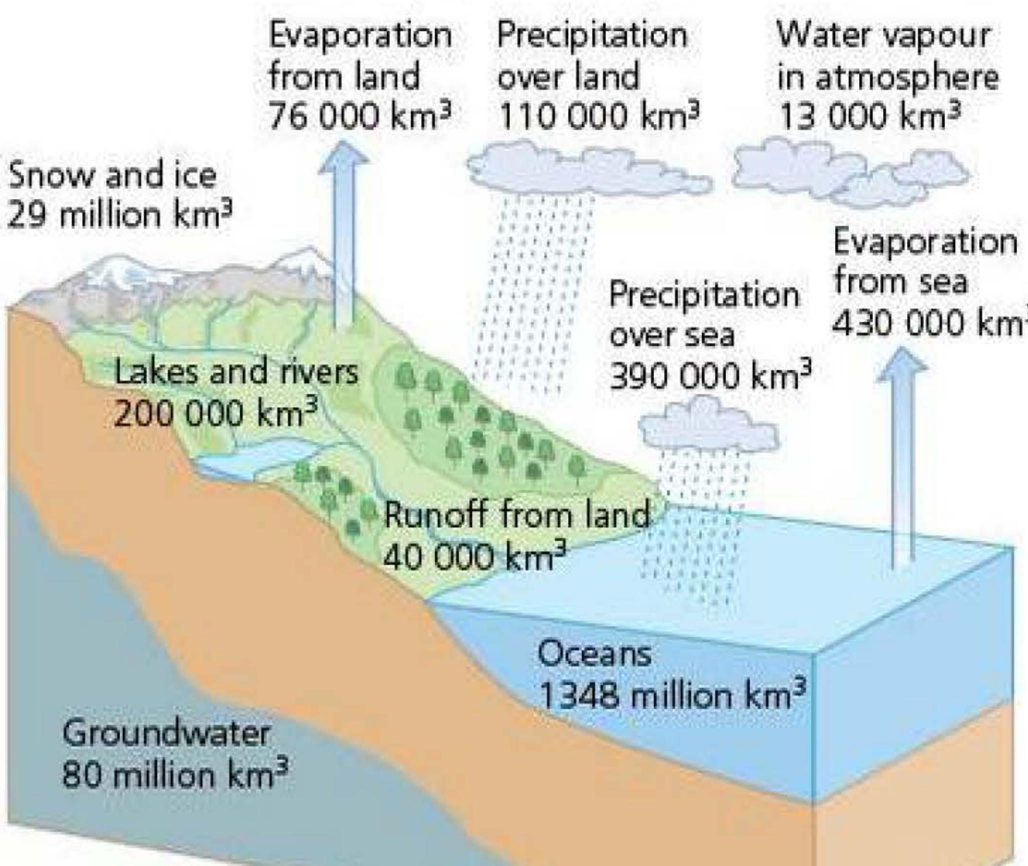
1 Hydrology and fluvial geomorphology

1.1 The drainage basin system

The hydrological cycle refers to the cycle of water between atmosphere, lithosphere and biosphere (Figure 1.1). At a local scale – the drainage basin (Figure 1.2) – the cycle has a single input, precipitation (PPT), and two major losses (outputs): evapotranspiration (EVT) and runoff. A third output, leakage, may also occur from the deeper subsurface to other basins. The drainage basin system is an open system as it allows the movement of energy and matter across its boundaries.



Source: *Advanced Geography: Concepts & Cases* by P. Guinness & G. Nagle (Hodder Education, 1999), p.245

