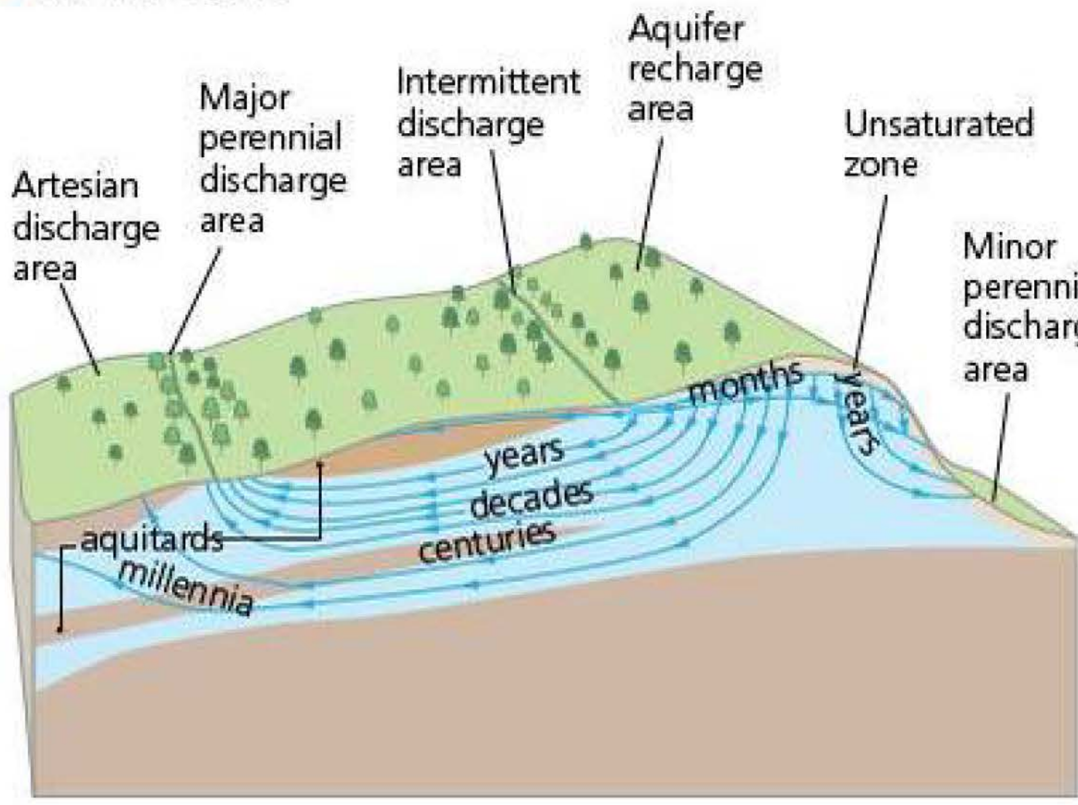
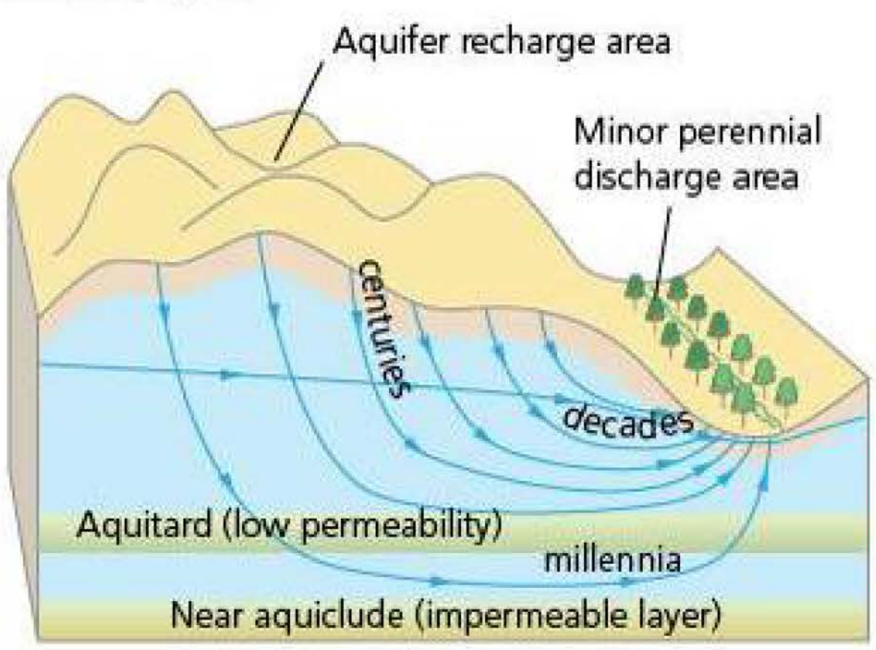
Aquifers (rocks that contain significant quantities of water) provide a great reservoir of water. Aquifers are permeable rocks such as sandstones and limestones. The water in aquifers moves very slowly and acts as a natural regulator in the hydrological cycle by absorbing rainfall that otherwise would 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.

