HYDROGRAPHS are line graphs that plot changes in a river’s discharge over time. Discharge is the volume of water passing along a river’s channel over a given period of time, usually expressed in cubic metres per second, or cubic metres per second, or cumecs. Hydrographs can record river flow on a daily, monthly, annual or individual storm event basis.

Types of hydrograph
The purpose of a hydrograph is to show variations in a river’s discharge in response to precipitation input into a drainage basin. An annual hydrograph shows a river’s discharge over a 12-month period. This shows what is called the river’s regime. Figure 1 shows an annual hydrograph for the River Exe in Devon. Clear peaks can be seen where the river’s discharge has increased rapidly due to heavy and prolonged rainfall during the winter months.

A storm hydrograph records an individual storm event by plotting the hourly discharge of a river. It shows how ‘flashy’ a catchment is – how quickly the river’s discharge increases in response to the precipitation event. The key components and terminology of a storm hydrograph are shown in Figure 2. A rainfall histogram is often plotted on the same graph to show the rainfall/discharge relationship. Figure 2 is an expanded example of a single event as shown on the annual hydrograph in Figure 1.

A rainfall histogram shows how much rain has fallen during the storm event and when the peak rainfall occurred. The rising limb shows the increase in the river’s discharge as the initial runoff reaches the channel. The steeper the rising limb, the faster the response of the river to the rainfall. The river’s discharge continues to increase until it reaches its peak discharge, its highest level. The river will then begin to subside, shown by the falling, or recession, limb. The falling limb often shows a gradual decline as throughflow and groundwater release water that seeps out of the river bank and into the river. This process is slower than surface runoff and maintains the river’s discharge under normal conditions. This is called the baseflow. The bankfull discharge is the stage at which a river’s water level reaches the top of its banks. It has reached its full holding capacity and any further increase in discharge will result in the river flooding onto the floodplain.

Factors affecting hydrographs
The most important part of the storm hydrograph is the lag time. This is the time interval between the peak rainfall and the peak discharge (when the river was at its highest point). Lag time tells us how long it takes for the
precipitation to run off from where it has fallen and into the river channel. The lag time will vary between catchments as all drainage basins have different characteristics. The shorter the lag time, the more dangerous a river is in terms of flooding, as there is little warning. The Boscastle disaster in 2004 was an example of this (see Case Study on page 3).

Water reaches a river channel by three key processes.

- It may flow across the ground as surface runoff (also called overland flow).
- It may seep into the river through soils and rocks as throughflow.
- It may seep into bedrock and move slowly through it as groundwater flow.
- A relatively small amount will fall directly into the river.

These methods of transfer occur at different rates due to a number of factors (Figure 3). These may include the physical characteristics of the drainage basin (such as its relief, its rock and soil type and vegetation cover), or human activities within the basin (such as farming activities, afforestation or deforestation, river management schemes and increased urbanisation). The impact of some of these factors upon a hydrograph are explained in more detail in Figure 3.

A river that has a short lag time is likely to have steep basin sides and perhaps be underlain by impermeable rock. The shorter the lag time, the more ‘flashy’ a catchment is said to be. This means that it responds quickly to a rainfall event. In contrast, a river with a long lag time is likely to have gentler valley sides, be underlain by permeable rocks that allow infiltration and possibly have a high density of vegetation cover that intercepts water on its way to the river channel.

<table>
<thead>
<tr>
<th>Factor</th>
<th>How it affects the hydrograph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount and intensity of precipitation</td>
<td>If there is more rain than the soil can absorb then overland flow will be generated. A long rainfall event will increase the flood risk as soils become saturated and can’t absorb any more moisture.</td>
</tr>
<tr>
<td>Permeability of the underlying rock</td>
<td>If the bedrock is impermeable, less water can infiltrate so there will be lots of surface water. This results in a short lag time and a higher peak discharge than in a basin with permeable rock.</td>
</tr>
<tr>
<td>Drainage basin size and shape</td>
<td>Larger basins react more slowly to storms because only part of the basin will experience the event. Smaller basins respond more rapidly as the whole basin is affected.</td>
</tr>
<tr>
<td>Relief</td>
<td>If the drainage basin has steep sides, water will run off quickly and have little time to percolate into soils.</td>
</tr>
<tr>
<td>Vegetation cover</td>
<td>A dense woodland will intercept water with its leaves, whilst its roots will draw water up from the soil and evaporate it back into the atmosphere. Roots and stems also slow down the passage of water both on the surface and underground.</td>
</tr>
<tr>
<td>Land use and human activity</td>
<td>Deforestation, urbanisation, agriculture and river management all affect the storage capabilities of a drainage basin. Dams built across a river will hold back floodwaters and regulate the flow, thereby reducing the peak discharge and increasing the lag time.</td>
</tr>
</tbody>
</table>

Figure 3: Factors affecting storm hydrographs

The purpose of hydrographs

Storm hydrographs provide useful information for flood management and prevention. In the UK the Environment Agency is responsible for issuing warnings to members of the public whose properties are at risk from flooding. The Environment Agency bases its forecasting of the flood risk on information obtained from monitoring rainfall, river levels, and tide and sea conditions.

