1 Hydrology and fluvial geomorphology

In this chapter you will learn about:

- How the hydrological cycle operates in general terms and the more specific ways in which water moves through a drainage basin.
- How storm and annual hydrographs are influenced by the climate and by the characteristics of the drainage basin.
- How the processes of erosion, transportation, deposition and sedimentation shape the river channel and help to produce the landforms found along the river's course.
- How people use rivers and how people contribute to the causes and effects of floods. The prediction, prevention and **amelioration** of river floods.

The drainage basin system

The hydrological cycle

The **hydrological cycle** is an example of a model (or theory). Geographers use models to help them describe and explain reality. The real world is complex and is often difficult to understand so geographers use models to simplify it. Models are useful because they help us understand the important processes and cycles that occur on the Earth's surface. However, because they are simplifications, they don't always tell the full story and they should be used with care. The hydrological cycle is a useful and versatile model because it can be applied at a range of scales, so the model applies to any land area on Earth.

The hydrological cycle is the way that water moves from the sea, through the air, onto (and into) the land, and back into the sea. It is driven by the sun's heat and by gravity. It is often known simply as the water cycle.

At any one time, the Earth's water is distributed as follows:

- 97 per cent is in the sea
- 2.1 per cent is frozen as snow and ice (mostly Greenland and Antarctica)
- 0.8 per cent is fresh water in rivers, lakes and the ground
- 0.1 per cent is in the atmosphere.

People use *fresh* water and fresh water accounts for less than 1 per cent of all the water on the planet. It is this 0.9 per cent of the Earth's water that is involved in the hydrological cycle at any one time. This is why we need to fully understand the hydrological cycle in order to use the available fresh water as efficiently and effectively as possible.

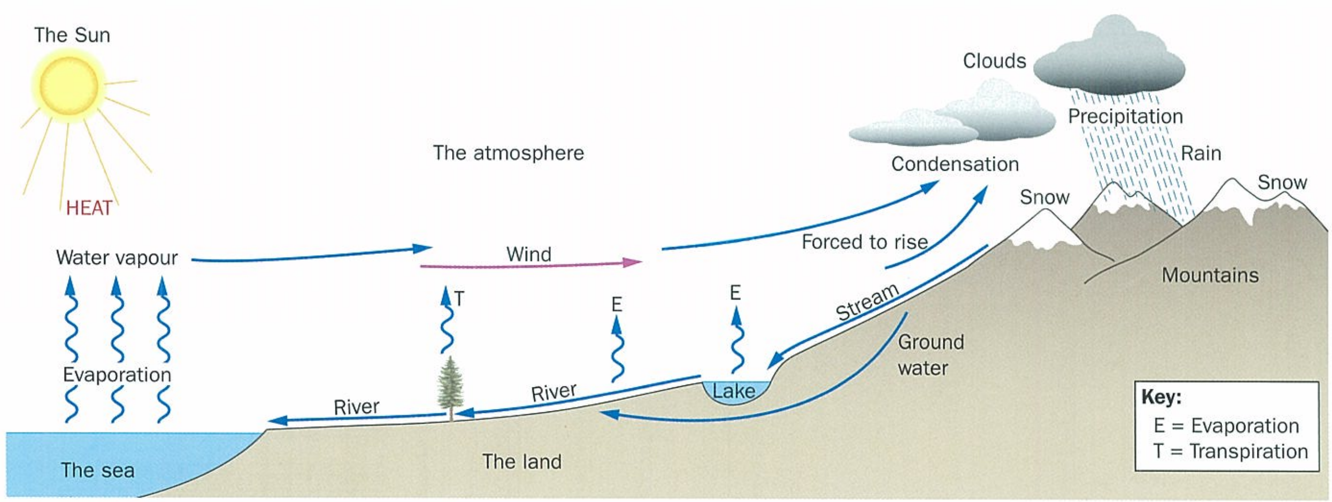

Fig. 1.1 The hydrological cycle

> **1.** Study Fig. 1.1 and then write a short paragraph to describe and explain the movement of water around the hydrological cycle. It should begin 'The sun shines down on the sea and...'.