a In humid regions



b In semi-arid regions



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 50 years, and in Saudi Arabia the groundwater reserve in 2010 was 42 per 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.

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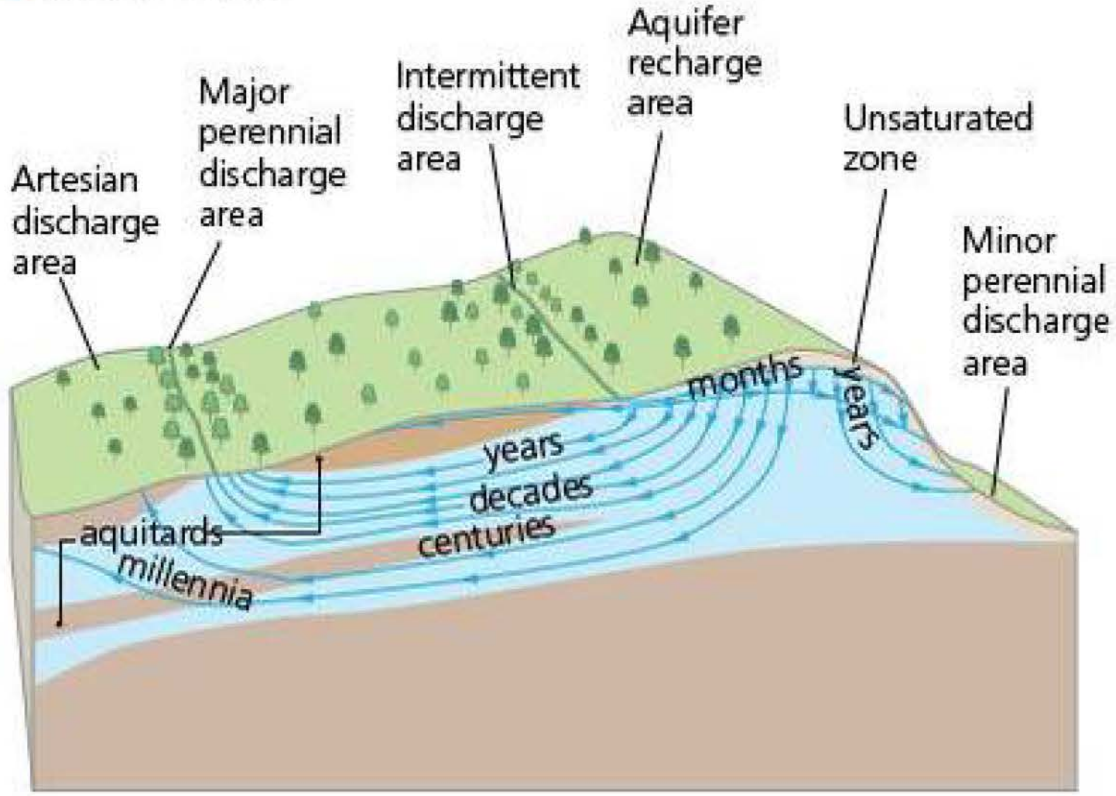

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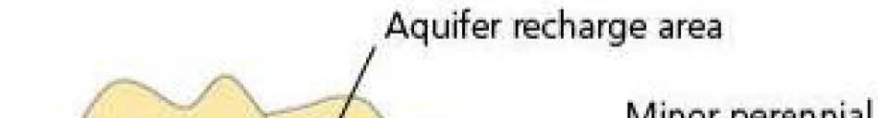