Figure 1.1 The global hydrological cycle

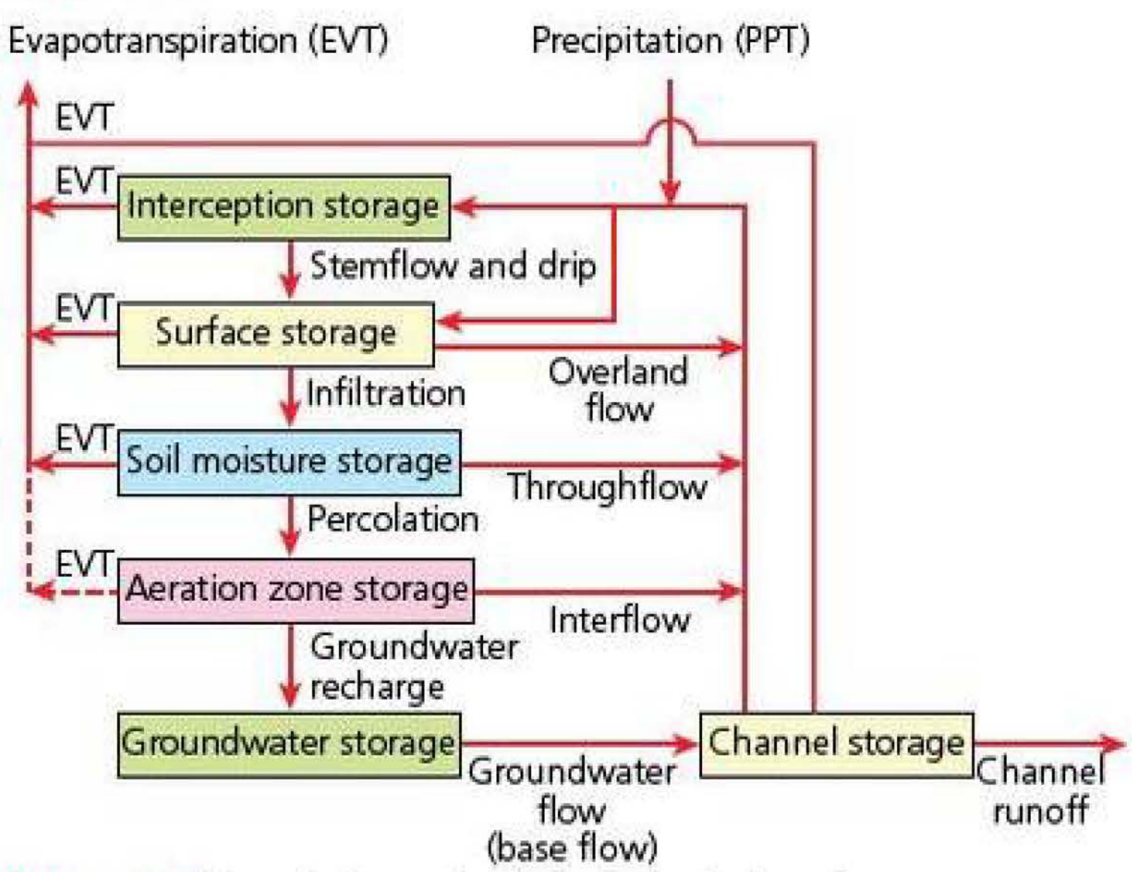


Figure 1.2 The drainage basin hydrological cycle

Water can be stored at a number of stages or levels within the cycle. These stores include vegetation, surface, soil moisture, groundwater and water channels.

Human modifications are made at every scale. Relevant examples include large-scale changes of channel flow and storage, irrigation and land drainage, and large-scale abstraction of groundwater and surface water for domestic and industrial use.

Outputs

Evaporation

Evaporation is the process by which a liquid is changed into a gas. The process by which a solid is changed into a gas is sublimation. These terms refer to the conversion of solid and liquid precipitation (snow, ice and water) to water vapour in the atmosphere. Evaporation is most important from oceans and seas. It increases under warm, dry conditions and decreases under cold, calm conditions. Evaporation losses are greater in arid and semi-arid climates than in polar regions.

Factors affecting evaporation include meteorological factors such as temperature, humidity and wind speed. Of these, temperature is the most important factor. Other factors include the amount of water available, vegetation cover and colour of the surface (albedo or reflectivity of the surface).

Evapotranspiration

Transpiration is the process by which water vapour escapes from a living plant, principally the leaves, and enters the atmosphere. The combined effects of evaporation and transpiration are normally referred to as evapotranspiration (EVT). EVT represents the most important aspect of water loss, accounting for the loss of nearly 100 per cent of the annual precipitation in arid areas and 75 per cent in humid areas. Only over ice and snow fields, bare rock slopes, desert areas, water surfaces and bare soil will purely evaporative losses occur.

Potential evapotranspiration (P.EVT)

The distinction between actual EVT and P.EVT lies in the concept of moisture availability. Potential evapotranspiration is the water loss that would occur if there were an unlimited supply of water in the soil for use by the vegetation. For example, the actual evapotranspiration rate in Egypt is less than 250 mm, because there is less than 250mm of rain annually. However, given the high temperatures experienced in Egypt, if the rainfall were as high as 2000mm, there would be sufficient heat to evaporate that water. Hence the potential evapotranspiration rate there is 2000mm. The factors affecting evapotranspiration include all those that affect evaporation. In addition, some plants, such as cacti, have adaptations to help them reduce moisture loss.

River discharge

River discharge refers to the movement of water in channels such as streams and rivers. The water may enter the river as direct channel precipitation (it falls on the channel) or it may reach the channel by surface runoff, groundwater flow (baseflow), or throughflow (water flowing through the soil).

