The Earth in our hands

- how geoscientists serve and protect the public

10 GROUNDWATER

About these briefings

The Earth is a dynamic planet. It is active and productive, offering humanity enormous opportunities. However, living on it also presents us with many dangers; some of our own making.

In our interaction with the Earth, geoscientists are in the front line. They seek and find the raw materials we use for agriculture, roads, buildings, energy, water supply and all the industries that provide wealth and health.

Geoscientists help society understand natural hazards and mitigate their effects. Such dangers include floods, landslips, volcanic eruptions and earthquakes.

Geoscientists also help to minimise hazards we have created (or made worse) by our activities. These include subsidence, and the disposal of waste.

With their unique understanding of the immensely long time spans over which Earth processes operate, geoscientists help communities world-wide to learn how to use the planet's resources safely, wisely, and sustainably.

This series of information sheets is dedicated to bringing this role to public attention.

Further information

Web sites

http://www.environment-agency.gov.uk/gwcl For information on national and local issues on groundwater resource development, protection and pollution and the EA's National Groundwater and Contaminated Land Centre.

http://www.iah.org International Association of Hydrogeologists (Tel: 01926 450677) supports research and information on groundwater.

http://www.nwl.ac.uk/gwf UK Groundwater Forum (Tel: 01491 838800) has recently produced a video *How rivers work: the role of groundwater*. It can be used to teach National Curriculum Science and Geography at Key Stages 3 and 4.

http://www.bgs.ac.uk British Geological Survey (Tel 0115 936 3100) has published *Groundwater – our hidden asset*. A layman's guide, useful for students of science subjects at Key Stage 4 and above.

http://www.ukwir.co.uk UK Water Industry Research (Tel: 0207 957 4507) has members from water service companies, the Water Companies Association, the Scottish Water Authorities and the Department of the Environment Northern Ireland Water Service.

http://www.minewater.net A UK-based site providing information and data-links on issues of mine water pollution and remediation.

http://www.claire.co.uk UK examples of contaminated land clean-up technologies designed to prevent/remediate groundwater pollution.

http://www.sniffer.org.uk Scotland and Northern Ireland Forum for Environmental Research (Sniffer) directs and manages research in air, water, waste and the environment (Tel: 01786 457700) and has produced hydrogeological and vulnerability maps of Scotland and Northern Ireland. Members include Scottish Environment Protection Agency (SEPA)

http://www.sepa.org.uk Environment and Heritage Service Northern Ireland (EHS)

http://www.ehsni.gov.uk Scottish Executive

http://www.scotland.gov.uk and Scottish Natural Heritage http://www.snh.org.uk

http://www.envirolink.org A US based site with useful links to environmental groups worldwide, news items and bulletin boards.

Groundwater – Water from Rock. Earth Science in Everyday Life. A/AS Geology, Geography, Environmental Sciences; Key Stage 4 Science. Joint Earth Science Teachers' Association (ESTA) and Geological Society leaflet. Available from the Geological Society http://www.geolsoc.org.uk

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10 GROUNDWATER

What is groundwater?

Groundwater is water that has seeped down from the surface and accumulated underground, moving slowly to feed lakes, rivers or the sea. It is present in the pore spaces of almost all rocks and sediments. Rocks and sediments that store and transmit groundwater in usable quantities are called aquifers.

Almost all rocks and soils contain spaces (pores). A "porous" rock has pore spaces, which may contain water. In a "permeable" rock the pore spaces are connected, so that water may pass through.

Why is groundwater important?

Groundwater accounts for almost all (97%) of the freshwater on Earth (excluding ice caps). The remainder is surface water, in rivers and lakes. Groundwater is important:

- as drinking water – groundwater is naturally filtered by the rock through which it passes, so it is usually safer and more reliable
- as an environmental resource – groundwater influences river flow and quality, and sustains fresh surface waters, wetlands and marshes.

