Rainfall events mean that the pattern of river flow is not smooth. This is illustrated by the hydrograph for the River Ock in Figure 1.25. Each time it rains the River Ock responds quickly, giving the hydrograph a jagged appearance. Each sudden rise and then subsequent fall in discharge can be closely studied using a storm (or flood) hydrograph. Storm hydrographs are graphs of discharge over the time period when the normal flow of a river is affected by a storm event.

The storm (flood) hydrograph

We have already seen that a hydrograph is a graph of river discharge against time. A **storm hydrograph** is the graph of the discharge of a river leading up to and following a storm or rainfall event. They are important because they can predict how a river might respond to a rainstorm. This can help in managing the river.

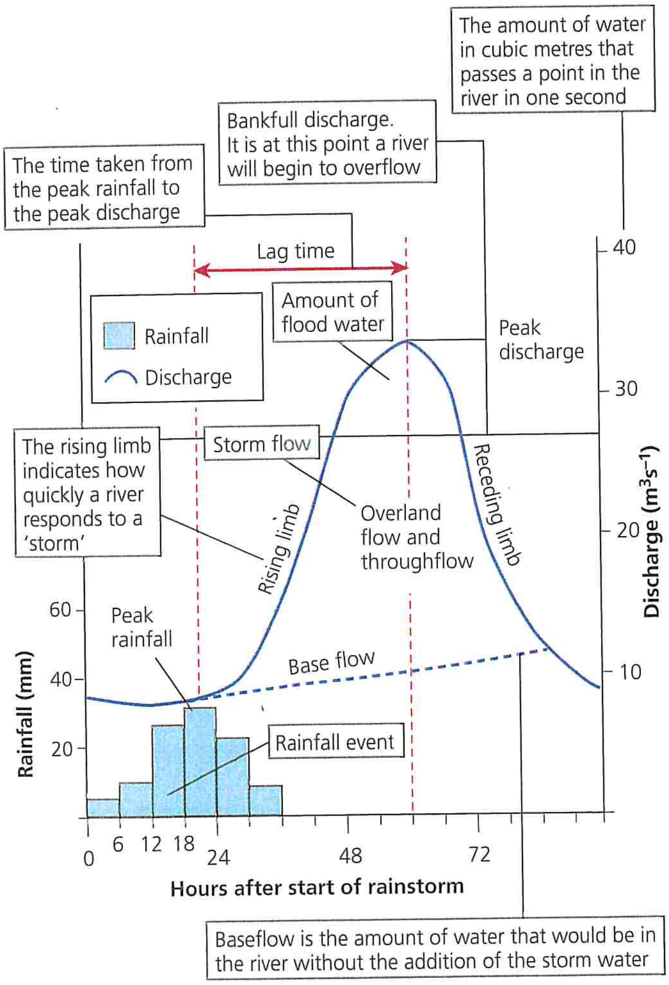

Figure 1.26 A storm hydrograph

The storm hydrograph starts with the base flow. The river is fed by throughflow of soil water and groundwater. The slow movement of this water means that the changes in discharge are small. As storm water enters the drainage basin the river begins to be fed by much more fast-moving water. The discharge rises, as shown by the rising limb of the storm hydrograph. It eventually reaches a peak discharge, the highest flow in the channel for that event. The time taken from the peak rainfall to the peak discharge is called the **lag time**. The discharge begins to fall as shown by the receding limb of the graph. When all the storm water has passed through, the river returns to its base flow.

Although all storm hydrographs have the same common elements, they are not all the same shape. Hydrographs that have a short lag time, high peak discharge, steep rising and falling limbs are described as being 'flashy'. Others are a lot more subdued with gentle rising and falling limbs, long lag times and low peak discharge. This shape is determined by both physical and human factors. Physical factors:

- Drainage basins that are more circular in shape lead to more flashy hydrographs than those that are long and thin because each point in the drainage basin is roughly equidistant from the measuring point on a river.

