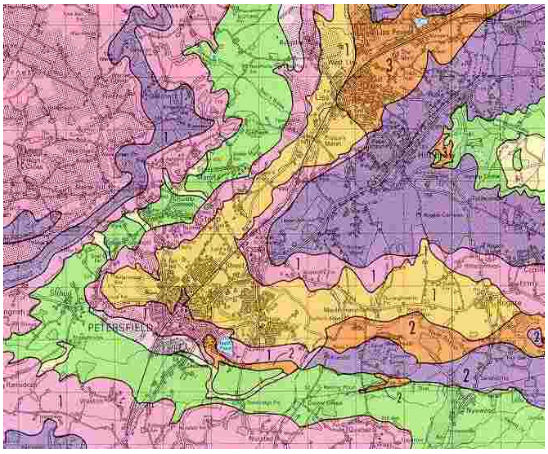


Figure 5-4 Extract from a groundwater vulnerability map (© Crown copyright. All rights reserved)

In the original maps, soil and drift mapping only took place over major and minor aquifers. The maps also contain a category called ‘non-aquifer’ for which the soils and drift were not specified. A further development of the digital data set is now available that extends the vulnerability mapping over the old ‘non-aquifer’ area.

5.3.3. New approach to vulnerability assessment

The Water Framework Directive has more stringent requirements. It is no longer sufficient to use the major, minor and non-aquifer designations, as described in the original *Policy and Practice for the Protection of Groundwater* and the associated vulnerability maps. The Directive requires us to define groundwater bodies on the basis of their support for ecosystems as well as for their capacity to supply drinking water. It is now recognised that the term non-aquifer can be misleading: some of these aquifers are permeable and can provide useful local water supplies and significant support to surface ecosystems.

We are now developing a new and more sophisticated approach to assessing groundwater vulnerability. This has a framework that considers both the physical movement of water and the movement of contaminants through the various layers of soil, drift and solid strata. It uses tools based on a Geographical Information System (GIS) and draws on the wider range of data sets now available. The new approach will allow an initial assessment of intrinsic and activity-specific vulnerability, both at a point or across an area. It will be able to assess the data and see the assumptions upon which the assessment is made. Aquifers will be reclassified into units that are compatible with the Water Framework Directive.

The nomenclature of aquifers will also change. We will in future refer to principal aquifers, secondary aquifers and unproductive strata derived from the importance of these aquifers in terms of groundwater as a resource that supports both abstraction and support to ecosystems etc. The current designations of major and minor aquifer will largely transfer across to principal and secondary. However some of the aquifers currently designated as non-aquifers will be subdivided into secondary aquifers and unproductive strata.

This new vulnerability framework has been developed because the Water Framework Directive requires us to take a more flexible approach. We will now be able to assess the impact of a wider variety of activities on a wider range of environmental objectives. We will be able to apply this approach in the varying hydrogeological conditions found across England and Wales and at different levels of detail.

5.4. Source Protection Zones

The previous sections show how all groundwater is vulnerable, whether it is exploited or not. Both European and national legislation require the protection and management of all groundwater, regardless of whether it is currently used, or how it is currently used. This is referred to as *groundwater resource protection*.

However, there is a distinction between this general protection and the specific protection that may be appropriate for individual sources – such as springs, wells and boreholes. The abstraction of groundwater modifies the natural flow regime in the aquifer. Depending on the amount of data available, it may be possible to define the source catchment area. This is the total area of land needed to support removal of water from the borehole. Protecting this area can be described as *groundwater source protection*, and it requires the definition of *Source Protection Zones* (SPZs).

Generally the closer a polluting activity or release is to a groundwater source the greater the risk of pollution. All groundwater abstraction sources may be liable to contamination and society needs to protect them. The major public water supplies are however a priority. To protect them we define zones for those sources and other major potable uses such as brewing. Of the estimated 100,000 groundwater abstractions in England and Wales, there are nearly 2,000 major public and food production supply sources with bespoke SPZs. Most of these are sources producing more than 500,000 litres a day. Other sources providing water intended for human consumption are given a default SPZ1 of radius 50m centred on the abstraction point.

Each zone has three subdivisions for each source (EA (1996)), moving out from the source these are:

- Zone I (Inner Source Protection);
- Zone II (Outer Source Protection);
- Zone III (Source Catchment).

An example of source protection zones is shown in Figure 5-5 overleaf.