Stores

Interception

Interception refers to water that is caught and stored by vegetation. There are three main components:

- interception loss – water that is retained by plant surfaces and that is later evaporated away or absorbed by the plant
- throughfall – water that either falls through gaps in the vegetation or that drops from leaves or twigs
- stemflow – water that trickles along twigs and branches and finally down the main trunk.

Interception loss varies with different types of vegetation (Figure 1.3). Interception is less from grasses than from deciduous woodland owing to the smaller surface area of the grass shoots. From agricultural crops, and from cereals in particular, interception increases with crop density. Coniferous trees intercept more than deciduous trees in winter, but this is reversed in summer.

Soil water

Soil water (soil moisture) is the subsurface water in soil and subsurface layers above the water table. From here water may be:

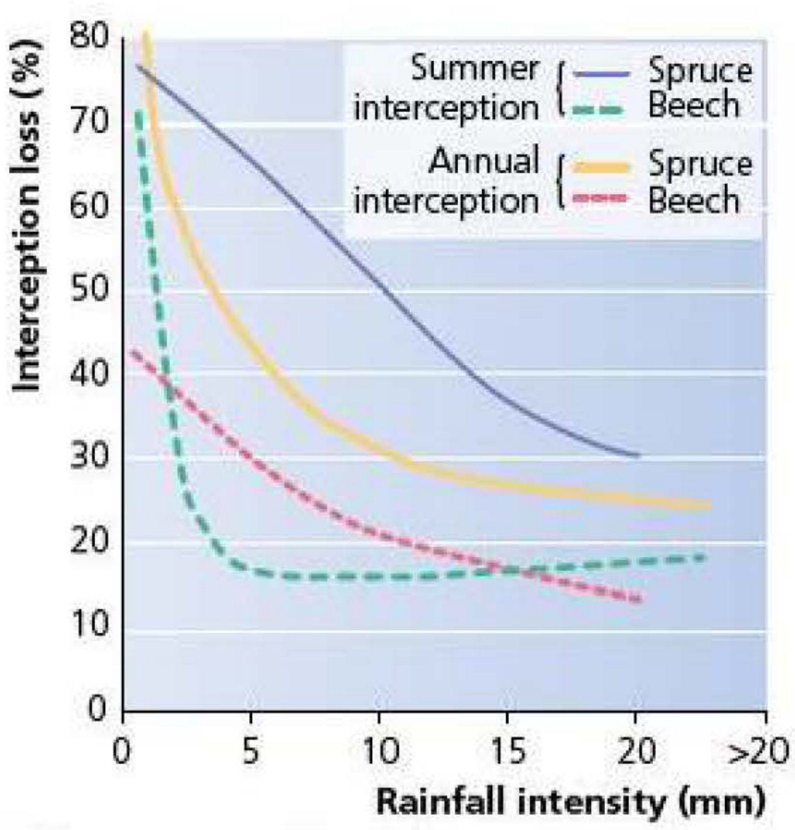
- absorbed
- held
- transmitted downwards towards the water table, or
- transmitted upwards towards the soil surface and the atmosphere.

In coarse-textured soils much of the water is held in fairly large pores at fairly low suctions, while very little is held in small pores. In the finer-textured clay soils the range of pore sizes is much greater and, in particular, there is a higher proportion of small pores in which the water is held at very high suctions.

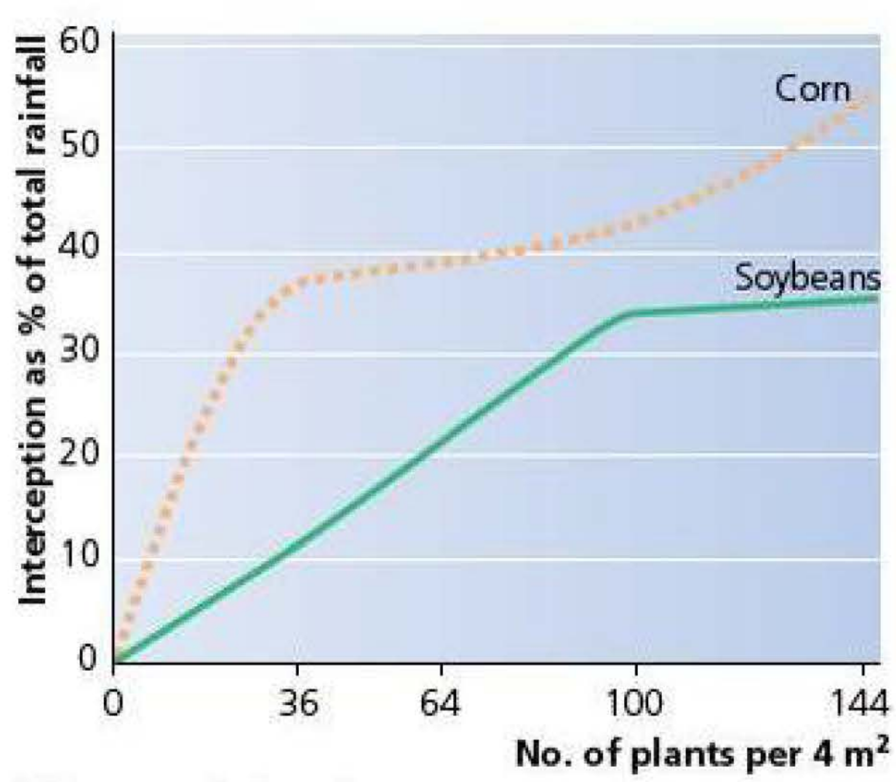
Field capacity refers to the amount of water held in the soil after excess water drains away; that is, saturation or near saturation. Wilting point refers to the range of moisture content in which permanent wilting of plants occurs.