The drainage basin as a system

This is the part of the hydrological cycle which operates once rain has fallen onto a **drainage basin**. It is known as the drainage basin system because it has inputs, stores, flows and outputs. Geographers often use a *systems approach* in their studies. As with models, the systems approach allows geographers to simplify reality in order to understand it.

The drainage basin system is an open, dynamic system: *open* because water and energy flow into, through and out of the drainage basin; *dynamic* because the system responds to changes in its inputs: e.g. river **discharge** varies in response to changing inputs of precipitation.

We have to understand the drainage basin system in order to be able to understand how rivers behave, especially if we want to explain changes in river discharge and river flooding.

The drainage basin

A drainage basin is the area of land drained by a river and its tributaries. A drainage basin supplies a river with its water.

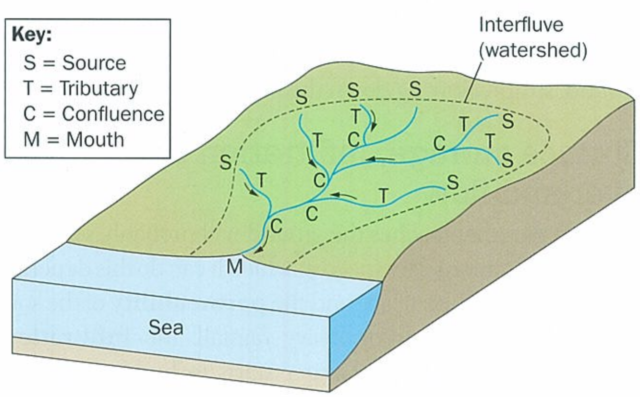

Fig. 1.2 A diagram of a typical drainage basin

Geographers in different parts of the world often use different words for the same thing. This is the case here. In the UK, 'drainage basin' is the phrase used to describe the area of land drained by a river and its tributaries. Some UK geographers also use the phrase 'river catchment'. This phrase is also used in the USA, as is the word 'watershed'. Confusion arises here because in the UK the word 'watershed' is used for the boundary of a drainage basin, not for the drainage basin itself. It is probably best to avoid the word 'watershed' and stick to 'drainage basin' and 'interfluve'.

Fig. 1.3 The source of a river. This photograph shows a stream rising from a series of springs. The water simply rises from the ground and flows off downhill as a new stream

> **2.** Write definitions of the following terms:
> - Interfluve
> - Source
> - Tributary
> - Confluence
> - Mouth.

