Geofile Online
JANUARY 2001
393

GARRETT NAGLE

GROUNDWATER

Of the total volume of available fresh water (excluding ice), 97% is underground, and up to 1500 million people rely on groundwater for drinking water. However, there are increasing pressures on the availability of groundwater. Population growth has led to increased demand for water. This has led to over-abstraction of groundwater, resulting in falling water tables and declining yields, land subsidence, saline intrusion and deterioration of fresh water ecosystems. In addition, pollution of groundwater from poor urban sanitation systems, industrial waste, chemical fertiliser and pesticides (intensive agriculture) has increased the problem.

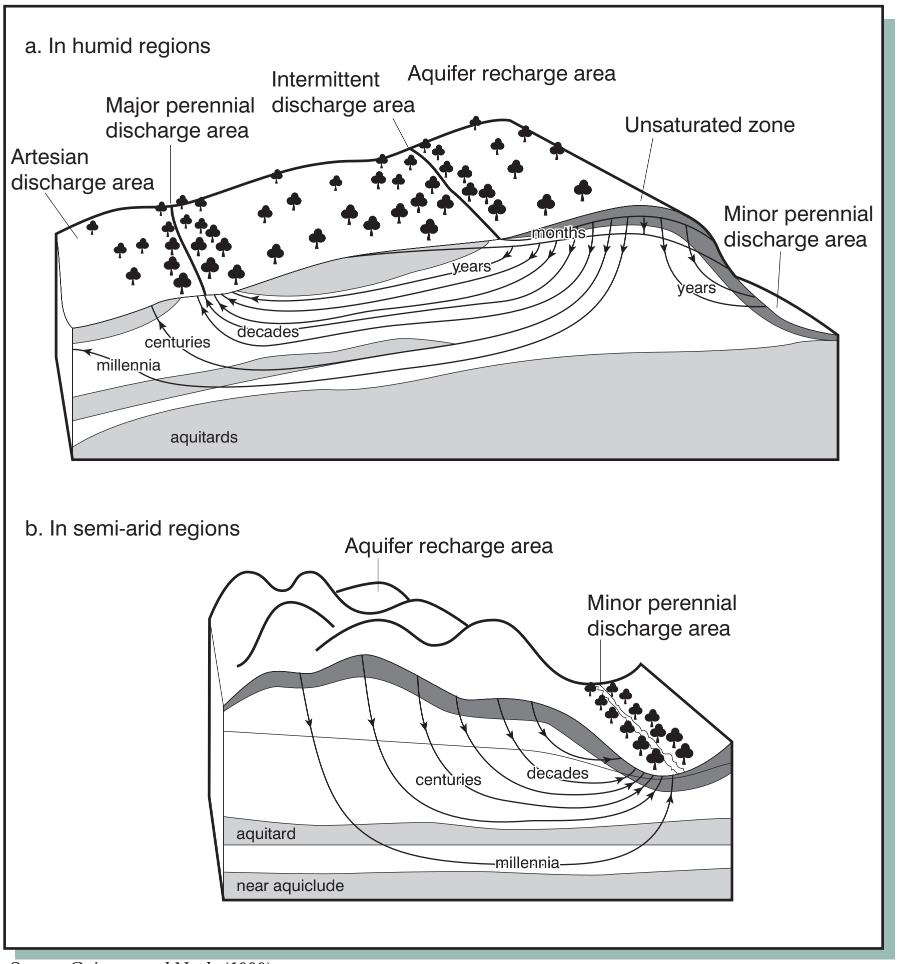
Groundwater

Groundwater refers to subsurface water (Figure 1). The permanently saturated zone within solid rocks and sediments is known as the **phreatic zone**, where nearly all the pore spaces are filled with water. The upper limit of the phreatic zone is known as the **water table**. The water table varies seasonally, being higher in winter following increased levels of precipitation. The zone that is seasonally wetted and seasonally dries out is known as the **aeration zone**, or the **vadose zone**. Most groundwater is found within a few hundred metres of the surface, but it has also been found at depths of up to 4 km beneath the surface.

Groundwater is important. However, while some soil water may be recycled by evaporation into atmospheric moisture within a matter of days or weeks, groundwater may take as long as 20,000 years to be recycled. In places where recharge is not taking place, groundwater must be considered a non-renewable resource.