Moving from Zone III the outermost, to Zone I we impose greater restrictions on activities and discharges to protect the abstraction.

An additional ‘Zone of Special Interest’ is defined in some areas. These zones highlight areas 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. These would include, for example, areas where solution features are known or are likely to exist and areas where run-off flows into rivers which "sink" down swallow holes within the catchment zone of the source.

The hydrogeological characteristics of the strata and the direction of groundwater flow determine the orientation, shape and size of the zones. In common with the groundwater vulnerability maps, SPZs are not currently statutory. However, we will use them to assist in our implementation of certain legislation and refer to them in our position and policy statements.

More details on SPZs are given in Part 3 of the GP3.

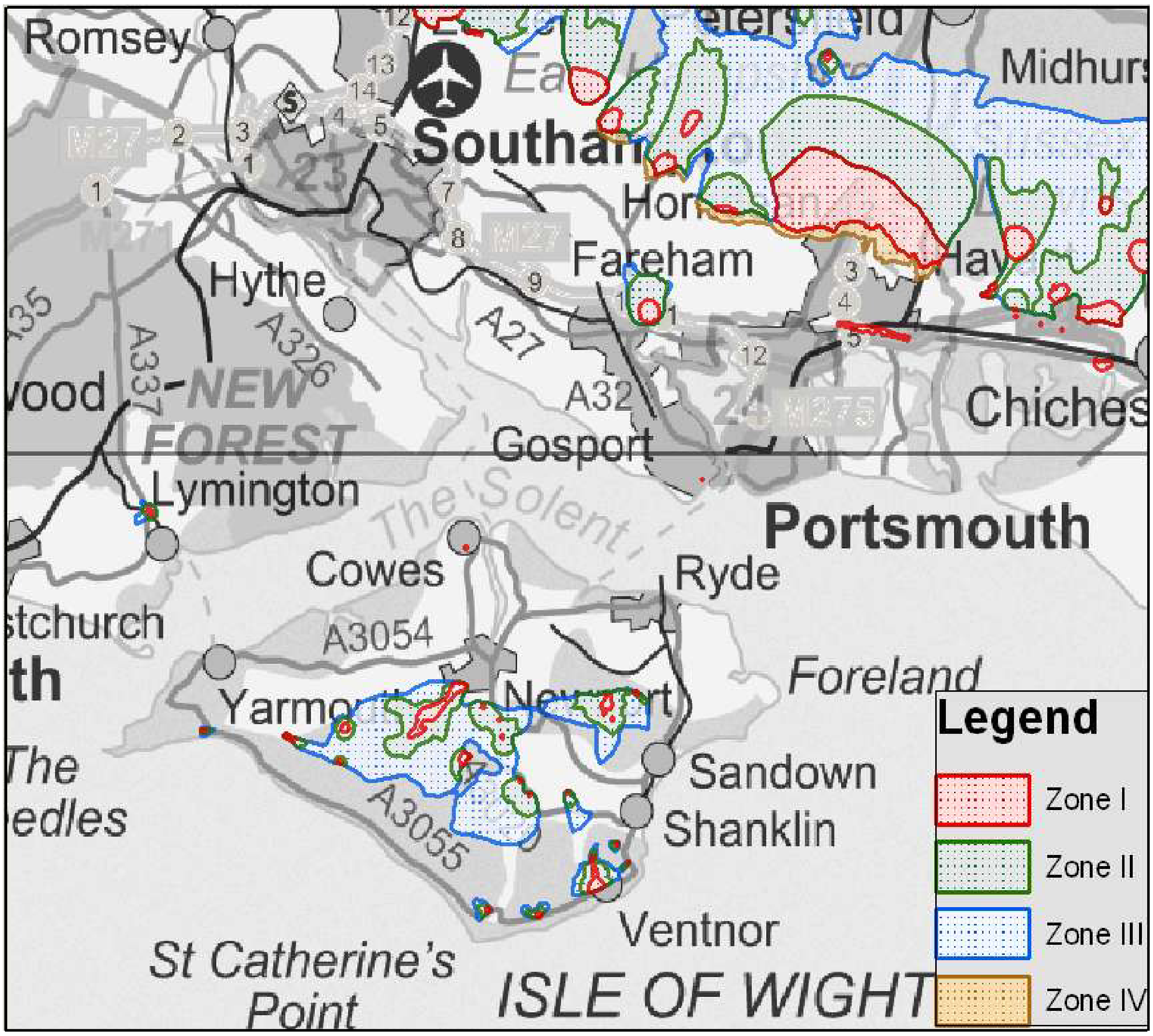


Figure 5-5 Example map illustrating some of the source protection zones in Hampshire and on the Isle of Wight (© Crown copyright. All rights reserved)

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Annex 1. Pollutants

This annex gives some basic information on the important and most commonly detected pollutants in groundwater. Each of the following sections explains what the pollutant is, some of its properties and why it is of concern for groundwater.