There are a number of important seasonal variations in soil moisture budgets (Figure 1.4):

- Soil moisture deficit is the degree to which soil moisture falls below field capacity. In temperate areas, during late winter and early spring, soil moisture deficit is very low, due to high levels of precipitation and limited evapotranspiration.
- Soil moisture recharge occurs when precipitation exceeds potential evapotranspiration – there is some refilling of water in the dried-up pores of the soil.
- Soil moisture surplus is the period when soil is saturated and water cannot enter, and so flows over the surface.
- Soil moisture utilisation is the process by which water is drawn to the surface through capillary action.



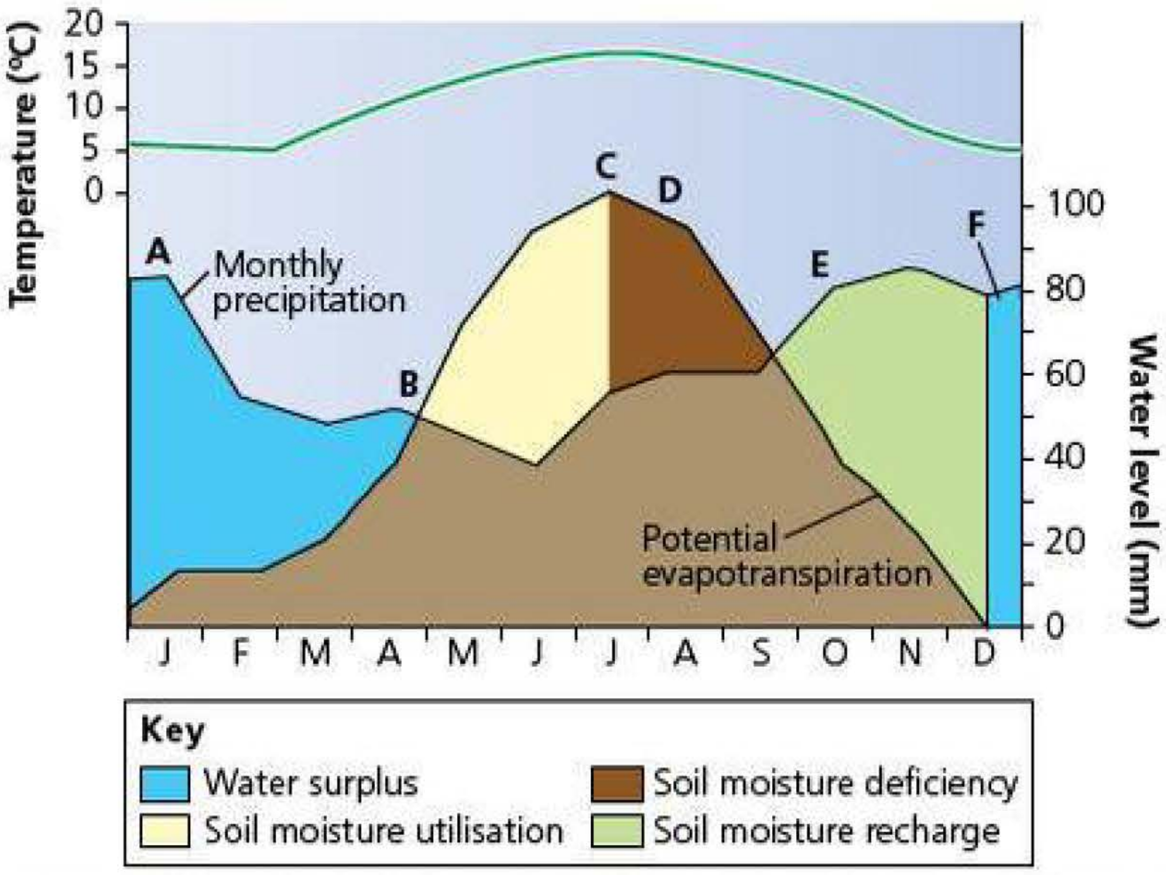
a From spruce and beech forests



b By two agricultural crops

Source: *Advanced Geography: Concepts & Cases* by P. Guinness & G. Nagle (Hodder Education, 1999), p.245

Figure 1.3 Interception losses for different types of vegetation



A Precipitation > potential evapotranspiration. Soil water store is full and there is a soil moisture surplus for plant use, runoff and groundwater recharge.