Aquifers (layers of permeable rock such as sandstones and limestones containing significant quantities of water) are great reservoirs of water. This water moves very slowly through the aquifer, which acts as a natural regulator in the hydrological cycle by absorbing rainfall which otherwise would reach streams rapidly. Equally, aquifers maintain stream flow during long dry periods.

Figure 1: How groundwater flows



Source: Guinness and Nagle (1999)

Unconsolidated material can store large volumes of water; e.g. sand can store up to 30% of its volume as water. Consolidated materials, by contrast, often have small pore sizes so that water is not transmitted very easily. The major aquifers in the UK are formed of sedimentary rocks such as limestone and sandstone. The largest is known as the chalk aquifer and underlies much of southern and eastern England (Figure 2). It contains up to 200 cubic km of water.

A rock which will not hold water is known as an **aquiclude** or **aquifuge**. These are impermeable rocks which prevent large-scale storage and transmission of water.

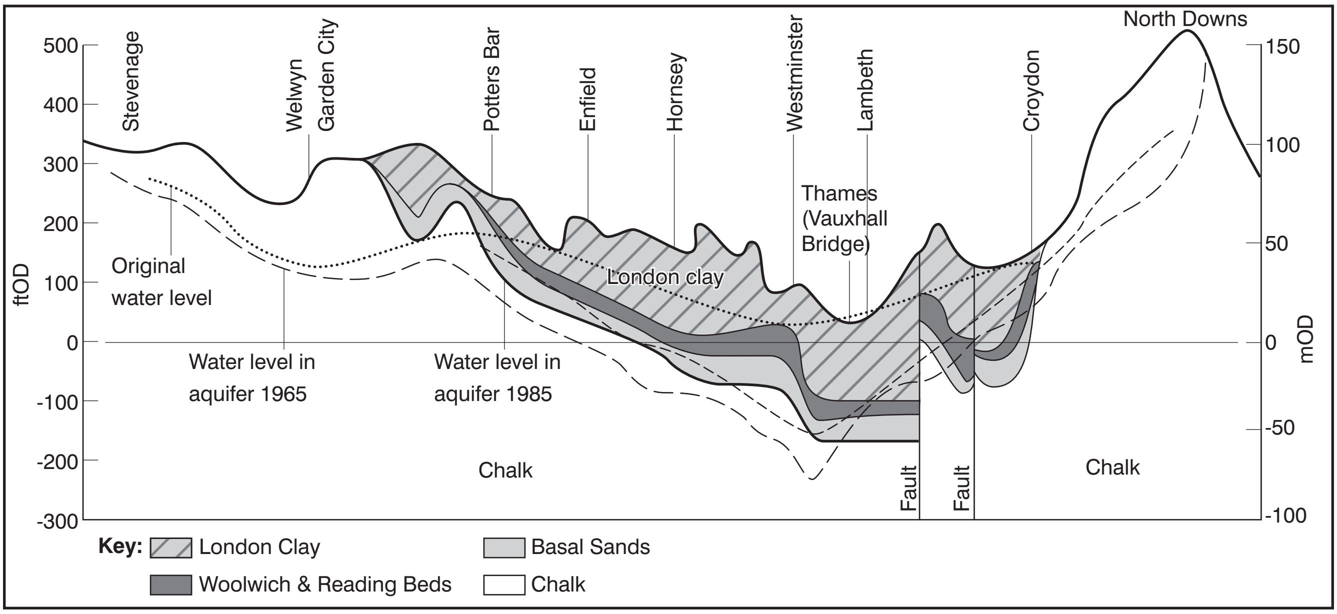
The world's great aquifers include those under the Sahara and those below the Ganges and the Indus in Asia. The aquifer under the Hwang He Plain of Eastern China provides water for over 160 million people and irrigates 200 million hectares. Aquifers are bounded below by an impermeable layer of rock. Above the aquifer is a layer of unsaturated rock – this boundary between the saturated and unsaturated rock is the water table. In some cases aquifers are bounded both above and below by impermeable rocks. This creates great pressure on the water – in the French province of Artois, water rises under its own pressure up wells which have been sunk into the aquifer (these are what are known as **artesian wells**).

The groundwater balance is shown by the formula

$\Delta S = Qr - Qd$

where ΔS is the change in storage (+ or –), Qr is recharge to groundwater and Qd is discharge from groundwater.

Figure 2: The London aquifer



Source: Guinness and Nagle (1999)

Groundwater recharge occurs as a result of:

- infiltration of part of the total precipitation at the ground surface;
- seepage through the banks and bed of surface water bodies such as ditches, rivers, lakes and oceans;
- groundwater leakage and inflow from adjacent aquicludes and aquifers;
- artificial recharge from irrigation, reservoirs, etc.