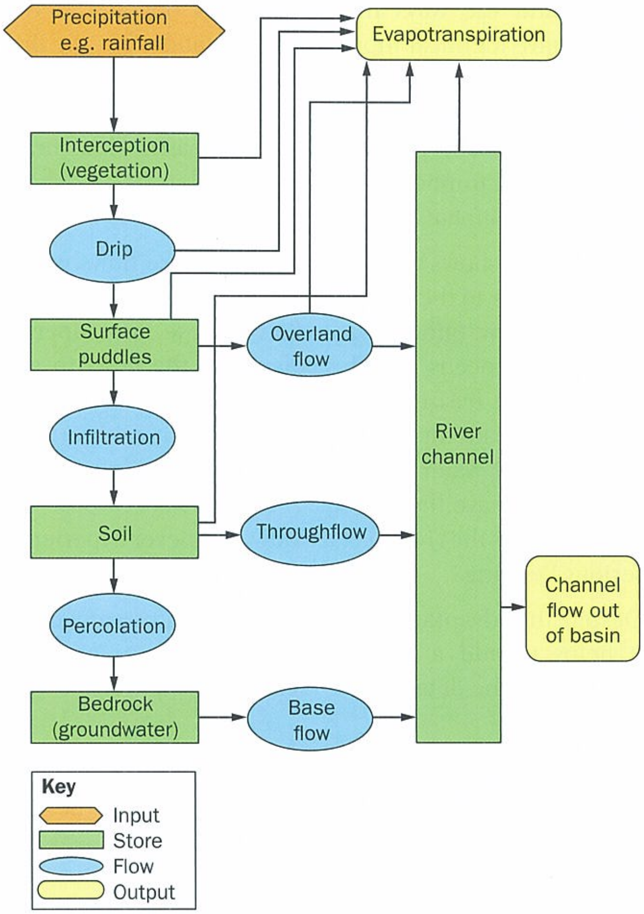

Fig. 1.4 The drainage basin system – a flow diagram

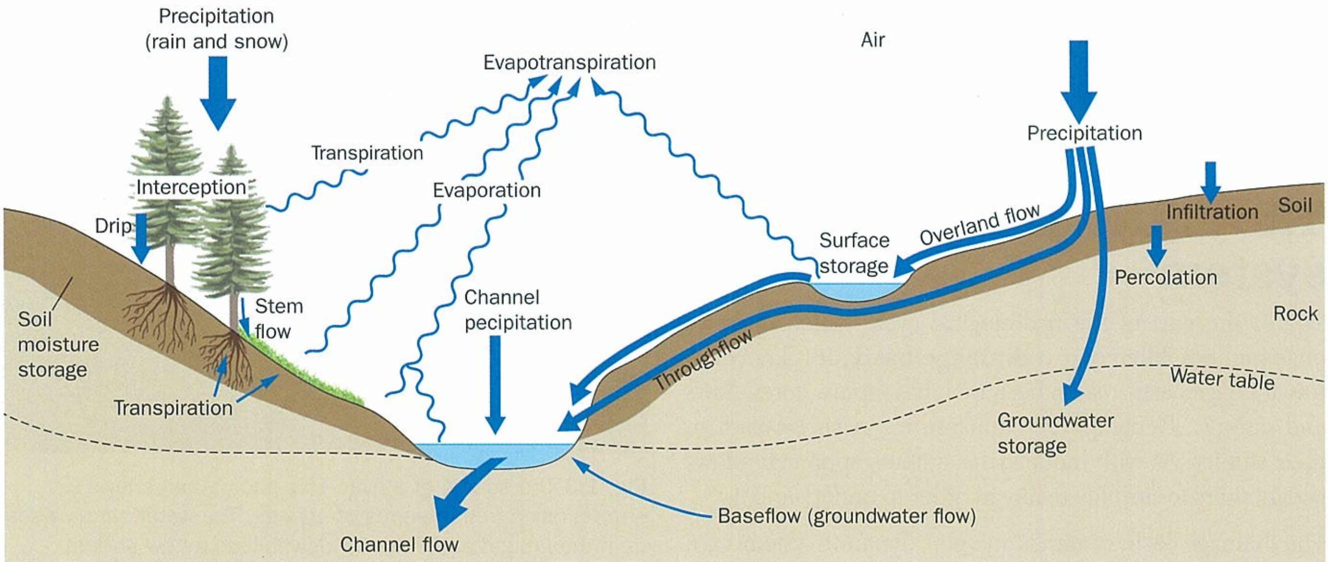

Fig. 1.5 The drainage basin system – a pictographic representation. This shows a cross-section of a river valley. The stream is flowing 'out of the page', towards the reader

Fig. 1.4 shows the drainage basin system reduced to its basic components. This is a combination of a model with the systems approach.

The drainage basin system only has one input (precipitation) but has two outputs: **evapotranspiration** and **channel flow** (river discharge). This helps us understand the ways in which rivers operate. If two basins have identical inputs of precipitation, but the first basin has much more evapotranspiration than the second basin, the first basin will have much less water in the main river (discharge) than the second basin. This simple fact has huge implications for the way that rivers behave in different climate zones and from season to season.

Fig. 1.4 also shows that there are only three flows which provide water to the river: **overland flow**, **throughflow** and **baseflow** (groundwater flow). These flows operate at different speeds and the balance of the flows in any one drainage basin will determine how quickly a river responds to an input of rainfall. A basin with a high proportion of water reaching the river via overland flow will tend to have flash floods. A basin where most of the water reaches the river via baseflow may never experience serious flooding.

Despite the advantages of simplified diagrams, sometimes it helps to add a little more complexity in order to understand the details more clearly (see Fig. 1.5).

The components of the drainage basin system

Precipitation

Water falling from the sky. Rain is the most important form of precipitation.

Interception

This is rain which is intercepted before it reaches the surface of the ground. It is usually intercepted by vegetation, especially by the leaves of trees. During a short summer shower it is possible to stay dry by standing under a tree because the tree's leaves 'intercept' and 'store' the raindrops before they reach the ground.