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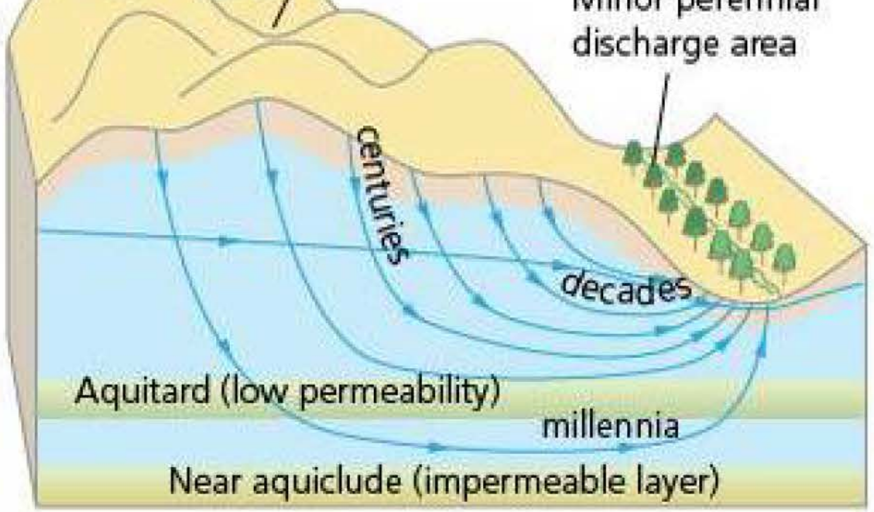

Source: *Advanced Geography: Concepts & Cases* by P. Guinness & G. Nagle (Hodder Education, 1999), p.248

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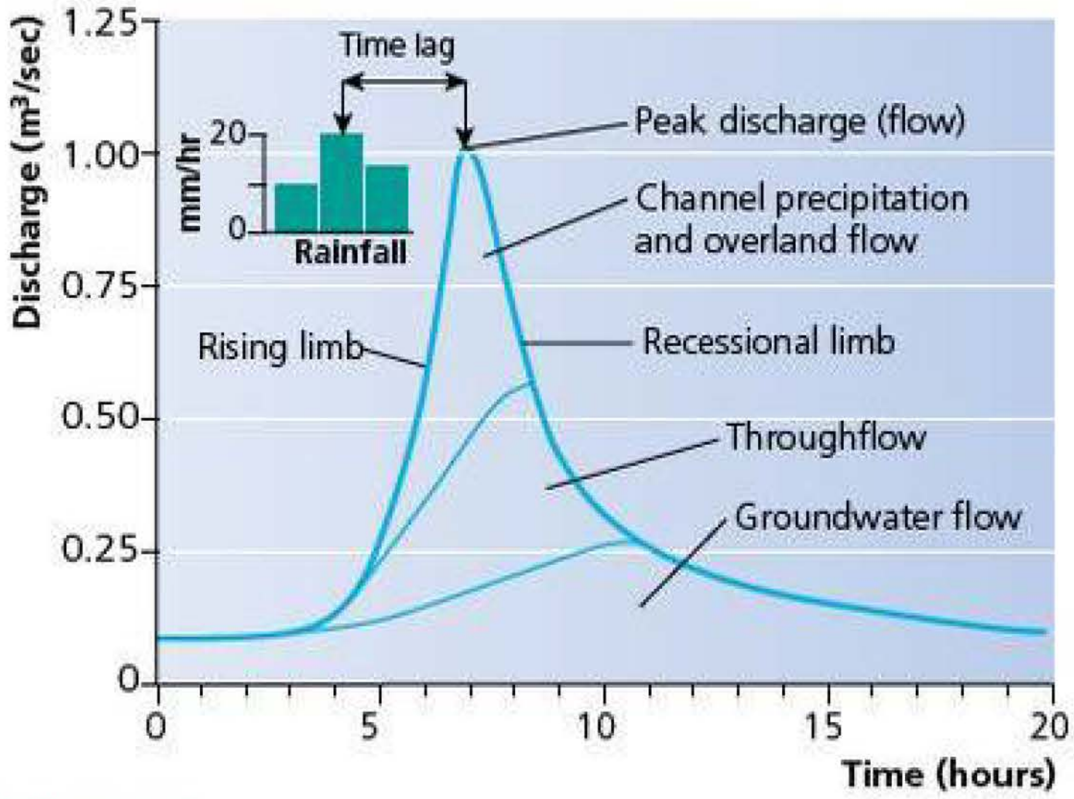