Losses of groundwater result from:

- evapotranspiration, particularly in low-lying areas where the water table is close to the ground surface;
- natural discharge by means of spring flow and seepage into surface water bodies;
- groundwater leakage and outflow through aquicludes and into adjacent aquifers;
- artificial abstraction through wells and by pumping, e.g. London Basin.

Groundwater supplies are recharged by rainwater which percolates through the soil and unsaturated layer at speeds which vary from millimetres per day in some areas to up to 10m per day in others. Some groundwater is as old as 30,000 years (that in the chalk aquifer under London is up to 18,000 years old) – this water can therefore be considered as a non-renewable resource, i.e. it is a relict feature.

Fossil groundwater is groundwater that is no longer being recharged. A good example is the water under the Sahara, some of which has been used for agriculture in Libya.

Aquifers and water supply

Aquifers are very useful supplies of water as they are not subject to abrupt changes of weather and they are cheap to develop. In addition they are often found close to where water is needed. They can also store huge volumes of water. Where the water table is more than 3m deep, there is little loss through evaporation.

Groundwater quality

There are a number of problems which affect groundwater supplies. These include:

- human activities – inadequate control of groundwater abstraction can lead to over-exploitation
- pollution of groundwater by cities, industry and agriculture
- industrial pollutants are often insoluble and heavier than water.

Soils and rocks filter and purify water. However water takes on some of the chemical properties of the rock. If the rock is polluted by industry, agriculture or landfill, the groundwater itself becomes polluted. As pollution can take a long time to manifest itself – up to 40–50 years in the case of nitrates in the chalk aquifer of southern England – the decline of groundwater quality is correspondingly long-term.

Effect of a reduced water table

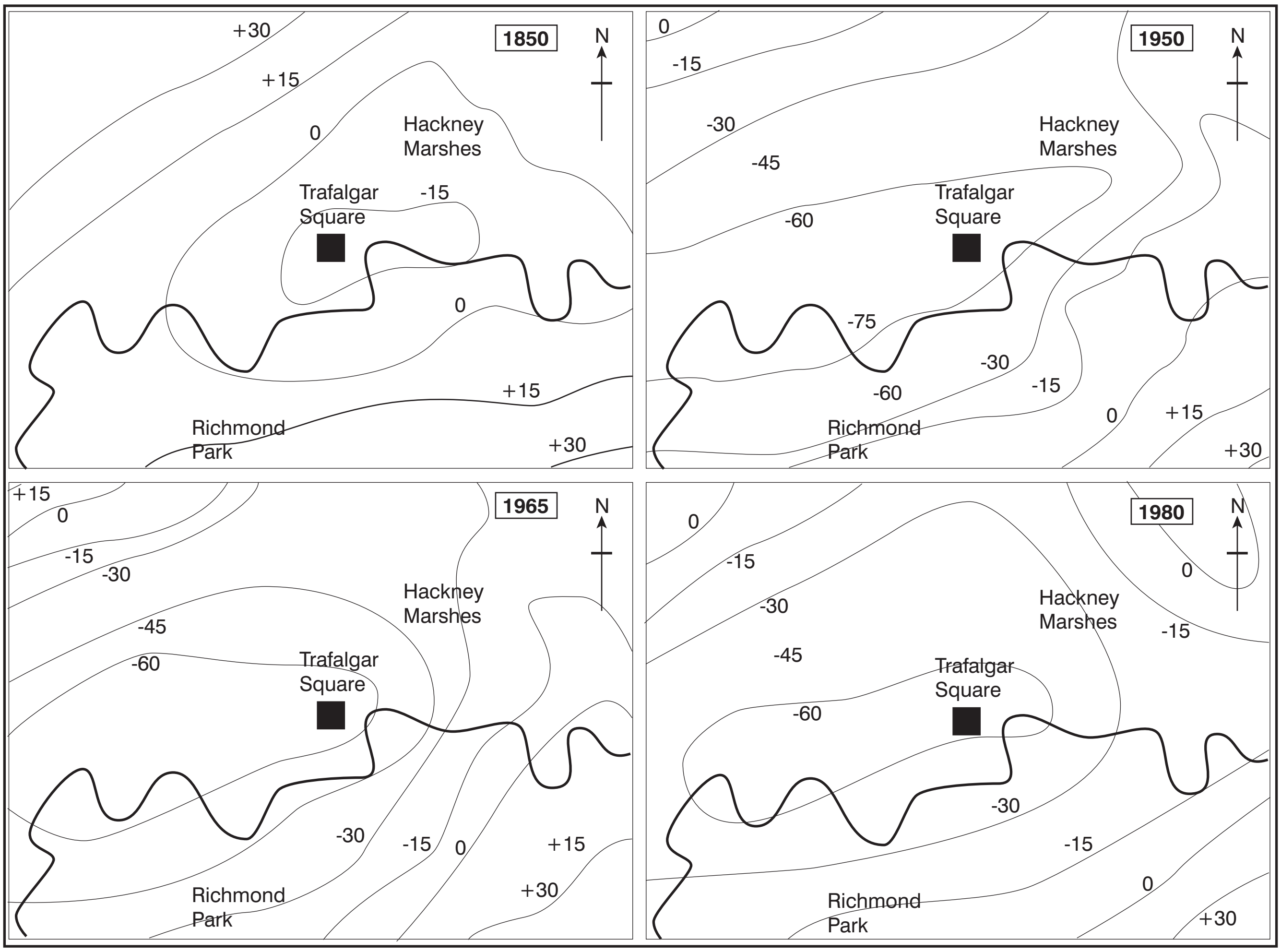
As water drains from the underground pores it causes rocks to contract. In the Las Vegas Valley parts have fallen by more than 1.5m. In Beijing the water table is declining at about 4m per year.

