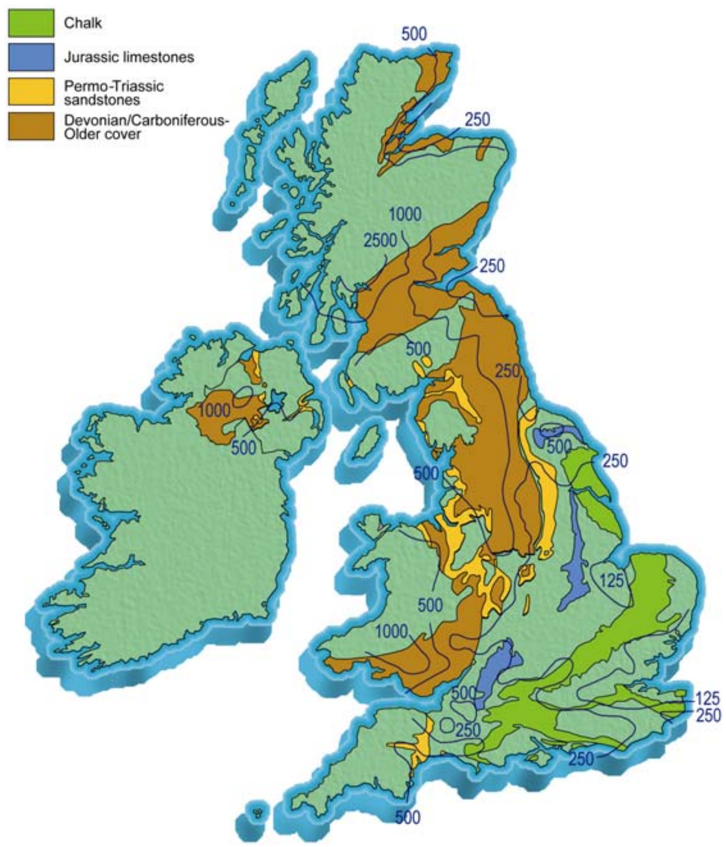
Groundwater resources

Groundwater resources depend upon rainfall and factors such as evaporation and the size of an aquifer's outcrop. Where the main aquifers crop out in the lowlands of England the potential infiltration is less than 500 millimetres / year and in the extreme east less than 150 millimetres / year.

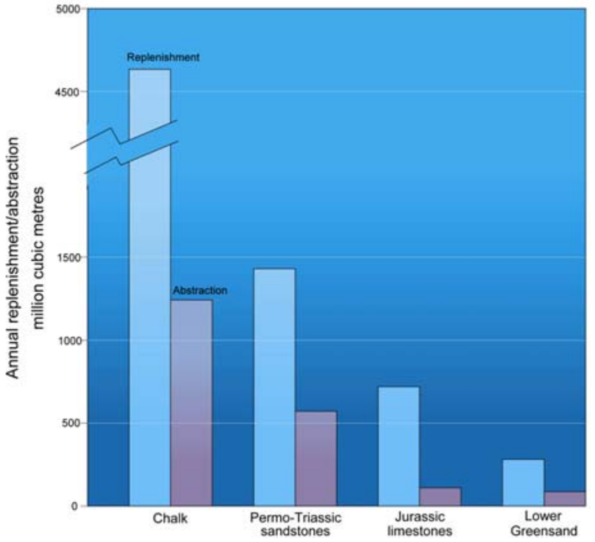
The average annual replenishment, or recharge, to the main aquifers of the Younger Cover (the Permian to Quaternary sequence) is 7 billion cubic metres, three times the total abstraction of groundwater in the UK. For the Chalk the recharge is some 4.6 billion cubic metres of which 30% is abstracted, and for the Permo-Triassic sandstones the figure is 1.4 billion cubic metres with 40% abstracted. Replenishment is considerably in excess of abstraction for the remaining aquifers in England and Wales except for the Lincolnshire Limestone where 50% of the replenishment of 86 million cubic metres / year is used for supply. In Scotland and Northern Ireland only a minute fraction of the replenishment is used for public water supply.

However, the annual replenishment of the resources is only part of the story. Aquifers store large volumes of water in the saturated zone, far in excess of that in surface reservoirs which is about 2500 million cubic metres. Springs are where groundwater overflows from aquifers but, as in surface reservoirs, water is stored in aquifers below the overflow levels. This storage remains available for development after springs have stopped flowing.