Throughfall (drip) and stemflow

In a prolonged rainstorm, the leaves become saturated and water will begin to drip to the ground. Stemflow is another important way in which water moves from the tree to the ground, simply flowing down the outside of the tree trunk.

Surface storage, infiltration and overland flow

The first rain that reaches the ground will probably soak into the soil (infiltration). The speed at which it can do this depends on the nature of the surface and the **permeability** of the soil. During prolonged and/or heavy rainfall, the **infiltration capacity** is exceeded and water starts to build up on the surface. This is surface storage and produces puddles. On a slope, this surface water will flow downhill towards the river, producing overland flow (surface runoff). Overland flow is a relatively quick process. When the soil is saturated and rain continues to fall, the rainfall will then produce surface runoff. This runoff is called saturated overland flow.

Urban surfaces such as concrete are designed to be flat and impermeable. They rapidly produce Hortonian overland flow, which is shallow, laminar, and fast-moving. Hortonian overland flow is most commonly encountered on city streets, construction sites and dirt roads in the countryside. This process poses a significant problem in steep, recently ploughed rural areas, where the water flowing over the surface can build up great speed and contribute to serious soil erosion.

Soil storage, percolation, and throughflow

In the soil, water is held in pores, so soil often feels quite damp.

- Clay soil has very small pores and does not let water pass through it easily - it is an impermeable soil, but holds water well. Infiltration rates of 0–4 mm/hour are typical.
- Sandy soil has many large pores and allows water to pass through it easily. The pores are gaps between the sand grains and they make the sand **porous**. It is this **porosity** which makes the sandy soil permeable, but losing its water very quickly. Infiltration rates of 6–12 mm/hour are typical.

A permeable soil allows water to pass through it in two ways. Water that flows down into the bedrock is called **percolation**. Water that flows downhill through the soil, parallel to the surface, is called throughflow. Throughflow gets water to the river more slowly than overland flow, but faster than baseflow.

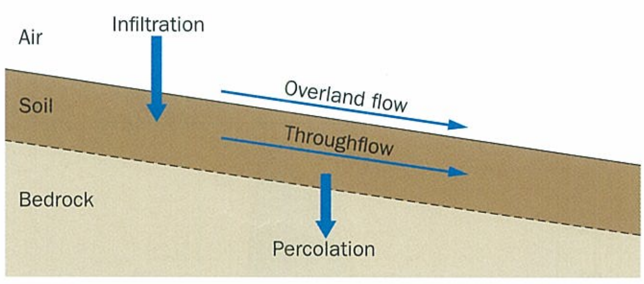

Fig. 1.6 Water in the soil

Groundwater and baseflow

Water that percolates into the bedrock is called **groundwater**. This water flows down through the rocks until it reaches the level of saturation or **water table**. Most groundwater eventually flows down through the rocks towards the nearest river. We call this baseflow or groundwater flow and it is normally a very slow process indeed. The water table moves up and down, depending on the amount of rainfall percolating downwards and the amount of baseflow flowing out of the rocks into the river. Where the water table reaches the surface other than at a river bed, groundwater reappears as a spring (see Fig. 1.3 on page 3). Where the rock structure is favourable, groundwater can remain in the rocks for a very long time. In the Sahara, there are underground stores of groundwater (**aquifers**) which fell as rain thousands of years ago.

Groundwater is an important source of fresh water. Wells can be dug and **boreholes** can be drilled down to the water table and the groundwater can be extracted. Because it has been filtered through the rocks, this water is normally very pure. Because of the continuous operation of the hydrological cycle, water is a renewable resource, but if groundwater is extracted faster than it is replaced, the water table will fall and the well will dry up. For example, the Saharan aquifers are being used unsustainably and they will eventually dry up. This is because the rate of **recharge** (water moving from the surface into the rocks) is much slower than the rate of **abstraction**.

Evapotranspiration

- Water evaporates from leaves, puddles and streams. The rate depends on the temperature of the water, the warmth and humidity of the air, and the speed of the wind.
- Plants draw water from the soil through their roots and allow it to evaporate into the air through their leaves. The water vapour exits the leaves through the stomata, pores which are found on the underside of the leaf. We call this **transpiration**.
- Together, we refer to this water loss from the basin as evapotranspiration. It is an important output of water from the basin and in an equatorial rainforest area it can amount to 80 per cent of the total output of water from the basin.