A.1. Nitrate and ammonia

Nitrate is a soluble compound of nitrogen and oxygen. It occurs naturally in the soil. It is the main form of nitrogen taken up by plants as an essential nutrient. Farmers maximise crop yields by applying nitrogen and other nutrients in the form of chemical fertilisers or livestock manure. Nitrate is also produced when soil processes break down the organic matter left over from crops such as potatoes or when grassland is ploughed up. Whatever the source, any nitrate not used by the plants is susceptible to leaching from the soil into groundwater. This usually happens during autumn and winter rainfall.

There are two main concerns about nitrates in groundwater. Firstly, high nitrate concentrations in drinking water can cause a serious blood condition in young babies. This is extremely rare though, and no cases have been recorded in the UK since 1972. To protect against this and other potential health problems, water companies must not supply drinking water with more than 50 mg/l of nitrate. This is the drinking water limit. Secondly, high nitrate concentrations are believed to contribute to the eutrophication of some surface waters. Eutrophication refers to the over-enrichment of waters with mineral and organic nutrients. These can promote a proliferation of plant life – especially algae, which reduces the dissolved oxygen content and often causes the extinction of other organisms. 50mg/l is the action level set by the Nitrates Directive for the designation of Nitrate Vulnerable Zones and the implementation of action plans to prevent eutrophication and pollution of surface waters and groundwater.

Nitrate concentrations are continuing to rise in many aquifers across England and Wales. This is a major concern. If farmers and others applying nitrates to the ground do not substantially change their current land use practices, we estimate that the drinking water limit of 50 mg/l will be breached in many more aquifers in the coming decades. The Nitrates and Water Framework Directives require the UK to reverse such rising nitrate trends.

Ammonia is a nitrogen and hydrogen compound. It is very soluble in water and toxic, especially to fish. In water ammonia exists as two species – unionised ammonia NH_3 and the ammonium ion NH_4^+. Unionised ammonia is the more toxic form. The drinking water limit for total ammonia (ammonia and ammonium) is 0.5 mg/l. This level is indicative of generally low quality or polluted water. Also reaction between ammonia and chlorine can reduce the disinfecting action of the chlorine when used for safeguarding drinking water. Toxic effects of nitrate on mammals only happen at a concentration significantly higher than 50mg/l, hence the 50mg/l drinking water limit. Fish however, begin to show problems when ammonia is present even at sub 0.1 mg/l concentrations (Fresh Water Fish Directive guideline value is 0.005 mg/l unionised ammonia).

The Groundwater Regulations classify ammonia as a List II substance. This means it must be limited in groundwater so that it does not cause pollution.

Most animals, plants and bacteria produce ammonia as a result of metabolic processes including the breakdown of organic matter. It is present at significant concentrations in sewage, manure, farm slurries, silage liquors and in the leachate (complex solution of water and other substances) found in landfill sites. Waste disposal – landfill in particular – needs controls to ensure that water quality standards are not breached. Landfill leachate can have ammonium concentrations in excess of 2000 mg/l. This may cause groundwater pollution and seriously compromise drinking water quality or harm fish if it discharges into a stream. Also, if ammonia is oxidised (or nitrified) in the ground it often becomes an additional source of nitrate.

A.2. Hydrocarbons

Hydrocarbon is a general term for a large family of organic compounds that consist solely of carbon and hydrogen atoms. Hydrocarbons include common substances such as benzene, petrol, paraffin, diesel, lubricating oil, greases, naphthalene and asphalt. They are in widespread use. They often exist in a great variety of complex mixtures, which can break down into other mixtures or single substances. Some hydrocarbons frequently contaminate groundwater. Examples include petrol from leaking tanks at filling stations and polycyclic aromatic hydrocarbons (PAHs) in the run-off from roads. Petrol and diesel leaks are usually point source pollution problems. PAHs represent a serious threat of diffuse pollution to the water environment. In theory, microbes can degrade many hydrocarbons to carbon dioxide and water under aerobic conditions. However, suitable conditions are often not present in groundwater. Hydrocarbons are classified as List I substances under the Groundwater Regulations and persistent hydrocarbons are Main Pollutants under the Water Framework Directive (2000/60/EC). Both directives prohibit the direct discharge of such hydrocarbons to groundwater.