The Chalk crops out over more than 20,000 square kilometres, rather more than twice that of the Permo-Triassic sandstones. The top 20 metres alone of the unconfined saturated zones of these two aquifers contain 4000 and 36,000 million cubic metres of water respectively. The much larger figure for the sandstones, despite the smaller outcrop, is because the specific yield (the volume of water if yields, when it drains naturally or is pumped) is much larger. A volume of the sandstone contains about 20 times as much drainable water as the same volume of the Chalk. If the volume of water in the confined zones is included, the figures for total storage are even larger. Although not all this water is available where it is required, and in some areas the permeability may not be favourable for large-scale development, the figures indicate the scale of groundwater storage in aquifers. A conservative estimate indicates that 20 times as



Potential infiltration to the principal aquifers in the UK (in millimetres/year).



Comparison of replenishment and abstraction of groundwater for the principal aquifers of the UK.

much water is stored in the upper 20 metres of the two main aquifers as in all the surface reservoirs in the UK.

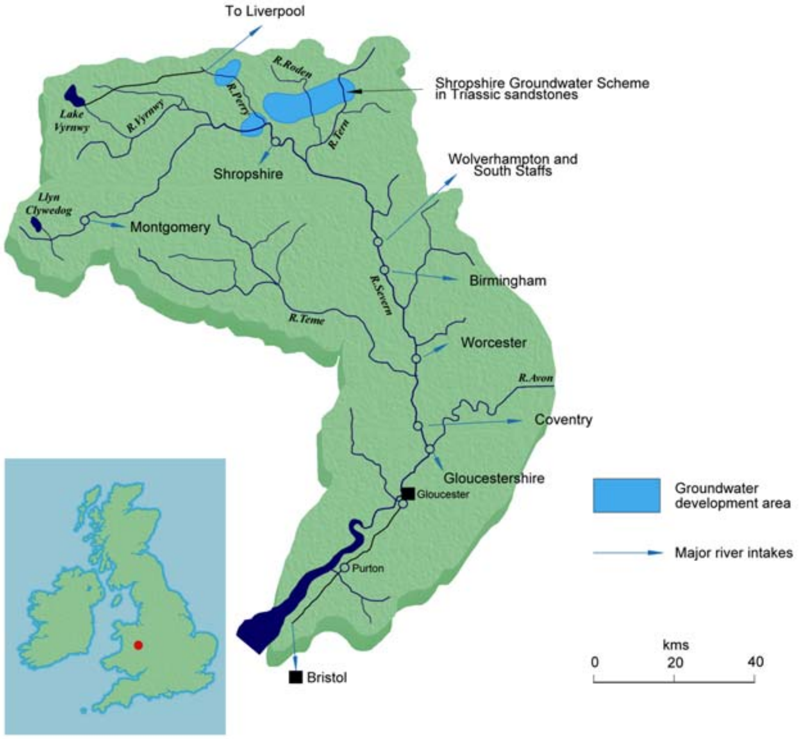
By providing the base flow component of river flow, groundwater is also the source of water abstracted at river intakes for public supply and other uses during dry periods. Because of the importance of maintaining river flows, several major schemes in England have been designed to pump groundwater into rivers in dry periods and thereby make water continuously available for abstraction at water supply intakes as well as protecting the aquatic environment.

The natural infiltration to an aquifer can be supplemented by a process called artificial recharge. The object is to make use of the large storage capacity of aquifers to store water that is surplus to requirements, for use when supplies are less plentiful. Water may be recharged through basins or boreholes, or simply spread over the ground in ditches or by controlled flooding.

Artificial recharge has been used only to a limited extent in the UK. The Chalk and overlying Palaeogene sands are being recharged in the London Basin with treated river water. During the 1960s and 1970s extensive field trials demonstrated that recharge of the Permo-Triassic sandstones and the Lower Greensand through basins and boreholes should present few problems but, so far, the technique has not been applied in these aquifers.

Shropshire groundwater scheme

The River Severn provides water for many communities in the West Midlands between Shrewsbury and Bristol. During the summer the river level may be insufficient to meet these needs



Triassic sandstones aquifer in Shropshire. Groundwater from the Triassic sandstones, as well as water from Lake Vyrnwy and Llyn Clywedog, is used to regulate the flow of the River Severn and thereby supply water for many communities.