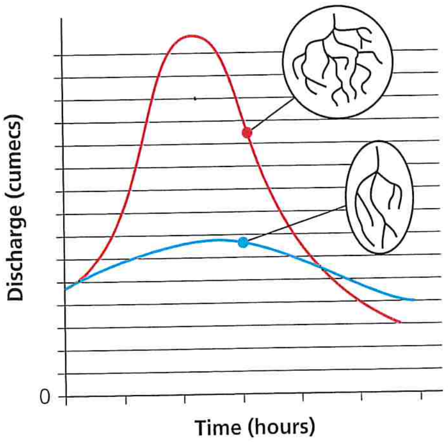

Figure 1.27 The influence of drainage basin shape on storm hydrographs: Water takes less time to reach the river in a round drainage basin than an elongated one

- Drainage basins with steep sides tend to have flashier hydrographs than gently sloped river basins. This is because water flows more quickly on the steep slopes, whether as throughflow or overland flow and so gets to the river more quickly (Figure 1.28, page 18).

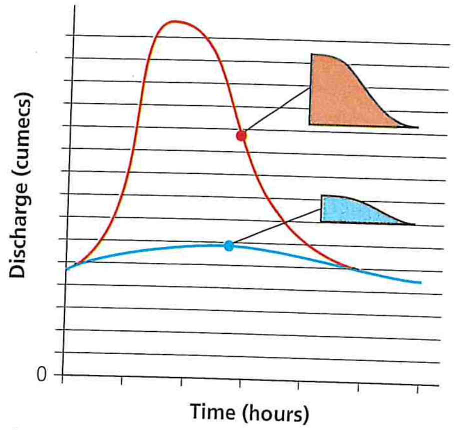

Figure 1.28 The influence of steepness on storm hydrographs: In steep sided drainage basins (or the upper reaches of a river) water gets to the river more quickly than in an area of gentle slopes

- Basins that have a high drainage density (that is, they have a lot of surface streams acting as tributaries to the main river) have flashy hydrographs. All the water arrives at the measuring station at the same time.

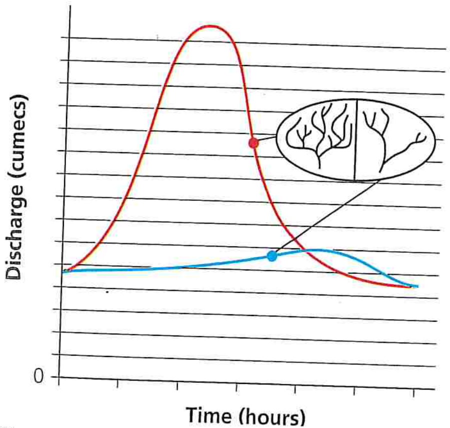

Figure 1.29 The influence of drainage density on flood hydrographs: Drainage basins with high drainage density have flashier river flows

- If the drainage basin is already saturated by antecedent rainfall then overland flow increases because infiltration capacity has been reached. Since overland flow is the fastest of the transfers the lag time is reduced. Again, peak discharge is higher resulting in a flashy hydrograph.
- If the soil or rock type within the river basin is impermeable (for example, clay soils or shale rocks) overland flow will be higher. Throughflow and infiltration will also be reduced, meaning a flashy hydrograph. The same can be said of surfaces baked hard by the sun during a long period of dry weather or frozen surfaces resulting from cold weather.

  On the other hand, drainage basins underlain by sandstones have a subdued hydrograph because the water soaks into this porous rock.
- Thick vegetation cover in drainage basins will have a significant effect on a storm hydrograph. Vegetation intercepts the precipitation, holding the water on its leaves; this slows the movement of rainwater to the ground and so to river channels. Water is also lost due to evaporation and transpiration from vegetation surfaces reducing how much gets to the river. This subdues the storm hydrograph, increasing lag time and reducing peak discharge.
- The amount and intensity of precipitation can affect storm hydrographs. Heavy storms with a lot of water entering the drainage basin over a short time result in higher discharge. The type of precipitation can also have an impact. The lag time is likely to be greater if the precipitation is snow rather than rain. This is because snow takes time to melt before the water enters the river channel. When there is rapid melting of snow the peak discharge could be high.
- Large drainage basins catch more precipitation and so have a higher peak discharge compared to smaller basins. Smaller basins generally have shorter lag times because precipitation does not have as far to travel.