Although not strictly hydrocarbons, fuel additives such as methyl tertiary butyl ether (MTBE) have recently gained a high profile. MTBE and other ether oxygenates (TAME, ETBE, etc) were developed to enhance the performance characteristics of unleaded petrol. However, they also represent a significant threat to groundwater quality, because of their solubility, mobility, poor bio-degradability, and low taste threshold. However, a recent R&D study (EA (2000c)) concluded that as long as the MTBE concentration in UK fuel does not significantly increase, the problem in the UK is manageable. The problem is greater in the USA where the MTBE concentration in petrol is much higher. MTBE is a good example of a substance that is not a particular issue in surface water because of its degradability, but is an issue in groundwater.

Motor fuels are undergoing rapid evolution. New additives may present as yet unforeseen risks to groundwater. These include biofuels and additives (ETBE can be produced from non oil sources) and ethanol.

Petrol delivery to filling station – hydrocarbons present a risk to groundwater both in the their transport and storage

A.3. Pesticides

Pesticides are chemicals used to control or destroy pests. They include insecticides, herbicides, fungicides and substances such as timber preservatives. The Department for Environment Food and Rural Affairs (Defra) and the Health and Safety Executive (HSE) have approved several hundred chemical products for use as pesticides and biocides (PSD (2001)). The bulk of pesticides are used in agriculture and horticulture, but they are also widely used in industry, in transport (to keep roads and railways weed-free), and in the home. By their very nature pesticides are toxic to living organisms. Although their chemical and physical characteristics vary greatly, many pesticides can easily pollute water. Part of the risk from pesticides is the level of their persistence in the environment. Some pesticides are highly persistent. Although others readily degrade, the breakdown products may occasionally be toxic.

Serious incidents of groundwater pollution due to pesticides are rare - they make up fewer than 1% of recorded pollution incidents). However, when they do occur they can cause severe environmental damage. As we become better at detection, we are identifying a wide range of pesticides in many groundwater supplies prior to treatment. In order to meet drinking water standards, water companies in many parts of England and Wales now face substantial costs from removing pesticides.

The Biocides and Plant Protection Products Directives require companies who currently produce or develop new pesticides to submit them to an approval process. This includes examining the risk to groundwater. PSD and HSE then either approve possibly with conditions, or refuse the use of the pesticide. The risk of groundwater pollution, is a factor in the approval process and may mean that conditions on use are applied or in high-risk cases lead to refuse of approval.

We have evidence that over time the approvals process and the restrictions on use are reducing pollution by pesticides. There remains a risk of groundwater pollution however and work needs to continue in this area. Our main concern now is dealing with pesticides that are still causing problems such as the use and disposal of sheep dip. These compounds are not subject to the approvals process described above, and are still the cause of too many pollution incidents that are mainly as a result of inappropriate use or disposal practices.
For further information see our pesticides report

A.4. Solvents

Solvents are liquid chemicals that are good at dissolving other substances. They are widely used in industrial processes, for example in the extraction or purification of other chemicals, for degreasing metal components, and as the fluid in dry cleaning. They are also the basis of many paints, varnishes, adhesives and cleaning products – many have the ability to dissolve oils, greases and fats. When we talk about groundwater pollution, the word solvent often refers to chlorinated hydrocarbons. These are denser than water (DNAPLs) so that, if they are present in sufficient quantity, they may migrate vertically downward through an aquifer. However, they are also soluble in water, and can therefore migrate as a dissolved phase with flowing groundwater. The complexities of dealing with solvents, which are mostly NAPLs, are described above (Section 2.4.1). Many solvents are persistent in groundwater. Their toxicity and complex behaviour in groundwater make this class of pollutants difficult to assess and clean up.

A.5. Pharmaceuticals and endocrine disrupters

Pharmaceuticals represent a large and ever-increasing number of substances. This group of substances also includes veterinary medicines such as sheep dip and antibiotics. They can reach groundwater via industrial discharges from manufacturing or research facilities or from animal wastes, or via on farm disposal. They are also present in sewage effluents, septic tank discharges, and in domestic waste. They are difficult to detect routinely, partly because of the large number of substances and the generally low concentrations. With the possible exception of those substances that are also approved pesticides (see above), the effects of their presence in groundwater are poorly understood.