Increasing river flow with groundwater. Groundwater is pumped from boreholes into some rivers during extended dry periods to maintain adequate flows in the rivers. The boreholes are sited some distance from the rivers and the water abstracted is taken from groundwater storage. In the short-term the abstraction does not affect the flow of the rivers.

while at the same time preserving the river's environment. When this occurs the flow is increased by releasing water stored in the Llyn Clywedog and Lake Vyrnwy reservoirs in the headwaters of the river in central Wales. However, in dry years, such as 1976, 1989 and 1995, the capacity of the reservoirs is insufficient to provide all the water required to maintain the river at an adequate level. In these exceptional years of drought another reservoir is also used to augment the flow of the river — the Triassic sandstones aquifer of north Shropshire.

Groundwater is pumped from boreholes in the sandstones and discharged through pipelines into the River Severn or its tributaries. It is expected that pumping will be required to some extent about one year in three, but for not more than 100 days even in a very dry year. The total abstraction that will ultimately be permitted from the sandstones will be 330 Ml/d, which will allow an increase in abstraction from the River Severn of about 225 Ml/d. The difference between the two figures is because groundwater would have entered the river naturally if pumping had not taken place, but is intercepted by the cones of depression that form around the boreholes.

The Shropshire Scheme is typical of many schemes that have been developed over the last 20 years to augment river flows and provide continuing water supplies and/or environmental benefits during droughts. They make use of groundwater storage that already exists and they can be developed in stages to meet the needs as they arise, so that capital does not have to be spent before it is necessary. The Shropshire Scheme is being developed in eight stages.