Human factors:

- Deforestation reduces interception rates allowing rainwater to hit the surface directly. The lack of vegetation roots reduces the infiltration rate into the soil. These both lead to rapid overland flow and flashy hydrographs. Deforestation also exposes the soil to greater rates of erosion, which leads to sedimentation of the channel. This reduces the **bankfull** capacity of a river and can lead to a greater chance of flooding.
- Afforestation has the opposite effect making it a useful flood prevention measure.
- Agriculture has a variety of effects, among which are:
  - Ploughing breaks up the topsoil and allows greater infiltration, subduing hydrographs. This can be enhanced by contour ploughing where furrows are created that run directly down slope, then they can act as small stream channels and lead

  to flashier hydrographs. Ploughing wet soils can cause impermeable smears in the subsoil called plough pans. These inhibit percolation leading to greater surface flows.
  - Terracing on hillsides stops movement of water downhill and subdues hydrographs.
  - Grass crops increase infiltration and lead to subdued hydrographs.
  - Large numbers of animals on small areas can impact soils leading to overland flows.
- Growth of urban areas and other large impermeable surfaces such as roads lead to flashy hydrographs (see Chapter 9). This is exacerbated by the very fact that settlements have been built on floodplains. This urban growth leads to the expansion of built-up, impermeable surfaces such as roads, car parks, shopping centres, etc. Most settlements are designed to transfer water as quickly as possible away from human activity to the nearest river. This is achieved through road camber, building design and drainage systems. In many cities in the UK there has been a continued loss of front gardens in favour of paved drives. Due to the growing number of two-/three-car families, an area of vegetated garden equivalent to 300 ha/year was lost in London between 1998 and 2006.

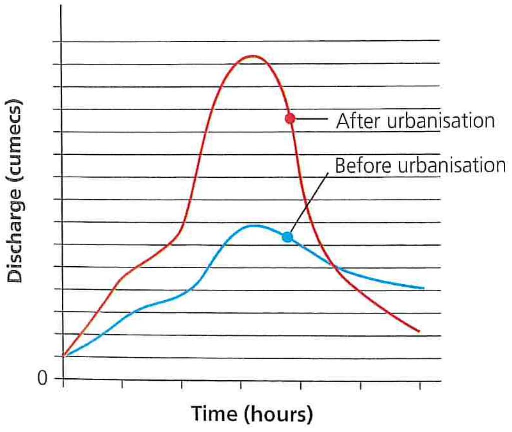

Figure 1.30 The influence of land use change on flood hydrographs: Impermeable surfaces shaped to get rid of water quickly, combined with a dense network of smooth drains, means that water gets to the river very quickly. The river itself can also be altered, for example, to move the water rapidly away from the urban area

Skills focus

You need to be able to draw storm hydrographs accurately and be able to label them with reasons for their pattern.

- Some soft engineering flood management schemes attempt to reduce flashiness in a river's hydrograph. Afforestation increases interception and infiltration. This slows down the progress of water to the river channel and subdues any changes in discharge.
- Water abstraction reduces the base flow and so more water must reach the channel before it reaches bankfull capacity.

Examples of how land use changes can affect the water cycle

Deforestation

Tropical South America contains the world's largest continuous tropical forest and savannah ecosystems. This region is environmentally important not only because of traditional ecological measures, such as its high biodiversity, but also because it generates more than a quarter of the world's river discharge. It has undergone explosive development and deforestation in the last 50 years as national and international demand for cattle feed (mostly soy), beef and sugar cane for ethanol, have increased. Already about 10 per cent of the rainforest in this large region has been converted to cattle pasture and agriculture.

Deforestation and forest degradation result in a complex set of changes to streams of all sizes. When forests are removed, the new vegetation generally has fewer leaves and shallower roots. This means it uses less water than the forest it replaces. The result is that less water evaporates from the land surface to be returned to the atmosphere; more water runs off of the land and stream flow is increased. The amount of change that occurs depends on local conditions including the amount of rainfall, how much of a watershed is deforested, topography, soils and the land use after deforestation. Studies have shown that there is little effect with less than 20 per cent of a basin deforested but a large increase with 50 to 100 per cent of a basin deforested. These changes occur at the local scale, but rivers of all sizes are affected when deforestation is extensive.