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HYDROGRAPHS AND PHYSICAL/HUMAN IMPACTS

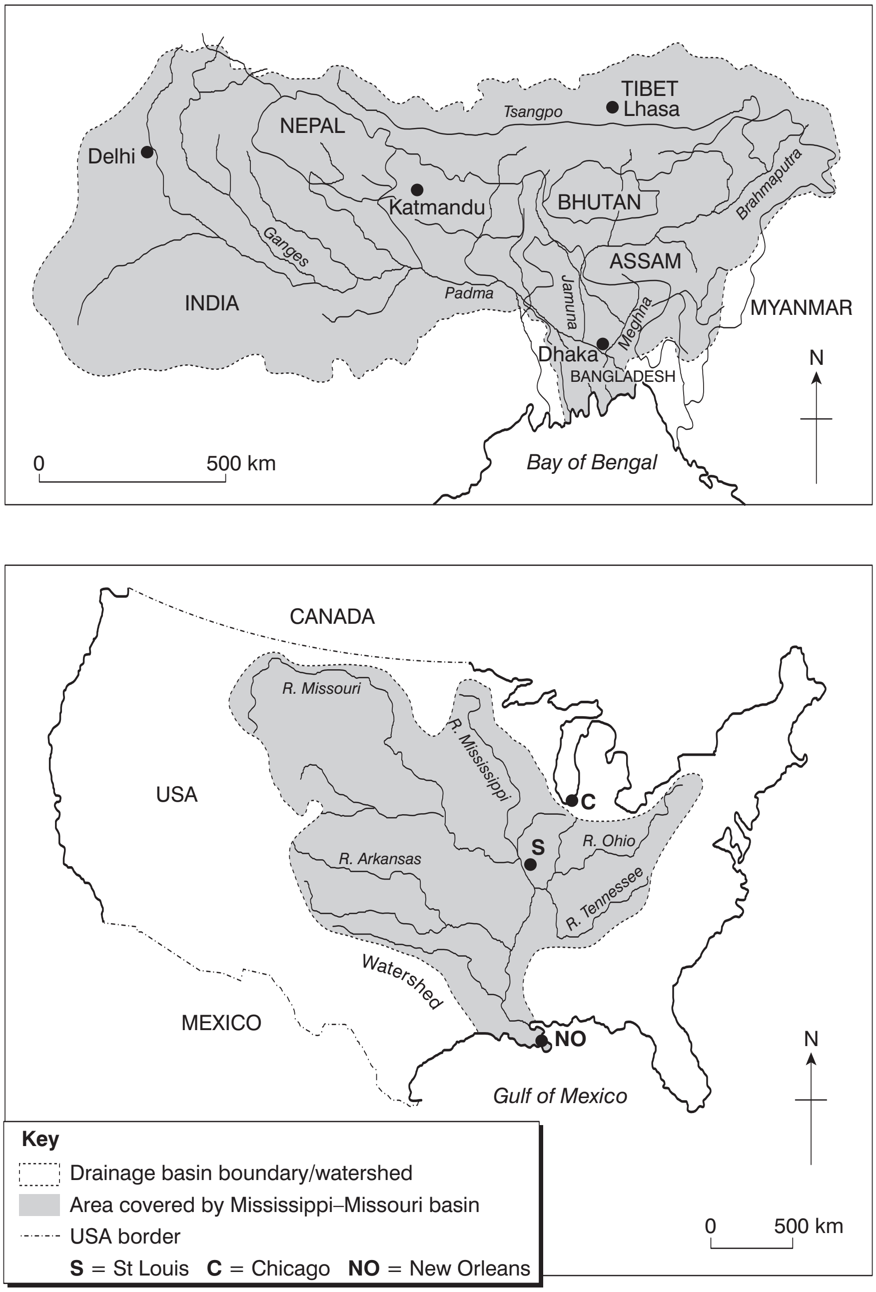
Introduction

The Boscastle floods of 16 August 2004 (see **Geofile** no. 494) graphically illustrated the impact of hydrological processes on people. This extreme flood event is calculated as having a 1:400 return period, an annual probability of 0.25%. **Hydrology** is the scientific study of water flows, river processes and their impacts on physical and human environments. The **hydrological cycle** describes the circulation of water through the atmosphere and across the Earth's surface. The **hydrograph** visually outlines a river's discharge over time. Understanding both are essential for river basin and flood management. This **Geofile** examines the natural systems which operate within the drainage basin and the impact of human modifications on the hydrograph.