B Potential evapotranspiration > precipitation. Water store is being used up by plants or lost by evaporation (soil moisture utilisation).

C Soil moisture store is now used up. Any precipitation is likely to be absorbed by the soil rather than produce runoff. River levels will fall or dry up completely.

D There is a deficiency of soil water as the store is used up and potential evapotranspiration > precipitation. Plants must adapt to survive; crops must be irrigated.

E Precipitation > potential evapotranspiration. Soil water store will start to fill again (soil moisture recharge).

F Soil water store is full. Field capacity has been reached. Additional rainfall will percolate down to the water table and groundwater stores will be recharged.

Figure 1.4 Soil moisture status

Surface water

There are a number of types of surface water, some of which are temporary and some are permanent. Temporary sources include small puddles following a rainstorm and turloughs (seasonal lakes in limestone in the west of Ireland), while permanent stores include lakes, wetlands, swamps, peat bogs and marshes.

Groundwater

Groundwater refers to subsurface water that is stored under the surface in rocks. Groundwater accounts for 96.5 per cent of all freshwater on the Earth (Table 1.1). However, while some soil moisture may be recycled by evaporation into atmospheric moisture within a matter of days or weeks, groundwater may not be recycled for as long as 20 000 years. Recharge refers to the refilling of water in pores where the water has dried up or been extracted by human activity. Hence, in some places where recharge is not taking place, groundwater is considered a non-renewable resource.

Table 1.1 Global water reservoirs

Reservoir		Value (km^{-3} x 10^{-3})	% of total
Ocean		1 350 000.0	97.403
Atmosphere		13.0	0.00094
Land		35 977.8	2.596
Of which	Rivers	1.7	0.00012
	Freshwater lakes	100.0	0.0072
	Inland seas	105.0	0.0076
	Soil water	70.0	0.0051
	Groundwater	8200.0	0.592
	Ice caps/glaciers	27 500.0	1.984
	Biota	1.1	0.00088

Channel storage

Channel storage refers to all water that is stored in rivers, streams and other drainage channels. Some rivers are seasonal, and some may disappear underground either naturally, such as in areas of Carboniferous limestone, or in urban areas, where they may be covered (culverted).

Flows

Above ground

Throughfall refers to water that either falls through gaps in vegetation or that drops from leaves or twigs. Stemflow refers to water that trickles along twigs and branches and finally down the main trunk.

Overland flow (surface runoff) is water that flows over the land's surface. Surface runoff (or overland flow) occurs in two main ways:

- when precipitation exceeds the infiltration rate
- when the soil is saturated (all the pore spaces are filled with water).

In areas of high precipitation intensity and low infiltration capacity, overland runoff is common. This is clearly seen in semi-arid areas and in cultivated fields. By contrast, where precipitation intensity is low and infiltration is high, most overland flow occurs close to streams and river channels.

Channel flow or stream flow refers to the movement of water in channels such as streams and rivers. The water may have entered the stream as a result of direct precipitation, overland flow, groundwater flow (baseflow) or throughflow (water flowing through the soil).

Below ground

Porosity is the capacity of a rock to hold water, for example sandstone has a porosity (pore space) of 5–15 per cent, whereas clay may be up to 50 per cent. Permeability is the ability to transmit water through a rock via joints and fissures.

Infiltration

Infiltration is the process by which water soaks into or is absorbed by the soil. The infiltration capacity is the maximum rate at which rain can be absorbed by a soil in a given condition.

Infiltration capacity decreases with time through a period of rainfall until a more or less constant value is reached (Figure 1.5). Infiltration rates of 0–4 mm/hour are common on clays, whereas 3–12 mm/hour are common on sands. Vegetation also increases infiltration. This is because it intercepts some rainfall and slows down the speed at which it arrives at the surface. For example, on bare soils where rainsplash impact occurs, infiltration rates may reach 10 mm/hour. On similar soils covered by vegetation, rates of between 50 and 100 mm/hour have been recorded. Infiltrated water is chemically rich as it picks up minerals and organic acids from vegetation and soil.