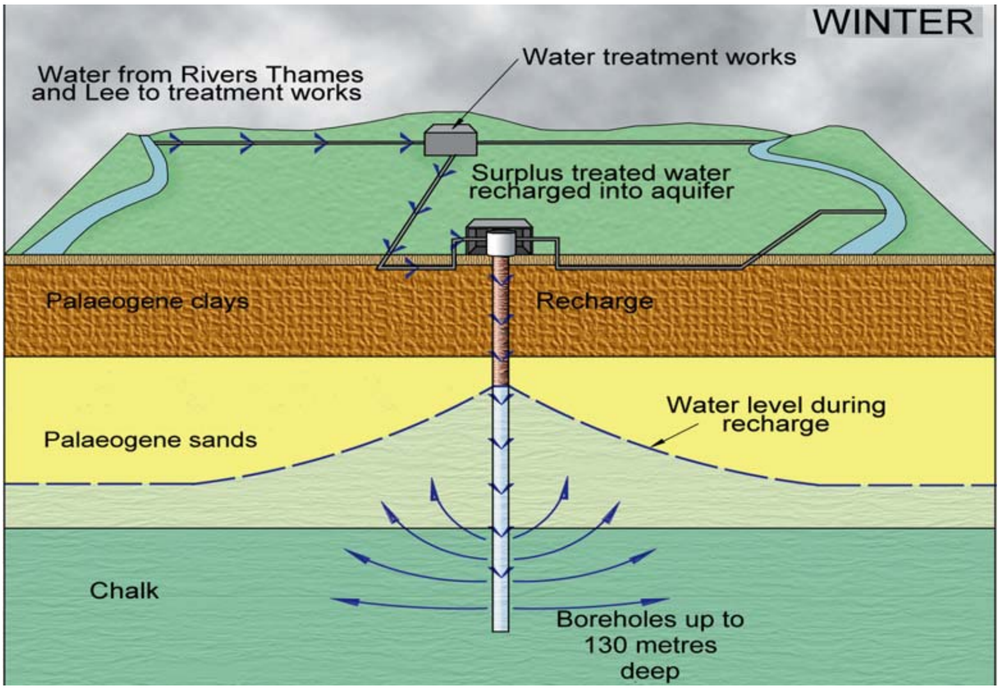
The reservoir under London

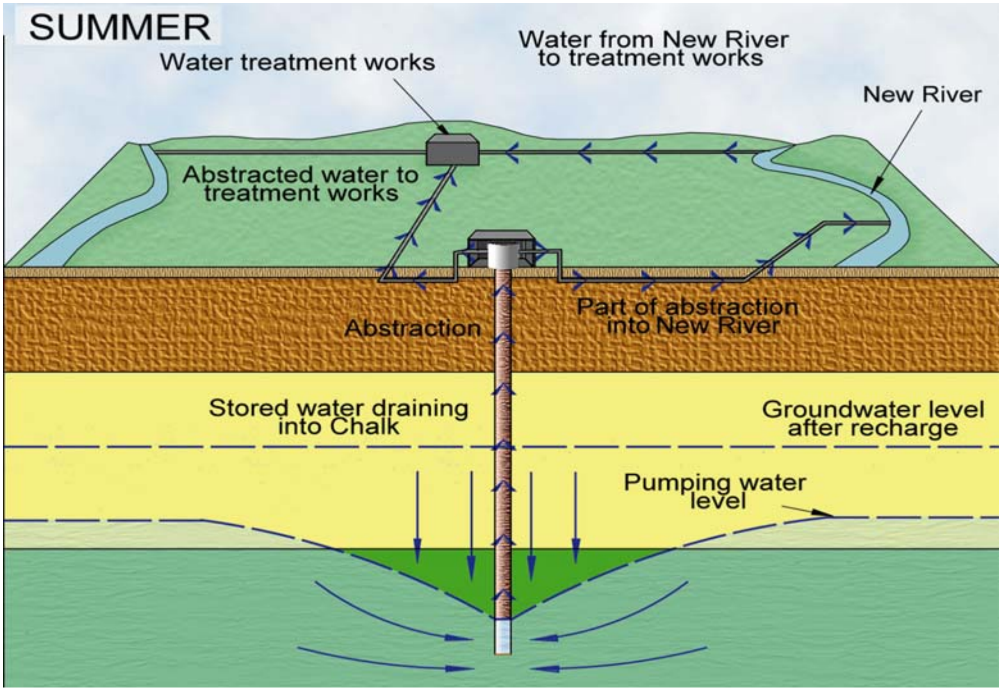
London is built on a thick layer of clay appropriately called the London Clay. Below the clay, the Chalk and Palaeogene sands form a major groundwater reservoir. They lie in a saucer-shaped depression extending from outcrops in the Chiltern Hills, passing below London and rising to the surface again in the North Downs. They form a classic confined aquifer.

Groundwater was first developed from the aquifers below London in the eighteenth century. Over the next 200 years many boreholes were drilled. The water level gradually fell and saline water from the tidal River Thames intruded into the aquifers where they crop out along the lower reaches of the river. These consequences were naturally seen as undesirable, but it is indisputable that the availability of a convenient source of water below London made a significant contribution to the economic development of the city in the nineteenth and early twentieth centuries. Between 1800 and 1965 the aquifers in the central part of the London Basin provided some 5700 million cubic metres of water. The groundwater storage was used very effectively.

A change in the pattern of water use is leading to a recovery of water levels below central London but the Chalk is still intensively exploited for public water supply in the Lee Valley, where 70 Ml/d are abstracted.

In the Lee Valley, the void space in the aquifers, made available by the fall in water level, is being replenished by artificial recharge. This began over 40 years ago. Thames Water increased the scale of the operation and now recharge water through 36 wells and boreholes. In the winter, when the demand for water is lower, surplus surface water from the Rivers Thames and Lee is treated and recharged into the Chalk. During hot dry summers, times of high demand for water, the stored water is pumped from the aquifers, treated





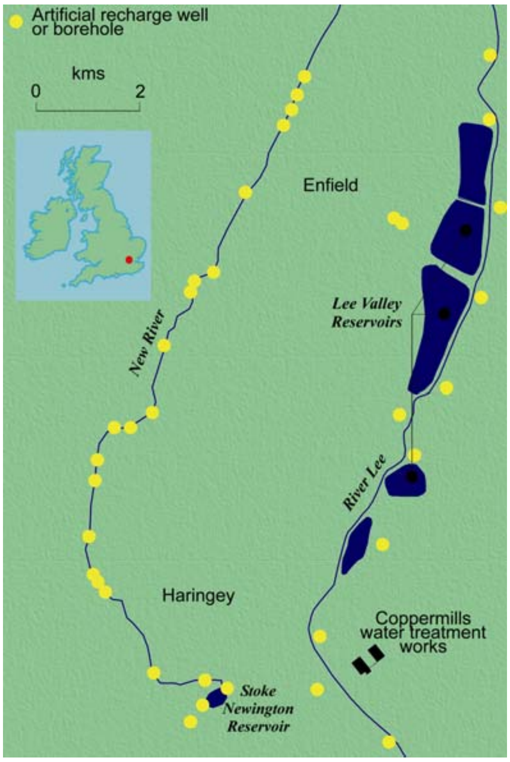
Artificial recharge of the Chalk in the Lee Valley. Surplus treated water is stored in the aquifer until it is needed. Water abstracted from boreholes sited along the New River is discharged into the river to maintain the flow, before being piped from the reservoir at Stoke Newington to the treatment works.