- In the USA 20% of irrigated land is fed by groundwater (groundwater depletion is widespread in the USA).
- Cities are being forced to buy farmland in order to acquire the rights to use the groundwater beneath that farmland.

Salt-water intrusion is common in places such as Manila (Philippines), where the use of groundwater has led to the water table falling by between 50 and 80m. Salt-water has seeped into the Guadalupe aquifer that lies under the city (5km inland from the sea). Salt-water intrusion is a huge problem in small ocean islands such as the Maldives, where groundwater is very often the only source of fresh water.

Rising water tables can compound the problem – **salinisation** is caused by a rising water table and the evaporation of irrigation water leaving behind salts. In some post-industrial cities where earlier urbanisation and industry created a heavy demand for water, this often

Figure 3: Changes in London groundwater levels, 1850–1980 (metres above or below sea-level)



Source: Guinness and Nagle (1999)

led to subsidence and saline intrusion. For example, in London, Liverpool, Manchester and Birmingham the water table decreased by over 30m. However, the closure of heavy industry in recent decades has meant that water tables have now begun to rise. In London the water table is rising by 2m per year, causing a threat to basements, tunnels, foundations and to underground or metro systems (Figure 3).

The effect of urbanisation

Waste water is a large and important resource. It can be used for irrigation (it contains nitrogen and phosphates), or it can be used to recharge the aquifer. Solid waste disposal, liquid effluent, heavy metals and so on are serious pollutants of groundwater. Urban growth, mainly marginal housing being built on areas previously used for solid waste disposal, worsens this problem.

The city of Merida in Mexico, population 535,000, obtains all its water supply of 240 million litres per day from a limestone aquifer. Most of the water is obtained from bore holes located outside the city. There is no sewerage system or storm water drainage. The high water consumption per head (460 litres per day), is greater than urban recharge (600mm per annum). By contrast however, pre-urban recharge was only about 100mm per year. The shallow aquifer is now contaminated by faecal coliforms and nitrates. However, the high recharge rate dilutes the nitrate somewhat.

The impact of agriculture

Human activity has seriously reduced the long-term viability of irrigated agriculture in the High Plains of Texas. Before irrigation started in the 1930s, the High Plains groundwater system was stable, i.e. in a state of dynamic equilibrium, with long-term recharge equal to long-term discharge. However, groundwater is now being used at a rapid rate to supply centre-pivot irrigation schemes. In under 50 years, the water level has declined by 30–50m in a large area to the north of Lubbock, Texas. The aquifer has narrowed by more than 50% in large parts of certain counties, and the area irrigated by each well is contracting as well yields fall. Agriculture is a major cause of pollution, especially when the soil is permeable. One problem is the level of nitrates in the soil, and this is linked to intensive methods of cultivation. Some nitrates come from untreated sewage, some from fertiliser and some from natural causes. The leeching of nitrates (especially fertiliser) is a serious waste.