Figure 1.8 A simple hydrograph

In contrast, a **river regime** is the annual variation in the discharge of a river. Stream discharge occurs as a result of overland runoff and groundwater springs, and from lakes and meltwater in mountainous or sub-polar environments. The character or **regime** of the resulting stream or river is influenced by several variable factors:

- the amount and nature of precipitation
- the local rocks, especially porosity and permeability
- the shape or morphology of the drainage basin, its area and slope
- the amount and type of vegetation cover
- the amount and type of soil cover.

On an annual basis, the most important factor determining stream regime is climate. Figure 1.9 shows generalised regimes for Europe. Notice how the regime for the Shannon at Killaloe (Ireland) has a typical temperate regime, with a clear winter maximum. By contrast, Arctic areas such as the Gloma in Norway and the Kemi in Finland have a peak in spring associated with snowmelt. Others, such as the Po near Venice, have two main maxima – autumn and winter rains (Mediterranean climate) and spring snowmelt from Alpine tributaries.

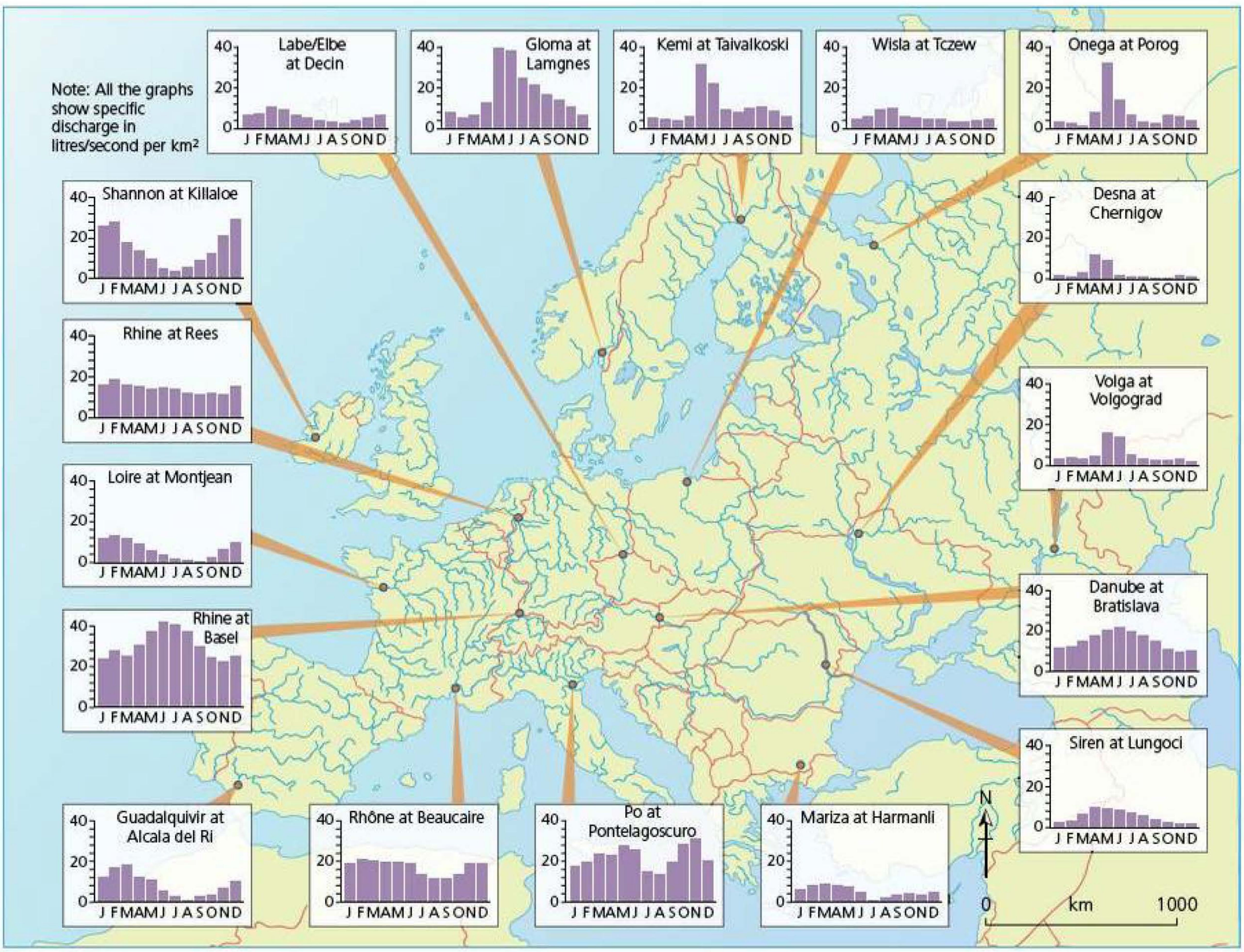
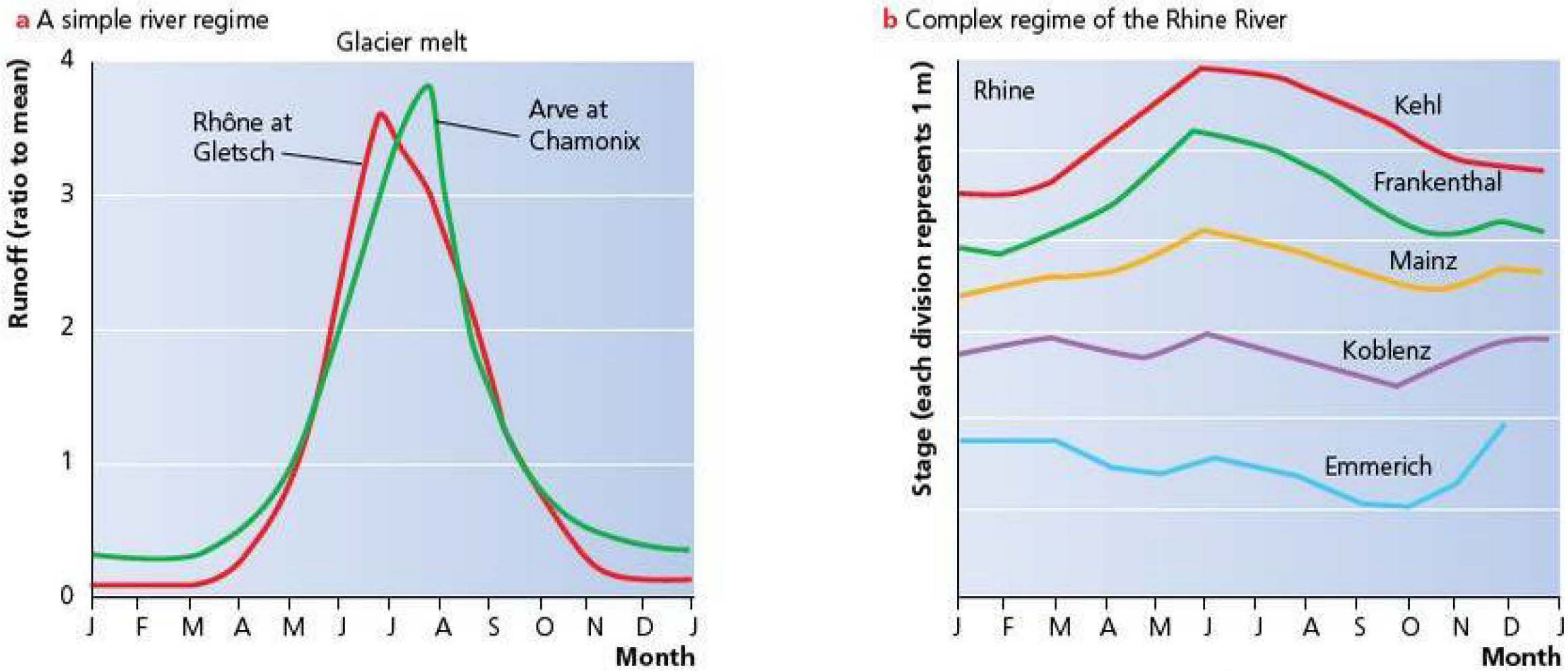