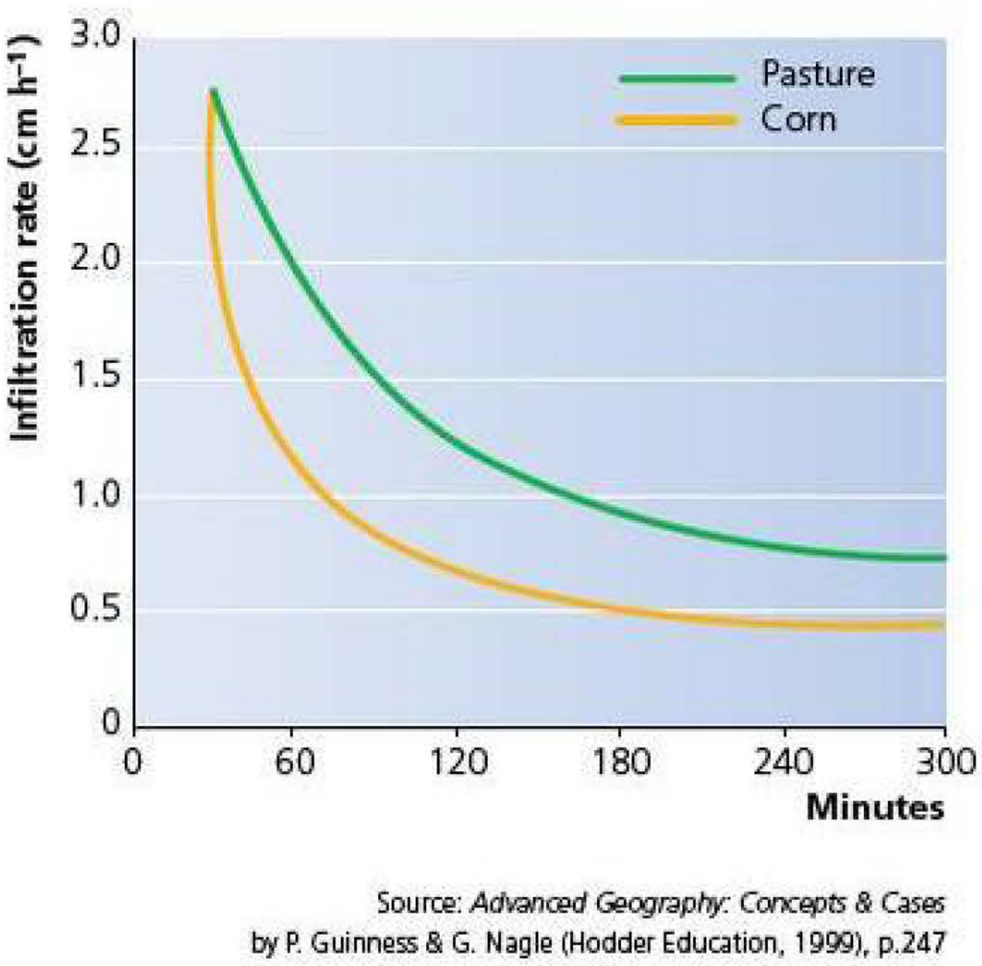


Figure 1.5 Infiltration rates under vegetation

Infiltration is inversely related to overland runoff and is influenced by a variety of factors, such as duration of rainfall, antecedent soil moisture (pre-existing levels of soil moisture), soil porosity, vegetation cover (Table 1.2), raindrop size and slope angle (Figure 1.6). In contrast, overland flow is water that flows over the land's surface.

Table 1.2 Influence of ground cover on infiltration rates

Ground cover	Infiltration rate (mm/hour)
Old permanent pasture	57
Permanent pasture: moderately grazed	19
Permanent pasture: heavily grazed	13
Strip-cropped	10
Weeds or grain	9
Clean tilled	7
Bare, crusted ground	6

Percolation

Water moves slowly downwards from the soil into the bedrock – this is known as percolation. Depending on the permeability of the rock, this may be very slow or in some rocks, such as Carboniferous limestone and chalk, it may be quite fast, locally.

Throughflow

Throughflow refers to water flowing through the soil in natural pipes and percolines (lines of concentrated water flow between soil horizons).

Groundwater and baseflow

Most groundwater is found within a few hundred metres of the surface but has been found at depths of up to 4 kilometres beneath the surface. Baseflow refers to the part of a river's discharge that is provided by groundwater seeping into the bed of a river. It is a relatively constant flow although it increases slightly following a wet period.

Underground water

The permanently saturated zone within solid rocks and sediments is known as the phreatic zone. The upper layer of this is known as the water table. The water table varies seasonally. In temperate zones it is higher in winter following increased levels of precipitation. The zone that is seasonally wetted and seasonally dries out is known as the aeration zone.