Previous flooding events shown on a flood hydrograph will also give a good indication of how a river will react to a high input of precipitation into the drainage basin. Hydrographs enable flood warnings to be issued early and action to be taken to reduce the flood risk. In catchments where there are permeable soils and bedrock and gradual slopes, flood levels will rise slowly and allow preparation, but in catchments with a ‘flashy’ flood response, coordination of warnings and actions needs to be fast.

Case Studies

Flooding in Carlisle, 2005

On 10 January 2005, heavy storms left a trail of devastation in Cumbria. The city of Carlisle on the River Eden bore the brunt of the damage as the equivalent
of two months’ rainfall was unleashed in 24 hours. Figure 4 shows a 7-day hydrograph for the Eden River at Sheepmount gauging station in Carlisle. Figure 5 shows the extent of the flooding in the city. The area immediately to the south of the River Eden was worst affected, where the natural floodplain has been heavily developed. The police station and fire station were swamped by approximately 2.5 metres of water, 70,000 people were left without power in the region, and 3 people lost their lives.

**Boscastle, August 2004**

On 16 and 17 August, 53 years after the Lynmouth flood disaster in North Devon, a very similar event occurred in North Cornwall in the popular tourist harbour village of Boscastle. August had been a wet month throughout England, and on the slopes of the Rivers Valency and Camel catchments around Boscastle, the soils were already quite saturated. In the late afternoon of 16 August more than 12 cm of rain fell in just a few hours (see Figure 6). The geography of the area, where the River Valency catchment has steep valley sides, meant that surface runoff was very rapid. The emergency services mounted an operation to rescue people as rivers in the local area began to rise at an alarming rate and burst their banks. At the flood’s peak some roads were submerged under 2.75 metres of water. The floodwaters swept more than a hundred cars out to sea, knocked down three houses, and destroyed local businesses. Boscastle is a popular tourist destination, and approximately 90% of Boscastle’s economy was dependent on tourism. As a result of the flood, many family-run bed and breakfasts and other businesses were forced to shut as the village set about clearing up after the disaster.

![Figure 5: Flooding in Carlisle, January 2005](image-url)
1 (a) Draw your own storm hydrograph. Add the following labels: lag time, peak discharge, rising limb, falling limb, base flow, storm flow.
(b) Define the term ‘lag time’.
(c) Explain why the lag time might be very short on some rivers, but quite long on others.
(d) What impact does lag time have on people living near a river?

2 (a) What is meant by the term ‘a river’s regime’?
(b) Study Figure 1. Explain why there are seasonal differences in the average discharge of the river.

3 Study Figure 6, showing the amount of rain that fell around Boscastle before and during the disaster.
(a) Approximately how much rain fell in total over the 4-hour period shown in Figure 6?
(b) When was the peak rainfall, and how much precipitation fell?

4 What effect would a very cold period of weather have on a storm hydrograph when there was heavy snowfall in a drainage basin that had a high altitude (height above sea level)?

5 How might deforestation in a drainage basin increase the risk of flooding?

6 (a) Consider how the following factors might affect the shape of a storm hydrograph. For each factor draw a simplified hydrograph to show what it might look like. Think about the response of the river, the steepness of the rising and falling limbs, and the height of the peak discharge.
   (i) A drainage basin with gently sloping valley sides
   (ii) A drainage basin which has saturated soils and experiences a heavy rainstorm
   (iii) A drainage basin covered by deciduous woodland
   (iv) A long thin drainage basin
(b) Select one of the four hydrographs that you have drawn in (a). Write a detailed explanation of the factors affecting its shape. Make sure you refer to specific hydrological processes.

7 ‘Urbanisation can have profound impacts on local hydrological systems.’ Explain this statement.

8 Study Figure 5, which shows the extent of the flooding in Carlisle during the January 2005 floods. The Environment Agency is now proposing that £35 million be spent on flood defences around the city. Compile a report setting out four different management strategies that could be viable in the city to prevent future destruction and devastation. You should assess the advantages and the disadvantages of each scheme.