The active ingredients from medicines can get into groundwater

Some pharmaceutical substances and chemicals used in industry are endocrine disrupters. These are natural and synthetic substances that can affect the normal functioning of the endocrine (hormone) systems.

Sources of these substances include agricultural pesticide use; industrial processes such as timber treatment; improper disposal of electrical transformers; and surfactants. A common route into the environment is through discharges to sewers. If these sewers leak, these substances could end up in groundwater.

We are unlikely to see problems due simply to the presence of these substances in groundwater. Effects may be seen at borehole abstractions, springs or where groundwater is entering rivers. These chemicals may then affect people or animals.

Our approach to these substances is based on preventing releases to the environment. (EA (2000d)).

A.6. Microbiological contaminants

Traditionally, scientists looking at groundwater quality have focused on natural hydrochemistry and chemical contamination. It is only relatively recently that microbiological contamination by pathogens has come into the spotlight. As a result there is relatively little published work on this subject. From the human health perspective, groundwater is well-known for its good microbiological quality. Most microbiological pollutants derive from land-based activities and are filtered out or die off as water moves down to the watertable. Some types of geology are more at risk from microbiological pollution – for example, fissured strata are more at risk due to rapid flow to and within the saturated zone. Possible sources of such pollution include: septic tanks, disposal of farm waste, municipal landfills, sewage sludge handling, leaking sewers, and recharge from rivers containing sewage effluent. Viruses are generally smaller than bacteria and are not so readily filtered out. Little is known about their survival in groundwater environments. Some can be persistent and could potentially travel a considerable distance in groundwater.

Cryptosporidium is relatively common in the natural environment and represents a routine risk to water quality. *E.coli* is also an important contaminant. The BSE (Bovine Spongiform Encephalopathy) prion and FMD (Foot and Mouth Disease) virus could be a risk to water supplies in an emergency such as an epidemic that resulted in the need for mass burial of infected carcasses. However, there is no evidence of their routine presence in groundwater.

A.7. Radioactive substances

Radioactive contaminants come from man-made and natural sources. Radioactive elements from human activities can enter the environment as a result of discharges during the nuclear fuel cycle, from weapons production or, from research. These include plutonium-239, americium-243, strontium-90 and caesium-137. These can potentially pollute groundwater if there are leaks or spills from nuclear facilities, or from high-level and intermediate-level nuclear disposal operations. Such facilities are closely regulated and covered by radioactive substances legislation. Nuclear weapons testing has also produced diffuse pollution by radiogenic substances.

Some radionuclides have become widely dispersed around the globe. One example is tritium (hydrogen-3). This radionuclide has a low radiotoxicity and a relatively short radioactive half-life (12.3 years). It is commonly found in low concentrations due to its production during atmospheric nuclear weapons testing in the 1950s and 60s, but may also be released from nuclear facilities. Tritium concentrations are now returning to background levels (1-5 Tritium Units) making groundwater dating using Tritium difficult. It is possible for scientists to use the Tritium:Helium-3 ratio to date groundwater recharged in the last 30 years[1]. There are also many radioactive isotopes used in domestic appliances, such as smoke detectors. The use of radioactive sources in domestic products in closely controlled, but they do find their way into the waste stream. As a result, low levels of radioactivity are found in some landfill leachates.

Radioactive isotopes of many elements exist naturally and can present a risk to people. In groundwater, the best known is radon-222 (^{222}Rn). Radon-222 is a daughter product of the breakdown of uranium-238. Naturally occurring uranium 238 is found most commonly in granite rock, and in a variety of other minerals found in many different types of rock. This means that radon-222 can be found in many different areas, not just those underlain by granite, as in Devon and Cornwall. Radon is a gas and can dissolve in groundwater flowing through suitable source rocks. The groundwater can then release the gas in confined spaces such as houses, where the gas may accumulate if no precautions are taken to vent it, although in many cases this is not the major source of radon build up. Radon degasses easily from water, and therefore it is not usually considered to be a problem in terms of drinking water.