Irrigation can cause salinisation of groundwater, especially if excessive irrigation leeches out salts present in the soil and the unsaturated zone.

The effect of industry

The worst industrial polluters tend not to be the big industries (which usually have got some effluent treatment), but small and medium-sized enterprises, e.g. paper, textiles, leather processing, metals, vehicle repairs, etc. Acids, oils, fuels and solvents and heavy metals are discharged directly into groundwater and nearby watercourses.

As mentioned above, in some areas, recent declines in industrial activity have led to reductions in the amount of groundwater being taken out of the ground. As a result, groundwater levels have begun to rise, adding to the problem of leakage from ancient, deteriorating pipe and sewer systems. This is happening in many British cities.

In London, due to a 46% reduction in groundwater abstraction, the water table in the chalk and tertiary beds has risen by as much as 20m. Such a rise has numerous implications, including:

- increase in spring and river flows
- restoration of flow from 'dry springs'
- surface water flooding
- pollution of surface waters and spread of underground pollution
- flooding of basements
- increased leakage into tunnels
- reduction in stability of slopes and retaining walls
- reduction in bearing capacity of foundations and piles
- increased **hydrostatic uplift** and swelling pressures on foundations and structures
- swelling of clays as they absorb water
- chemical attack on building foundations.

Where groundwater levels are continuing to fall, there are various methods of recharging groundwater resources, providing that sufficient surface water is available. Where the materials containing the aquifer are permeable (as in some alluvial fans, coastal sand dunes or glacial deposits), water-spreading is used. By contrast, in sediments with impermeable layers, such water-spreading techniques are not effective, and the appropriate method may then be to pump water into deep pits or into wells. This method is used extensively on the heavily settled coastal plain of Israel, both to replenish the groundwater reservoirs when surplus irrigation water is available, and to offset the problems associated with salt-water intrusion from the Mediterranean.

Groundwater resources in the Thames Basin

The importance of groundwater in the Thames region cannot be underestimated. There are hundreds of private, domestic and commercial boreholes and springs in daily use. The total volume of groundwater licensed for abstraction amounts to over 2,305 million litres/day, of which about 85% is used for potable supply. Water companies in the region operate over 300 public supply sources from groundwater. Groundwater also provides a considerable base flow component to many rivers, especially in the upper reaches of the catchment.

Approximately two-thirds of the catchment is permeable and thus subject to direct recharge from rainfall. There is potential for polluting discharges to infiltrate into the ground in these areas. Rainfall varies from 850mm/year in western parts of the catchment to less than 650mm/year in eastern parts. Rates of recharge to groundwater vary considerably, from 524mm/year in the north-west to 124mm/year in the east.

Particular groundwater problems which are occurring in the Thames Basin are as follows:

- Flows in several rivers have been depleted as a result of large groundwater abstractions close to the headwaters or along the river valleys. Worst affected are the rivers Misbourne, Ver, Wey, Pang and the Letcombe Brook.
- Groundwater has been affected by saline intrusions along the River Thames.
- Rising nitrate concentrations are evident in other parts of the catchment.
- Other chemicals, such as pesticides, are in widespread usage across the catchment and the frequency of detection in groundwater has risen.
- Groundwater in some urban areas has been contaminated by leakage from sewers and through widespread usage of chemicals such as solvents.

Management options

Groundwater is undervalued, inefficiently exploited and inadequately protected. There are two basic means of protecting groundwater:

- control abstraction
- control pollution.

Controlling abstraction requires legal and administrative steps:

- declare groundwater a resource available for the use in a controlled way
- issue licences to abstract groundwater.

Controlling pollution depends on the nature of the threat and the vulnerability of the aquifer:

- point sources, e.g. land fills and industrial discharges – discharges can be easily identified
- diffuse sources, e.g. the application of fertilisers and pesticides are less easy to pinpoint.

Since pollutants travel faster in the aquifer than in the soil/unsaturated layer above it, the nature of material within the aquifer is important in terms of aquifer vulnerability. The most vulnerable types of aquifer, in which transmission is more rapid, include fractured rocks, e.g. limestone and shallow water tables.

Bibliography and recommended reading

Guinness, P., and Nagle, G. (1999) *Advanced Geography: Cases and Concepts*, Hodder.
Nagle, G. (2000) *Advanced Geography*, Oxford University Press.

Focus Questions

1. Why are groundwater reserves important?

2. With the use of examples, explain how human activity affects groundwater.

3. In what ways can groundwater be managed sustainably?