once again and then distributed. Part of the water from the boreholes and wells is pumped into the New River which carries it to a reservoir at Stoke Newington. It is then piped to the treatment works. The flow in the river is thereby maintained, preserving this historical aqueduct, built in 1613, to bring groundwater from springs in Hertfordshire to the heart of London.

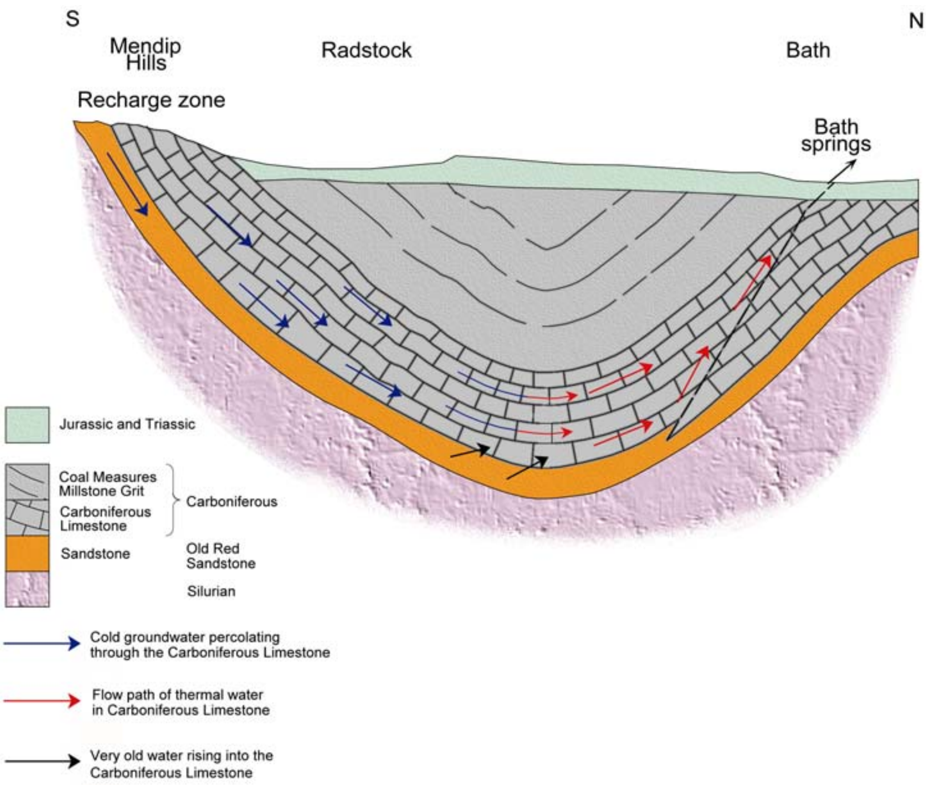
Artificial recharge now provides Londoners with 100 million litres of water per day at times of drought.

Hot and saline waters

The seventeenth and eighteenth centuries saw fashionable society indulging in the re-emergence of an old pastime of 'taking the waters'. The practice continued into the nineteenth century but declined after that in the UK, although remaining popular in Europe. 'Taking the waters' involved the luxury of bathing in and / or drinking the mineral or thermal waters of spa towns such as Bath, Buxton and Cheltenham. The waters were believed to be good for rheumatism, respiratory illnesses, skin conditions and digestive disorders.



Sites of artificial recharge boreholes and wells in the Lee Valley.



The origin of the thermal springs at Bath. Groundwater flows through the Carboniferous Limestone in a huge siphon extending from the Mendip Hills. It descends to depths of about 2 kilometres before rising up fractures to discharge as springs at Bath, some 15 kilometres to the north. As it flows through the rocks it becomes hotter and when it flows from the springs the temperature is 46°C. The water is probably several thousand years old but it includes a very much older component derived from the underlying Old Red Sandstone.