[1] USGS Toxic Substances Hydrology Program Definitions: Tritium
http://toxics.usgs.gov/definitions/tritium.html

A.8. Thermal pollution

The temperature of liquids people discharge to groundwater can cause pollution. This factor is in addition to the chemical and microbiological composition of the discharge. Water that is otherwise clean can cause pollution if it is hot. (Heat is a pollutant under the Water Framework Directive.) One impact heat can have is to cause extra growth of indigenous organisms that are potentially pathogenic, when otherwise, the temperature would have been too low for them to survive, e.g. *Legionella pneumophila*, the cause of legionnaires' disease. The most common sources of heat pollution in groundwater are the discharge of cooling water and hot industrial effluents. Ground source heat pumps are also now increasing in popularity. These either extract heat from groundwater for space heating or heat it up by using groundwater for cooling. The cooling of groundwater by heat pumps can also cause problems. The groundwater may freeze or cold water may impact on other users or environmental receptors.

A.9. Metals

Impact of mining on groundwater

Mining activity is now minimal in the UK. However, the legacy from the past mining of coal and metals still poses a threat to groundwater and surface water. The main sources of pollutants from mining are:

- metal-contaminated water from the rebound of groundwater depressed by pumping;
- leaching of metals from spoil heaps (waste rock piles) into surface and groundwater.

The main pollutants include iron, zinc, lead, cadmium, manganese, copper and acidity (low pH). These contaminants are released when oxygen in the air reacts with minerals in the rock found near coal seams and mineral veins. The metals are then dissolved in the returning groundwater, or by rain in the case of spoil heaps.

Mining has taken place in the British Isles since the Bronze Age. It has always been associated with pollution. This long history is reflected in place names such as *Redruth* and the *Red River* in Cornwall, and *Afon Goch Amlwch* (red river) on Anglesey, Wales. Pollution from mining activities is difficult to deal with because of the length of time over which discharges can persist. Also, because mining invariably disturbs land on a large scale, it causes diffuse pollution. This is irrespective of whether it is opencast, deep mining, or spoil dumping.

There are many areas where groundwater and surface water are susceptible to pollution from historic metal and coal mining. Examples of potential or actual pollution from mining can be found in northern and western England, Wales and Kent but there may be a pollution risk wherever there has been mining.

Figure 6-1 Discharge of ferruginous mine water (groundwater) to river (Professor Paul Younger, University of Newcastle)

The dewatering of deep mines to allow mineral extraction lowered groundwater levels, sometimes by hundreds of metres. Groundwater in many of the coalfields has been depressed since the nineteenth century. When mining stops, the pumps used to keep the mines dry are turned off. The subsequent rise in groundwater (rebound) can cause flooding. Oxidised minerals dissolve into the groundwater as it rises back into the dewatered levels. This leads to high concentrations of metals (particularly iron) and sulphate in the rising groundwater. The result is the pollution of many square kilometres of groundwater. This groundwater can subsequently discharge to surface waters or overlying aquifers. The effects of iron-rich groundwater discharging to rivers are shown in Figure 6-1.

Other sources of metals

Metals may also enter groundwater from other sources. The use of inorganic fertilisers such as rock phosphate can introduce cadmium into the soil. This may leach into groundwater. Cadmium concentrations in phosphate fertilisers are lower now than in the 1980s but still remain a concern.

Land contamination is another potential source of metal pollution. Industrial activity is the usual reason for the presence of potentially polluting levels of metals in land. Examples of such activity are steel works, foundries, lead smelters and similar heavy industries. Metal pollution is difficult to deal with in a sustainable way. Metals do not degrade naturally. For example, copper oxide may react and become copper sulphate but the copper is still present. The upside is that many metals become bound to material in the soil or rock. This means that they do not move and pollute groundwater. However, the risk of groundwater pollution does increase if the ground is disturbed – for example during redevelopment.

Finally, metals are naturally present in the rocks forming aquifers. These metals will also naturally occur in the groundwater, although not normally in high enough amounts to cause a problem. However, in some cases dissolved metal concentrations can cause problems. For example, naturally occurring iron and manganese in some areas cause clogging, discolouration and taste problems. This is most common in sandstone or interlayered aquifers. Human activities, groundwater pumping, or effluent discharges for example, can also cause naturally occurring metals to become mobilised. Changes due to introduction of oxygen or changes in acidity can allow metals to become soluble and to move into the groundwater. A well known example is the case of mine water pumping above. Here, air in the open mine tunnels oxidises pyrite leading to mobilisation of metals when the mine water pumping stops and groundwater returns.