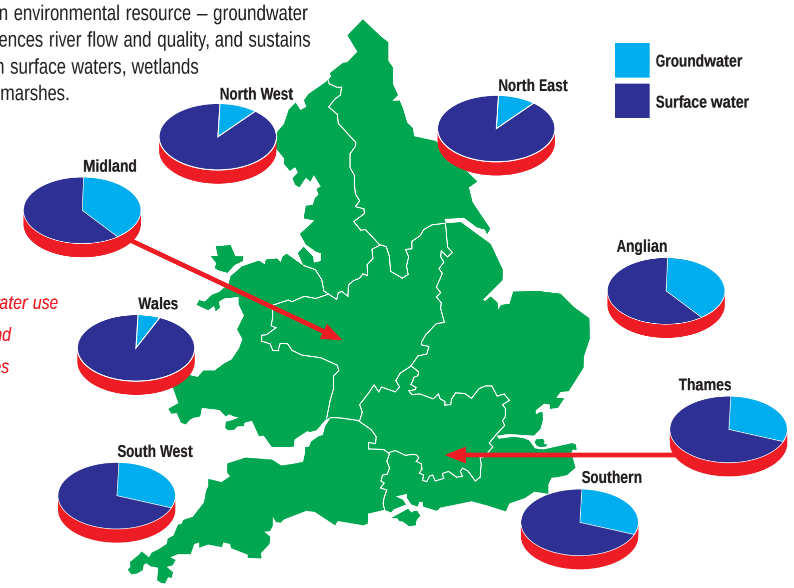

Fig. 2: Groundwater use in England and Wales

The extent of groundwater use in the UK varies with geology. In England and Wales groundwater provides roughly one third of public water supplies directly, and virtually all private supplies. Indirectly, it provides a much larger proportion of public supply; groundwater discharged through springs and inconspicuous zones of seepage (many below water level, in river beds) accounts for a high proportion of the average flows of rivers from which water is abstracted (see Fig 2, below).

In NW England and in Wales, where the climate is wet and extensive aquifers fewer, reliance on direct groundwater supplies is relatively low - although spring waters from the Carboniferous limestones are important sources in many upland areas. Groundwater resources are much more substantial in parts of central and southeast England, where as much as 80% of public water supply can come from pumping wells. Some towns in the east of England (e.g. Brighton, Doncaster, Hartlepool and Berwick-upon-Tweed) rely entirely on groundwater for public supplies. Even major cities like London, Birmingham and Nottingham relied historically on underlying aquifers for public and industrial supply.

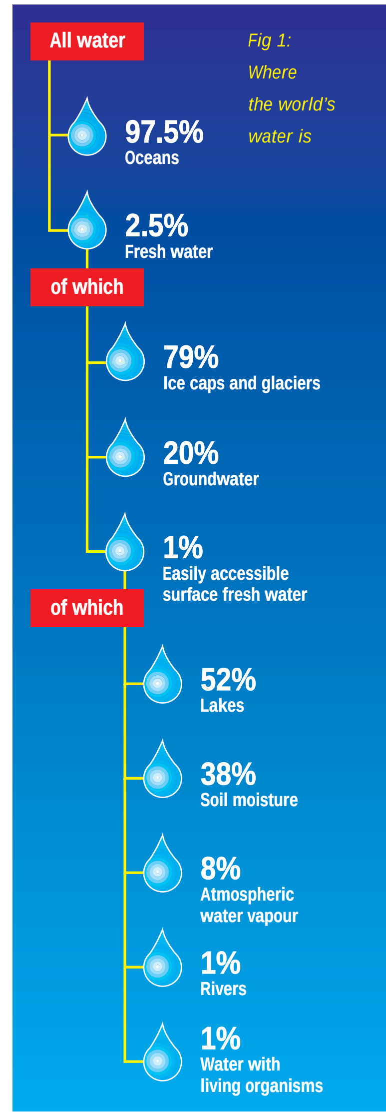

Fig 1: Where the world's water is

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Groundwater reserves

Water in UK aquifers tends to move along fractures in the rock. Groundwater generally moves very slowly and is only seen where boreholes have been drilled, or when springs discharge. Because groundwater is mainly out of sight, problems (such as contamination) can take many years to appear - by which time the damage may be widespread and irreversible. The way that groundwater moves can bring seemingly well separated waste and freshwater systems into contact.

In many places ground- and surface-water are directly connected and groundwater makes a major contribution to river flow. In southern England, up to 90% of flow in some streams and rivers is discharge from the Chalk aquifer. For this reason, pumping groundwater can affect river flow - sometimes so much that the river vanishes.

The major UK aquifers, e.g. the Chalk and the Permo-Triassic sandstones, are conveniently located in areas of lower rainfall where demand is also above average. In such areas, protecting groundwater is particularly important.

Managing groundwater

Sustainable management of the national groundwater resource involves concern for both volume and chemical composition.

Groundwater reserves (volume)

How much water can be extracted without damaging quality or long-term yield? It is important not to diminish supplies (deplete reserves) quicker than they are replenished (recharged).