Figure 1.9 River regimes in Europe



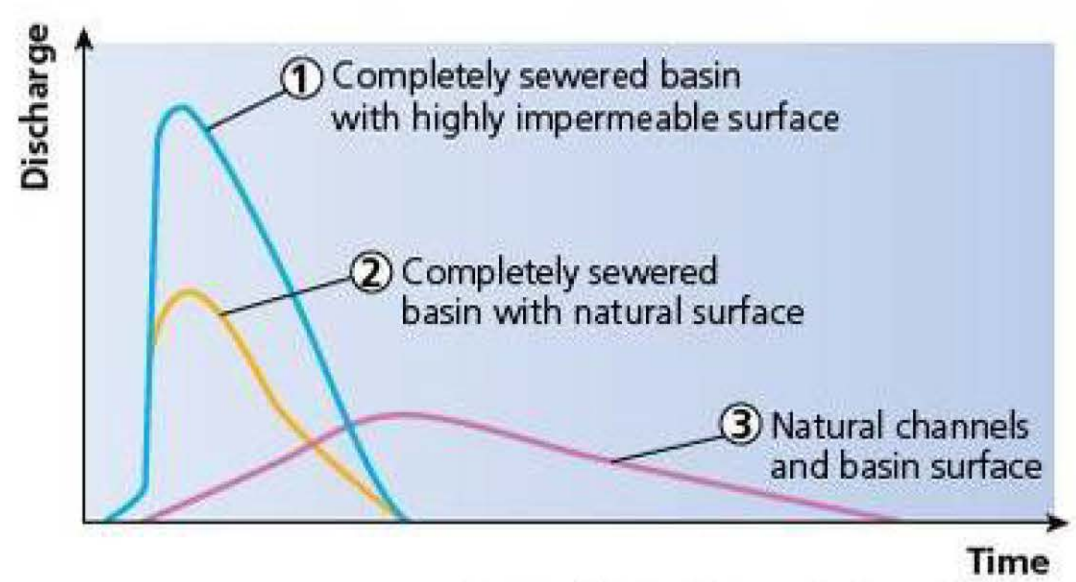
Source: *Advanced Geography: Concepts & Cases* by P. Guinness & G. Nagle (Hodder Education, 1999), p.262

Figure 1.10 Simple and complex river regimes

Figure 1.10a shows a simple regime, based upon a single river with one major peak flow. By contrast, Figure 1.10b shows a complex regime for the River Rhine. It has a number of large tributaries that flow in a variety of environments, including alpine, Mediterranean and temperate. By the time the Rhine has travelled downstream, it is influenced by many, at times contrasting, regimes.

Influences on hydrographs

The effect of urban development on hydrographs is to increase peak flow and decrease time lag (Figure 1.11). This is due to an increase in the proportion of impermeable ground in a drainage basin, as well as an increase in the drainage density. Storm hydrographs also vary, with a number of other factors (Table 1.3) such as basin shape, drainage density and gradient.



Source: *Advanced Geography: Concepts & Cases* by P. Guinness & G. Nagle (Hodder Education, 1999), p.255

Figure 1.11 The effects of urban development on storm hydrographs

Table 1.3 Factors affecting storm hydrographs

Factor	Influence on storm hydrograph
Climate	
Precipitation type and intensity	Highly intensive rainfall is likely to produce overland flow, a steep rising limb and high peak flow. Low-intensity rainfall is likely to infiltrate into the soil and percolate slowly into the rock, thereby increasing the time lag and reducing the peak flow. Precipitation that falls as snow sits on the ground until it melts. Sudden, rapid melting can cause flooding and lead to high rates of overland flow, and high peak flows.
Temperature, evaporation, transpiration and evapotranspiration	Not only does temperature affect the type of precipitation, it also affects the evaporation rate (higher temperatures lead to more evaporation and so less water getting into rivers). On the other hand, warm air can hold more water so the potential for high peak flows in hot areas is raised. Increased vegetation cover intercepts more rainfall and may return a proportion of it through transpiration, thereby reducing the amount of water reaching stream channels. The greater the return through evapotranspiration, the less water is able to reach stream channels, and therefore the peak of the hydrograph is reduced.
Antecedent moisture	If it has been raining previously and the ground is saturated or nearly saturated, rainfall will quickly produce overland flow, a high peak flow and short time lag.