Most of the mineral waters used for therapeutic purposes have a dissolved solute content of more than 1000 milligrams per litre, in other words they taste salty and some are very salty, including those at Harrogate and Leamington Spa where the total dissolved solute contents are about 16,000 milligrams per litre. Most of the waters are not thermal waters. Many are associated with clays and derive their mineral content from soluble minerals that occur in these deposits. Groundwaters in rock formations such as the London Clay, the Kimmeridge Clay, the Oxford Clay and the Lower Lias are almost invariably of a mineral character with a high sulphate content. Many of the waters that have been developed as spas issue from the Lower Lias. Yields are small but sufficiently persistent to have supplied the therapeutic centres of Cheltenham and many smaller spas. The salt deposits of the Triassic rocks are a further important source of mineral water and have been developed at Droitwich and Leamington Spa.

Thermal waters are found as natural springs only in the Peak District of Derbyshire and at Bath, Bristol and Taff's Well, in South Wales. They are warm rather than hot waters. The maximum temperature recorded is 46°C at Bath. These waters have all been heated as they circulated to considerable depths in fractures in the Carboniferous Limestone, although they do not all issue from this rock. Only the thermal waters issuing at Bath and Bristol are mineral waters and they contain relatively low total dissolved solutes.

In the UK the temperature below the ground increases with depth at an average rate of 25°C per kilometre but in places it exceeds 30°C per kilometre. As a consequence hot groundwaters in permeable rocks at depth of some 1½ to 3 kilometres represent a source of thermal energy. Advantage of this has only been taken at Southampton where brines at a temperature of 75°C are pumped from Triassic sandstones at a depth of 1.7 kilometres and used to heat buildings in the centre of the city.

There are signs that 'taking the waters' is making a comeback in the UK. A number of towns are planning to reopen spa baths. There seems to be little doubt that wallowing in warm saline water makes one feel better.

Bottled water — a matter of taste

Supermarkets' shelves carry an impressive selection of bottled waters. This clearly reflects public concern about the quality of tap water. The increase in demand for bottled water has been attributed to better taste, or great purity, or a real or perceived health benefit. Whatever the reason over 500 million litres are sold each year in the UK.

Almost all bottled waters are groundwaters. They are collected from springs or boreholes selected because the sites are generally in upland areas remote from sources of pollution, and they provide a water which does not contain undesirable chemicals such as excessive nitrate. Many have very low concentrations of dissolved constituents, and some are carbonated artificially.

Bottled waters are 'natural waters'; they are bottled from the source after only limited

The Great Roman Bath at Bath. The bath is filled by thermal water from the King's Spring, one of the three thermal springs at Bath.

treatment, mainly filtration if that is necessary. Consequently they have not been sterilised. They can contain bacteria, although most would be harmless.

In contrast, public water supplies provided from groundwater sources have been sterilised before distribution and they meet the stringent drinking water standards of the European Union and the World Health Organisation.

Bottled water is 500 to 1000 times more expensive than tap water and as sold in restaurants can exceed the cost of petrol or wine sold by the carafe.

Climate change

A change of climate resulting from the increasing amounts of the 'greenhouse gases' in the atmosphere, particularly carbon dioxide, methane, nitrous oxide, tropospheric ozone and chlorofluorocarbons, is now more widely accepted. Much uncertainty surrounds the detailed effects in the UK. Average temperatures are predicted to have increased by 1 to 5°C by 2080s. Winters will be generally wetter and summers substantially drier for the whole of the UK. Summers will tend to be more prolonged, curtailing the winter recharge season. Droughts will be more common and dry winters of much greater significance.

The effect of climate change on groundwater resources depends upon any change in the volume and distribution of infiltration. If drier warmer summers lead to the seasonal deficits in the moisture content of soils extending into the autumn, the winter recharge season for aquifers would be shortened. This could be compensated, at least to some extent, by an increase in winter rainfall. Lower rainfall in the spring would have an effect on groundwater levels, spring flows and the volume of base flow in rivers during the subsequent summer. Aquifers are recharged more effectively by prolonged steady rain, which continues into the spring, rather than short periods of intense rainfall.

An important outcome of climate change is likely to be that groundwater storage will assume increasing importance. It will have to be developed in conjunction with surface water within more complex regional water-resources management systems that incorporate seasonal use of groundwater and artificial recharge, as well as the flexible transfer of water between regions to counter uneven distribution of the basic resource — rain.