Recharge occurs primarily through infiltration of rainfall or melting snow, which moves down through the soil to the water table - below which the rocks are water-saturated. (It can also occur by leakage from rivers.)

In Britain, groundwater recharge occurs mainly from October to April. From May to September, most rainfall is used by growing plants or returns to the atmosphere by evaporation, and recharge is negligible. Dry winters cause more problems with groundwater than dry summers because little of the expected recharge arrives.

Aquifers may be "topped up" by artificial recharge, using surplus potable water from rivers or lakes. In other schemes (e.g. around the rivers Severn in Shropshire and Clwyd in North Wales) groundwater is pumped from specially sited boreholes into nearby rivers to maintain flows in dry periods, thus allowing downstream abstraction to continue. In winter, when water demand drops, the boreholes cease pumping and the aquifer is allowed to recover.

In some urban areas (e.g. London and Birmingham) groundwater levels are rising because water abstraction has fallen over the last 40-60 years, mainly because of the decline in heavy industry. In London, where levels are rising at up to 2.5m per year, schemes are being developed to use the additional resource to supplement flows in the Thames and its tributaries. Moreover, with treatment to reduce concentrations of certain pollutants, it can be used to supplement the public water supply.

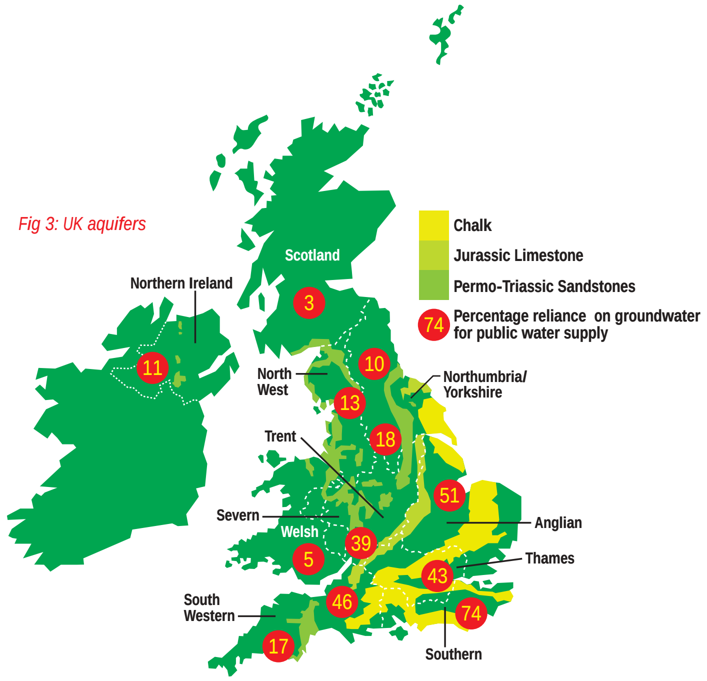
Groundwater in Birmingham is now used to supplement the flow of the upper Trent. However, the return of the water table to pre-industrial levels can damage deep structures - foundations, basements and underground railway tunnels - designed and constructed when it lay much deeper. Such urban groundwaters are often so high in sulphate that they are especially aggressive towards ordinary lime-based cements.

Another unwanted consequence of rises in groundwater level is found in many former mining districts of the UK, where the subsurface has been rendered permeable by excavation and collapse of mines. Water rising in abandoned workings is typically of very poor quality (see Fig 4, opposite).

Management and protection of groundwater quality

Pollutants at surface may be washed into aquifers by the rain, and spills of liquids can lead directly to groundwater pollution. Surveys over the past 20 years have increasingly shown that groundwater quality reflects overlying ground-use.

Fig 3: UK aquifers



Rapid urban and industrial expansion, bringing increasing environmental pollution, has increased the pressure on groundwater quality. Untreated industrial and domestic discharge enters the ground and watercourses directly or indirectly. Sources include:

- Industry – leaks from storage tanks (e.g. for liquid fuels and solvents)
- Urbanisation – dispersed pollution from many small leaks from sewers (microbiological and chemical contaminants), small commercial and industrial concerns, and domestic premises
- Agriculture – pesticides and fertilisers, manure and slurry (natural and synthetic)
- Landfill sites – domestic and industrial waste, and the leachates and gases they may yield
- Radioactive waste – (see *Radioactive Waste Disposal*, in this series)
- Seawater – intrusion into aquifers