Channel flow

Rainfall reaches the river via overland flow, throughflow and baseflow. Once it is in the river it flows downhill towards the sea as river discharge. This is another output from the drainage basin.

3. (a) Copy and complete the following table using the words listed below:

Inputs	Flows	Stores	Outputs

Evapotranspiration	Infiltration	Soil
Vegetation	Baseflow	Drip (throughfall)
Overland flow	Bedrock	Ground water
Rainfall	Percolation	Stem flow
Throughflow	Puddles	

(b) Name the output not listed in the table.

The drainage basin system and human activity

People need water for many purposes including agriculture. Farmers need to have water in the soil in order to grow their crops. The amount of water in the soil depends on the balance between precipitation and **potential evapotranspiration**. **Actual evapotranspiration** is the amount of water that leaves the drainage basin in the form of water vapour going back to the atmosphere. Potential evapotranspiration is the amount of water that could go back to the atmosphere if an unlimited supply of soil moisture was available. For example, in a desert area such as Egypt, rainfall is about 45 mm per year. The actual evapotranspiration is also 45 mm per year because that is all the water that is available. However, the climate of Egypt is so hot and dry that the potential evapotranspiration is over 2000 mm per year. The balance between the precipitation and potential evapotranspiration is known as the **water budget**.

The water budget (or water balance) is an 'accounting' of the inputs and outputs of water. It can be determined by calculating the inputs, outputs and storage changes of water in the drainage basin. The input of water is from precipitation and outputs are evapotranspiration and channel flow.

It is usually stated in the form of an equation:

$$S = P - Q - E$$

where S = soil storage

P = precipitation

Q = channel flow out of the basin

E = evapotranspiration.

This water balance equation is used by hydrologists to plan and manage water supply within a drainage basin. It can be used to suggest possible water supply shortages for which special measures like hosepipe bans can be introduced to preserve water stocks. It has implications for irrigation, pollution control and flooding, too. The water balance changes from season to season.

Case study: Malaga in southern Spain

Fig. 1.7 Location of Malaga

Malaga is on the Costa del Sol in southern Spain. The Costa del Sol is an important tourist area and there are many small farms producing fruit and vegetables for the tourist hotels and for export. Farmers need enough water in the soil for their crops to grow during the summer tourist season when the crops are in great demand. The annual rainfall is 526 mm but very little falls during the summer. The important question for farmers is how much of this water is available in the soil for their crops. Southern Spain has high summer temperatures and the potential evapotranspiration is high at the time when rainfall is low. The water budget graph shows this information.

The graph for Malaga shows the problems that local farmers face. Evaporation exceeds precipitation from April to October and the soil moisture is used up by the end of May. From June to October there is a soil moisture deficit and crops will not be able to grow unless irrigation water is available from reservoirs or deep wells.