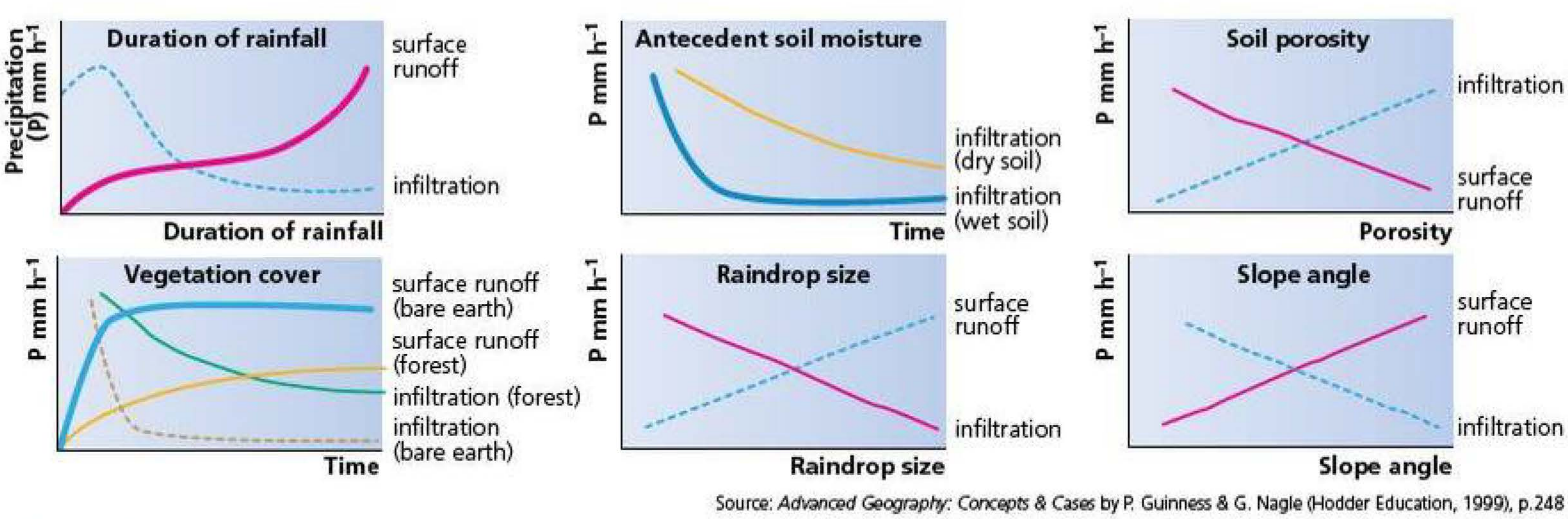
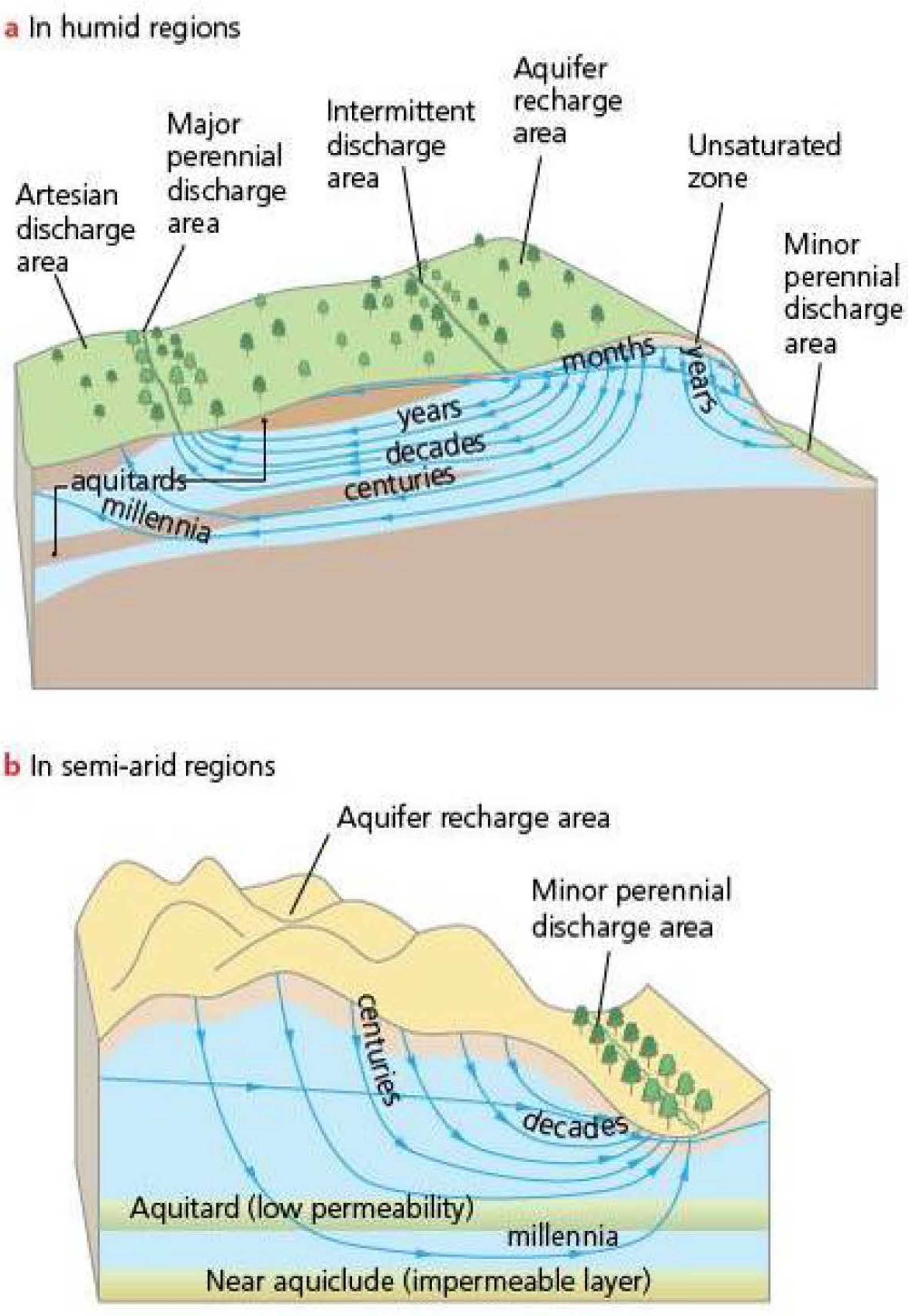