A.10. Other pollutants

There are other substances that can threaten groundwater quality. Some examples of those that have caused groundwater pollution or are of concern include:

- industrial chemicals such as bromate;
- fire-fighting foams containing hazardous substances such as PFOS (perfluorooctane sulphonate);
- naturally occurring substances that are mobilised by human activity so they present a hazard, such as arsenic.

7. Glossary

A

Aquifer	a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater (Water Framework Directive, 2000).
Abstraction	removal of water from surface water or groundwater, usually by pumping.
Abstraction Licence	a licence issued by the Environment Agency under the Water Resources Act 1991 to permit water to be abstracted.
Adsorption	process by which a thin layer of a substance accumulates on the surface of a solid substance.
Artesian flow	overflow of groundwater where water rises under pressure above the top of the aquifer.
Attenuation	break down or dilution of a contaminant.

B

Baseflow	that part of the flow in a watercourse made up of groundwater and discharges. It sustains the watercourse in dry weather.
Baseline quality	is the concentration of a given element, species or chemical substance present in solution which is derived from natural geological, biological, or atmospheric sources'.

C

Cesspit/pool	sealed tank used to collect sewage. It has no outlet and requires periodic emptying.
Confined	where permeable strata are covered by a substantial depth of impermeable strata such that the cover prevents infiltration.
Conservative pollutants	pollutants which can move readily through the aquifer with little reaction with the rock matrix and which are unaffected by biodegration (eg chloride).
Contamination	with respect to groundwater is the presence of substances or heat above the normal natural background. For contamination due to anthropogenic influences this is below a level where harm may occur and therefore is not causing pollution (pollution is described in water legislation as harm from substances or heat arising from human activity). Where elevated concentrations of naturally occurring substances in groundwater have the potential to cause harm but are not due to human activity there is contamination but no pollution.

Controlled Waste	defined by Environmental Protection Act 1990, S.75. It includes household industrial and commercial waste.
Controlled Waters	defined by Water Resources Act 1991 S.104. They include all groundwaters and inland waters and estuaries.

D

Dedicated Land	land used for spreading sewage sludge above the normal requirements for agricultural use.
Degradable pollutants	pollutants which readily, break down. delayed yield, 6.
Derogation	term used for loss of water resources or deterioration in water quality (usually relating to a particular source).
Diffuse source pollution	pollution from widespread activities with no one discrete source.
Discharge Consent	a consent issued by the Environment Agency under Water Resources. Act 1991, Sch. 10.
DNAPL	Dense non aqueous phase liquid. Liquids that are immiscible with and denser than water.
Drift Deposits	term used to include all unconsolidated superficial deposits (eg. fluvioglacial, alluvium etc) overlying solid rocks.
Dual porosity aquifers	an aquifer with primary intergranular porosity in rock matrix and secondary permeability due to fractures or solution features.

E

Effective porosity	that part of the total porosity which can transmit water.
Effective rainfall	proportion of rainfall that can infiltrate to an aquifer after evapotranspiration.

F

Formation	term used to describe a sequence of rock layers.
Fractures/fissures	natural cracks in rocks that enhance rapid water movement.
Fissure flow	groundwater movement through fissures rather than between grains in the rock. There may be a combination of fissure and intergranular flow in some aquifers.

G

Groundwater	all water which is below the surface of the ground in the saturation zone *(below the water table)* and in direct contact with the ground or subsoil (Groundwater Directive, 1980 and Water Framework Directive, 2000).

H

Hydrogeological characteristics	properties relating to flow of water through rock eg. permeability, transmissivity, porosity etc.
Hydrological cycle	circulation of the earth's water in atmosphere, surface water, oceans and groundwater and their relationship.
Hydraulic conductivity	a measure of the ability of a material (usually a geologic strata) to transmit water. It is effectively a measure of how well pore spaces are interconnected.
Hyporheic zone	a complex area of enhanced biological and geochemical activity at the interface between groundwater and surface water.

I

Intergranular flow	groundwater flow between individual grains of rock. In some aquifers there may be an combination of intergranular and fissure flow.
Intrinsic vulnerability	the vulnerability of groundwater to pollution from activities at the undisturbed ground surface.
Intergranular permeability	see primary permeability.