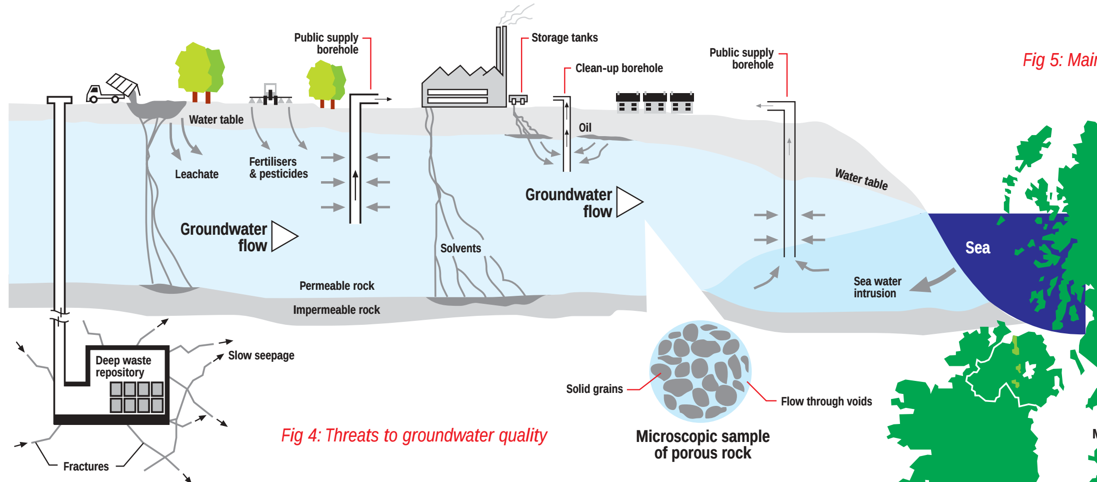


Fig 4: Threats to groundwater quality

Groundwater pollution can arise from "point" or "diffuse" sources – or both. A survey by the Environment Agency (1995) concluded that landfills are the most numerically significant "point" source. Sources with the greatest impact were agriculture and leaking petroleum storage tanks. Once groundwater is contaminated, the impact may be widespread, even if extraction takes place many kilometres away from the original pollution source.

Old gasworks are also significant, as are dry-cleaning facilities and engineering works. Other sources of pollution include industrial solvents (particularly from degreasing of metal components), tanneries, printing works and aircraft maintenance facilities. Recent surveys have revealed widespread contamination of urban aquifers by leaking sewers.

Examples

Landfill sites

Pollution can be controlled if landfills are sited properly, designed and constructed (with appropriate containment barriers and linings), monitored and managed (see *Landfill & Waste* in this series). The Environment Agency seeks to ensure that potentially polluting wastes management activities are not located on aquifers, by influencing local development plans, inserting suitable conditions in waste management licences etc., or refusing to issue them altogether, where appropriate.

Agriculture

Widespread or inappropriate applications (or application rates) of fertilisers, pesticides and organic manures (including slurries and recycled sludges) may contaminate ground- and surface-waters with nitrate and/or phosphate. Animal slurry, a potent mix of faecal matter and urine, can be 100 times more polluting than raw domestic sewage. Silage effluent (the liquid produced by preserving fodder crops harvested while still green) is up to twice as polluting again.

Many farms have fuel storage tanks that may leak into the soil and pollute groundwater, as can stores of liquid fertilisers, feed ingredients or pesticides. Manure and slurry storage facilities, tractor and vehicle washing facilities and cattle yards may also contaminate run-off drainage. These point sources of pollution can be reduced by appropriate measures such as spill/leak containment or relocating tanks.

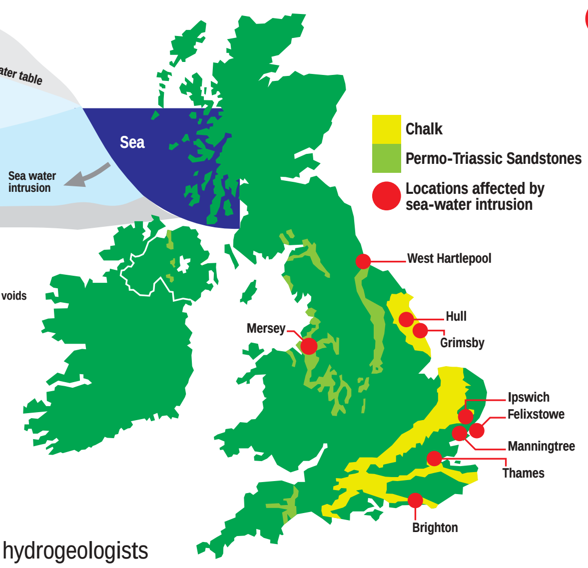
Mine waters

Waters flowing from coal and metal mines (see above) often contain high levels of iron, aluminium and zinc. They may also be acidic. Polluted mine waters may continue to flow from abandoned workings for many years and can damage aquatic life.