⇨

Factor	Influence on storm hydrograph
Drainage basin characteristics	
Drainage basin size and shape	Smaller drainage basins respond more quickly to rainfall conditions. For example, the Boscastle (UK) floods of 2004 drained an area of less than 15 km². This meant that the peak of the flood occurred soon after the peak of the storm. In contrast, the Mississippi River is over 3700 km long – it takes much longer for the lower part of the river to respond to an event that might occur in the upper course of the river. Circular basins respond more quickly than linear basins, where the response is more drawn out.
Drainage density	Basins with a high drainage density, such as urban basins with a network of sewers and drains, respond very quickly. Networks with a low drainage density have a very long time lag.
Porosity and impermeability of rocks and soils	Impermeable surfaces cause more water to flow overland. This causes greater peak flows. Urban areas contain large areas of impermeable surfaces. In contrast, rocks such as chalk and gravel are permeable and allow water to infiltrate and percolate. This reduces the peak flow and increases the time lag. Sandy soils allow water to infiltrate, whereas clay is much more impermeable and causes water to pass overland.
Rock type	Impermeable rocks such as granite and clay produce greater peak flows with a more flashy response. In contrast, more permeable rocks such as chalk and limestone produce storm hydrographs with a much lower peak flow (if at all) and with a much delayed/less flashy response (greater time lag).
Slopes	Steeper slopes create more overland flow, shorter time lags and higher peak flows.
Vegetation type	Forest vegetation intercepts more rainfall, especially in summer, and so reduces the amount of overland flow and peak flow and increases time lag. In winter, deciduous trees lose their leaves and so intercept less.
Land use	Land uses that create impermeable surfaces, or reduce vegetation cover, reduce interception and increase overland flow. If more drainage channels are built (sewers, ditches, drains), the water is carried to rivers very quickly. This means that peak flows are increased and time lags reduced.

Section 1.2 Activities

1 Compare the river regimes of the Gloma (Norway), Shannon (Ireland) and Rhine (Switzerland). Suggest reasons for their differences.
2 Table 1.4 shows precipitation and runoff data for a storm on the Delaware River, New York. Using this data, plot the storm hydrograph for this storm. Describe the main characteristics of the hydrograph you have drawn.
3 Define the terms *river regime* and *storm hydrograph*.
4 Study Figure 1.11, which shows the impact of urbanisation on storm hydrographs. Describe and explain the differences in the relationship between discharge and time.

Table 1.4 Precipitation and runoff data for a storm on the Delaware River, New York

Date	Time	Duration of rainfall	Total (cm)
29 September	6 a.m.	12 hours	0.1
29 September	6 p.m.	12 hours	0.9
30 September	6 p.m.	24 hours	3.7
30 September	12 p.m.	6 hours	0.1
		Total	**4.8**

Date	Stream runoff (m³/s)
28 September	28.3 (baseflow)
29 September	28.3 (baseflow)
30 September	339.2
1 October	2094.2
2 October	1330.1
3 October	594.3
4 October	367.9
5 October	254.2
6 October	198.1
7 October	176.0
8 October	170.0
9 October	165.2 (baseflow)

1.3 River channel processes and landforms

Erosion

Abrasion (corrasion) is the wearing away of the bed and bank by the load carried by a river. It is the mechanical impact produced by the debris eroding the river's bed and banks. In most rivers it is the principal means of erosion. The effectiveness of abrasion depends on the concentration, hardness and energy of the impacting particles and the resistance of the bedrock. Abrasion increases as velocity increases (kinetic energy is proportional to the square of velocity).

Attrition is the wearing away of the load carried by a river. It creates smaller, rounder particles.

Hydraulic action is the force of air and water on the sides of rivers and in cracks. It includes the direct force of flowing water, and **cavitation** – the force of air exploding. As fluids accelerate, pressure drops and may cause air bubbles to form. Cavitation occurs as bubbles implode and evict tiny jets of water with velocities of up to 130 m/s. These can damage solid rock. Cavitation is an important process in rapids and waterfalls, and is generally accompanied by abrasion.

Corrosion or **solution** is the removal of chemical ions, especially calcium. The key factors controlling the rate of corrosion are bedrock, solute concentration of the stream water, discharge and velocity. Maximum rates of corrosion occur where fast-flowing, undersaturated streams pass over soluble rocks – humid zone streams flowing over mountain limestone.