Figure 1.6 Factors affecting infiltration and surface runoff

Aquifers (rocks that contain significant quantities of water) provide a great reservoir of water. Aquifers are permeable rocks such as sandstones and limestones. The water in aquifers moves very slowly and acts as a natural regulator in the hydrological cycle by absorbing rainfall that otherwise would reach streams rapidly. In addition, aquifers maintain stream flow during long dry periods. Where water flow reaches the surface (as shown by the discharge areas in Figure 1.7), **springs** may be found. These may be substantial enough to become the source of a stream or river.



Source: *Advanced Geography: Concepts & Cases* by P. Guinness & G. Nagle (Hodder Education, 1999), p.248

Figure 1.7 Groundwater and aquifer characteristics

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 rocks and aquifers
- **artificial recharge** from irrigation, reservoirs, and so on.

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**, along aquicludes and into adjacent aquifers
- **artificial abstraction**, for example the water table near Lubbock on the High Plains of Texas (USA) has declined by 30–50m in just 50years, and in Saudi Arabia the groundwater reserve in 2010 was 42per cent less than in 1985.

Section 1.1 Activities

1 Define the following hydrological characteristics:
 a interception b evaporation c infiltration.
2 Study Figure 1.2.
 a Define the terms *overland flow* and *throughflow*.
 b Compare the nature of water movement in these two flows.
 c Suggest reasons for the differences you have noted.
3 Figure 1.3 shows interception losses from spruce and beech forests and from three agricultural crops. Describe and comment on the relationship between the number of plants and interception, and the type of plants and interception.
4 Figure 1.6 shows the relationship between infiltration, overland flow (surface runoff) and six factors. Write a paragraph on each of the factors, describing and explaining the effect it has on infiltration and overland runoff.
5 Comment on the relationship between ground cover and infiltration, as shown in Table 1.2.
6 Define the terms *groundwater* and *baseflow*.
7 Outline the ways in which human activities have affected groundwater.

1.2 Discharge relationships within drainage basins

Hydrographs

A **storm hydrograph** shows how the discharge of a river varies over a short time (Figure 1.8). Normally it refers to an individual storm or group of storms of not more than a few days in length. Before the storm starts, the main supply of water to the stream is through groundwater flow or baseflow. This is the main supplier of water to rivers. During the storm, some water infiltrates into the soil while some flows over the surface as overland flow or runoff. This reaches the river quickly as **quickflow**, which causes a rapid rise in the level of the river. The **rising limb** shows us how quickly the **flood** waters begin to rise, whereas the **recessional limb** is the speed with which the water level in the river declines after the peak. The **peak flow** is the maximum discharge of the river as a result of the storm, and the **time lag** is the time between the height of the storm (not the start or the end) and the maximum flow in the river.