Seawater intrusion

If groundwater in coastal areas is abstracted faster than it is recharged by rainfall, salt water may be drawn inland toward boreholes, turning previously fresh water brackish. Quite small concentrations of salt make water unsuitable for domestic, agricultural and industrial use. Seawater intrusion into over-exploited coastal aquifers is increasingly giving cause for concern because of current global population growth trends and urbanisation in coastal megacities.

Fig 5: Main areas of seawater intrusion in UK



The role of hydrogeologists

Hydrogeologists play a vital role in establishing and understanding the relationships between geology, water and pollution. Their understanding enables better models of subsurface conditions to be constructed, leading to improved site investigation, risk assessment and restoration techniques, with the ultimate aim of improving and sustaining groundwater reserves and quality.

Working tools

Computer-based mathematical modelling

Increasingly, computer-based mathematical models are used to predict groundwater flow and contamination patterns.

Hydrogeological mapping and risk assessment

Constructing hydrological maps is an essential step in developing an understanding of how groundwater systems work. This is important in the development of mathematical models and the rational use of their output. It also assists in gathering and presenting information on groundwater levels and quality to the public, industry and governmental bodies.

Areas can be assessed for pollution risk using screening tools such as vulnerability maps. These highlight areas of elevated groundwater vulnerability, by integrating information on geological and soil classes (rock and soil type) and their general hydraulic/geochemical properties, catchment areas, groundwater pathways and properties (porosity, permeability and degree of saturation) and topography. For example, fractured limestones with thin soil cover and a shallow water table are more vulnerable to pollution than those in chalk or sandstone beneath a thick layer of clay.

A combination of hydrogeological mapping and computer modelling is used to delineate protection zones and catchments around groundwater sources. The Environment Agency recognises more than 76,000 smaller sources and 4000 larger sources in England and Wales, around which protection zones have been/need to be established. These areas can then be designated as Groundwater Protection Zones (GPZs), and fall within a protective legislative framework designed and enforced by the Environment Agency in accordance with European Union guidelines.

Geochemistry, geophysics, remote sensing

Geochemical characterisation of water and soil samples, along with techniques such as field monitoring of chemicals in water leaching from mines, landfills and other pollutant sources, enables hydrogeologists to assess groundwater pollution.

Geophysical techniques are used to log the hydrological properties of rocks forming the walls of boreholes. Site investigation techniques include electrical resistivity, ground-penetrating radar, remote imaging and more exotic techniques such as laser-induced UV fluorescence - which together enable a 3D understanding of groundwater systems to be built up over a wide area, reducing the need for expensive drilling.

Regulation and legislation

The main piece of legislation for managing the development and protection of groundwater in England and Wales is the Water Resources Act 1991 and the statutory body for implementing it is the Environment Agency. The Act contains detailed rules for controlling the abstraction (pumping) of groundwater to ensure that people can obtain water needed for supply while not causing unacceptable environmental damage.

Under the Act it is an offence to pollute water. In addition, the *Control of Pollution (silage, slurry and agricultural fuel oil) Regulations 1991* set minimum standards for the construction of new or improved waste stores. The regulations can also apply to existing stores.

The Environment Agency can call on the *Groundwater Regulations 1998 (Groundwater Directive)* and draft *Landfill Regulations 2001 (Landfill Directive)* as the basic framework for protecting groundwater resources. Possible pollutants are listed, some of which will no longer be allowed in landfill sites - while others will be subject to restrictions. Individual landfill licences state which substances they can take. Provisions to control groundwater pollution by leaching from contaminated land are currently being developed as well.

Codes of Good Agricultural Practice for Water, Air and Soil (COGAPs – issued by the Department for the Environment, Food and Rural Affairs (DEFRA)) provide practical guidance to help farmers and growers avoid causing pollution, and to protect soil. Within the next 15 years, most of the above legislation will be revised to ensure UK harmonisation with the newly established EU Water Framework Directive.