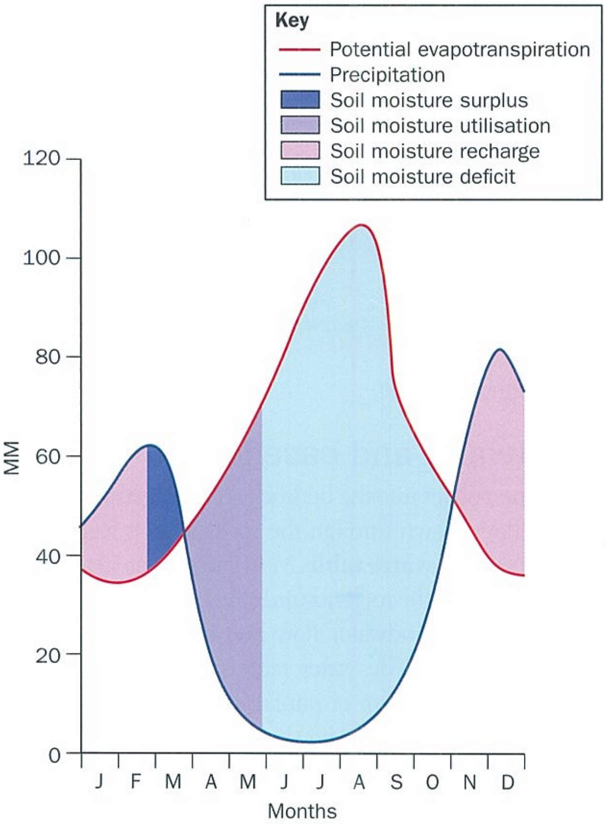

Fig. 1.8 Water budget graph for Malaga, Spain

Streams dry up at this time. Water supply for local people and tourists becomes a problem too – this is why there are so many reservoirs in the hills behind Malaga, storing winter rainfall for use in the summer. Soil moisture is recharged between November and March, but there is only a surplus for one month. Non-irrigated crops can only be grown during the winter months which are warm, as well as wet.

4. Use Fig. 1.8 to compare potential evapotranspiration with precipitation in southern Spain. You should quote figures in your answer. Remember that when you are asked for a comparison you should not write two separate accounts.

RESEARCH Find out what the water budget graph looks like for a tropical rainforest area. Suggest how this water budget might influence the nature of the natural vegetation in the rainforest.

Discharge relationships within drainage basins

River discharge

The amount of water flowing down a river at any one time is called the discharge of the river. Discharge is measured in cubic meters of water per second (cumecs). Most large rivers have several gauging stations along their length, where a continuous record is kept of the river's discharge at that point.

The discharge of a river changes over time, depending on the amount of precipitation, the amount of evapotranspiration and the nature of the drainage basin itself. Drainage basins are open, dynamic systems and changes of discharge over time illustrate the *dynamic* nature of drainage basins.

→ *Key fact 1:* Any factor that increases evapotranspiration will reduce river discharge because water is going back to the atmosphere rather than into the river.

→ *Key fact 2:* Any factor that increases overland flow at the expense of throughflow and baseflow or groundwater flow will increase river discharge because overland flow gets water to the river much more quickly than the other two flows.

The factors affecting river discharge

Climatic factors

The climate has a major impact on the operation of the drainage basin system. River discharge responds to changes in the input of precipitation and to changes in the outputs of evaporation and transpiration.

Precipitation

Precipitation is the major factor affecting river discharge because it is the only input into the system. Large amounts of rainfall will cause river levels to rise while a period of dry weather will lead to falling river levels. The *type* and *intensity* of rainfall are also important. Heavy rainfall from a thunderstorm arrives at the surface quickly, exceeding the infiltration capacity of the soil and causing rapid surface run-off which increases discharge. Steady, drizzly rain arrives on the surface slowly and has more chance of infiltrating into the soil. This slows the rate at which water reaches the river, producing a smaller rise in discharge. Snowfall arrives on the surface as a solid and can't drain away. Sudden rapid melting can lead to a lot of overland flow (especially if the soil is frozen) and this increases the discharge. If the warm weather that melts the snow is accompanied by heavy rainfall, the discharge can be very high - the river, in effect, receives two inputs of precipitation at the same time.

Antecedent moisture

If the ground is already saturated from previous rainfall, a new input of rain will not be able to infiltrate into the soil, causing large amounts of overland flow and increasing discharge rapidly.

Temperature and evaporation

When temperatures drop below freezing point, the soil becomes frozen and impermeable. Rain which falls on frozen soil runs across the surface rapidly, increasing discharge quickly. Temperature also affects evaporation rates. When temperatures are high, evaporation is also high, resulting in less water reaching the river.

Transpiration and evapotranspiration

Forests in a river basin tend to reduce the discharge of the river. Increased interception and increased transpiration mean that evapotranspiration could be a more important output from the drainage basin than river discharge. In the Amazon basin in Brazil, 80 per cent of the rain that falls goes back to the atmosphere, reducing the discharge of the rivers. Vegetation also encourages infiltration and throughflow rather than overland flow. This reduces the speed at which rainfall reaches the river, reducing river levels.