L

Landfill site	used for waste disposal into/onto land.
Leachate liquor	formed by the act of leaching.
Leaching	removal of soluble substances by action of water percolating through soil, waste or rock.
List I and II substances	groups of substances that must not cause groundwater pollution as defined by Groundwater Regulations 1998.
LNAPL	light non aqueous phase liquid. Liquids that are immiscible with and less dense than water.

N

NAPL	non aqueous phase liquid. Liquids that are immiscible with water.
Natural attenuation	naturally occurring subsurface processes that reduce the mass, toxicity, volume or concentration of organic and inorganic contaminants in both the unsaturated and saturated zones.
Non-degradable pollutants	pollutants that do no readily break down.

O

Outcrop	where strata are at the surface, even through they may be obscured by soil cover.

P

Primary permeability	permeability related to flow between grains within the aquifer.
Prohibition notice	a notice served under Water Resources Act 1991, S.86 to prevent or control a discharge of effluent. May also refer to a notice served under Regulation 19 of the Groundwater Regulations to prohibit or control indirect discharges of substances in List I or List II.
Perched Water Table	water level supported by low permeability layer above main water table.
Permeability	the ability of a material to transmit a fluid. In geology, usually the ability of a rock to transmit water.
Point Source Pollution	pollution from a discrete source eg. petrol station, septic tank, landfill.
Porosity	ratio of volume of void space to the total volume of the rock.
Porous	having microscopic pores between the rock grains (not necessarily interconnected).
Potable Water	see water intended for human consumption.
Permeable	a material that will allow the transmission of a fluid.
Pollutant	any substance liable to cause pollution (Water Framework Directive 2000/60/EC).
Pollution	the direct or indirect introduction, as a result of human activity, of substances or heat into the air, water or land which may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems, which result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment (Water Framework Directive 2000/60/EC).
Principal aquifer	geological strata that exhibit high permeability and usually provide a high level of water storage. They are capable of supporting water supply on a strategic scale and are often of major importance to river base flow (formerly known as major aquifer).

R

Recharge	water which percolates downward from the surface into groundwater.
Rehabilitation	restoring good quality by natural or artificial means.
River augmentation	the use of groundwater to support river flows.

S

Saturated zone	zone of aquifer where all fissures and pores contain water (ie below water table).
Secondary aquifer	a wide range of geological strata with a correspondingly wide range of permeability and storage. Depending on the specific geology, these subdivide into permeable formations capable of supporting small to moderate water supplies and baseflows to some rivers, and those with generally low permeability but with some localised resource potential. (Includes the former minor aquifers but also some of the former non-aquifers).
Secondary permeability	permeability related to groundwater flow within fissures rather than between grains (see Primary Permeability).
Septic tank	small tank receiving and treating sewage by bacteria where effluent overflows.
Soakaway	system for allowing water or effluent to soak into the ground, commonly used in conjunction with septic tanks.
Source	point of abstraction of water eg. well, borehole, spring.
Specific vulnerability	considers the nature of the activity under scrutiny and the characteristics of the contaminant that is posing a threat to groundwater and may also consider the removal or bypass of soil or drift and the unsaturated zone, cf intrinsic vulnerability.
Spring	natural emergence of groundwater at surface.
Strata	layers of rock, including unconsolidated materials such as sands and gravels.

T

Trade effluent	effluent derived from a commercial process/premises.
Transfer station	waste disposal facility where waste is collected prior to transport to final disposal point.
The precautionary principle	Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation. (Securing the Future - UK Government sustainable development strategy Defra (formerly DETR) 1999).

U

Unproductive strata	these are geological strata with low permeability that have negligible significance for water supply or river base flow (formerly formed part of the non-aquifers).
Unsaturated zone	zone of aquifer between soil and watertable which is partly saturated (ie that part of the aquifer above the watertable).

W

Water intended for human consumption

means:

(a) all water either in its original state or after treatment, intended for drinking, cooking, food preparation or other domestic purposes, regardless of its origin and whether it is supplied from a distribution network, from a tanker, or in bottles or containers;

(b) all water used in any food-production undertaking for the manufacture, processing, preservation or marketing of products or substances intended for human consumption unless the competent national authorities are satisfied that the quality of the water cannot affect the wholesomeness of the foodstuff in its finished form (European Directive 98/83/EC).

Water cycle	see hydrological cycle.
Water table	top surface of the saturated zone within the aquifer.
Weathered zone	vertical zone within soil/rock affected by weathering from the action of water, heat, ice etc.

Y

Yield	quantity of water able to be removed from an abstraction source.

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