Seasonality

In **temperate** areas of the world, such as Ireland, the season of the year has an important influence on river discharge. In Ireland, rainfall is spread fairly evenly throughout the year, but trees tend to be dormant in winter and have little effect on discharge at this time of year. The colder weather also reduces evaporation rates. This reduction in evapotranspiration is a major reason why Irish river levels are higher in winter. In tropical monsoon areas and in areas with a savanna climate, seasonality is also important. Rainfall occurs during the summer, increasing river discharge during this season. In areas with a Mediterranean climate, the opposite is true. Rainfall is mostly in the winter and streams tend to dry up during the summer.

Drainage basin characteristics

The nature of the drainage basin affects the way water moves through it. Interception, infiltration and percolation all impact on the amounts of overland flow, throughflow and baseflow. These, in turn, determine the speed at which water moves through the drainage basin to the river. The rate at which water arrives at the river affects river discharge.

Size and shape of the drainage basin

Basin size is important. Smaller drainage basins collect less rainfall than larger basins and the discharge of their rivers is smaller as a result. Smaller basins also respond more rapidly to inputs of rainfall. In 2004, heavy rain fell on the small drainage basin that includes Boscastle in the UK. The basin responded so rapidly that the flash floods gave people no warning and no time to prepare. Basin shape also affects flooding. Circular basins respond more promptly to rainfall inputs and have a higher discharge than long, narrow basins of a similar area.

Drainage density

This is the total length of surface streams per square km. It is related to the infiltration rate. Basins with low infiltration have more overland flow and a higher **drainage density** than basins with high infiltration. As a result, drainage basins with a high drainage density respond more quickly to inputs of rainfall so they have rapid surface run-off and a rapidly rising, high discharge.

Soil and rock type

A drainage basin with impermeable soil and bedrock will have a great deal of overland flow but less throughflow and baseflow. Because overland flow is a much faster process than the other two flows, this sort of basin will have higher discharge. A drainage basin with permeable (or porous) soil and bedrock will have much more infiltration and percolation, so throughflow and baseflow (groundwater flow) will be more important than overland flow. This will result in lower river discharge because throughflow and baseflow are much slower than overland flow. Baseflow from the large groundwater store in a basin with permeable rock will also keep the summer discharge relatively high, reducing seasonal variations in discharge.

Permeable rocks allow water to pass through them for different reasons. Granite and limestone contain tiny cracks, mostly vertical joints and horizontal bedding planes. Water can percolate down through these rocks along the cracks and we call these rocks *pervious* as a result. Chalk and Sandstone are made up of particles with pore spaces between the particles. Water can soak down through the pore spaces so these rocks are porous. Pervious limestone and porous sandstone are both permeable, in that they let water percolate down through them, but for different reasons.

Slopes

A drainage basin with steep slopes will have more overland flow and higher river levels than a basin with more gentle slopes where there is more time for water to infiltrate.

Vegetation type and land-use

Forests growing in a river basin tend to reduce the discharge of the river because forests increase interception, leading to greater evaporation. Forests also lead to increased transpiration, which also removes water from the basin before it can reach the river. Any land-use that creates impermeable surfaces or reduces vegetation cover tends to increase overland flow and river discharge. Pasture land allows rainfall to soak into the ground, but has less evapotranspiration than the forest it may have replaced, increasing river discharge. Floodplains tend to be fertile and are often used for arable farming which can involve the use of heavy machinery. These machines squash the soil, reducing infiltration, increasing overland flow and river discharge.

5. Explain how evapotranspiration influences river discharge.
6. Explain how overland flow, throughflow and baseflow affect river discharge.
7. 'Climatic factors are more important than drainage basin characteristics when explaining variations in river discharge'. To what extent do you agree with this statement?

Hydrographs – graphing the changes in river discharge

A graph showing how the river's discharge changes over time is called a **hydrograph**.

- A graph showing how a river's discharge changes over the course of one year is called an **annual hydrograph**.
- A graph showing how a river's discharge changes over a short period of time, responding to a single input of rainfall is called a **storm hydrograph**.

Each of these graphs can be used by hydrologists to help them understand the nature of a drainage basin and the factors that affect the discharge of its river. Water is a valuable resource so it is important to understand the river if its water is to be used sustainably. River flooding is an important hazard and if people are to manage flooding effectively, it is important to understand the way a river behaves and the factors that affect the changes in its discharge.

Annual hydrographs

Annual hydrographs are useful when hydrologists study the responses of a river to its environment. The following examples are all taken from the British Isles.