The hydrology of the river basin

The river basin is the area drained by a single river or a number of rivers comprising a river system. It is defined by the watershed which separates basins and gives them their shape. River basins vary in size from a few hectares to thousands and may form a nested hierarchy where the smaller catchment areas are an integral part of the larger ones. For example, the River Ganges is 1.1 million sq km, the Mississippi-Missouri 3.2 million sq km and the Amazon 7.05 million sq km (Figure 1). The **river basin** can be thought of as a system with the **inputs** of precipitation, solar energy and potential energy, and the **outputs** of channel runoff (the total quantity of water reaching a river channel from its catchment area within a given time), kinetic energy, sediment loss, deep outflow and evapotranspiration (Figure 2). Components of slope, land use, geology, height, area and shape affect the functioning of the basin.

Figure 1: Drainage basins and catchment areas for Rivers Ganges and Mississippi-Missouri



Source: Burton 1995, 1999

Most river basins cope naturally with variation in inputs with little or no impact on people or the physical environment. In such conditions the system is thought to be in equilibrium or homeostasis. However, the effectiveness of the basin system to cope with variations in rainfall will depend on a wide range of variables, as well as the quantity and intensity of the rainfall. In the case of so many unexpected floods, such as those at Boscastle, it is the intensity of the storm which creates the problem. Where rainfall is continuous and light, such as winter drizzle, there will be fewer short term changes. However, over a longer period even light rain may lead to a gradual accumulation of water that exceeds the system's capacity to deal with it. Precipitation may not just arrive in the form of rain; snow and ice bring their own characteristic delay in the release of water. Later, during a sudden rise in temperature, meltwater may release a greater torrent than the equivalent amount of rain.

Stores in the basin hydrological system play an important part in regulating flows of water. Stores can be compared to a row of sponges

Figure 2: Flows and stores in the drainage basin system

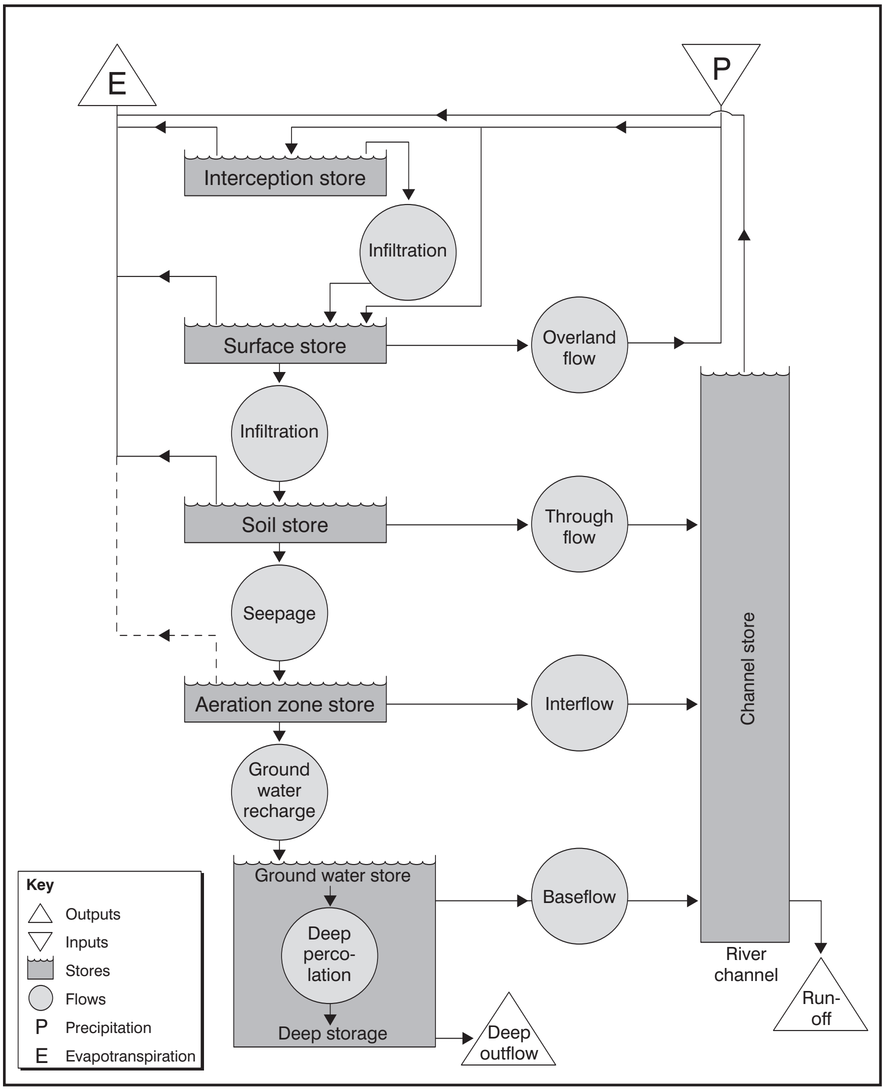
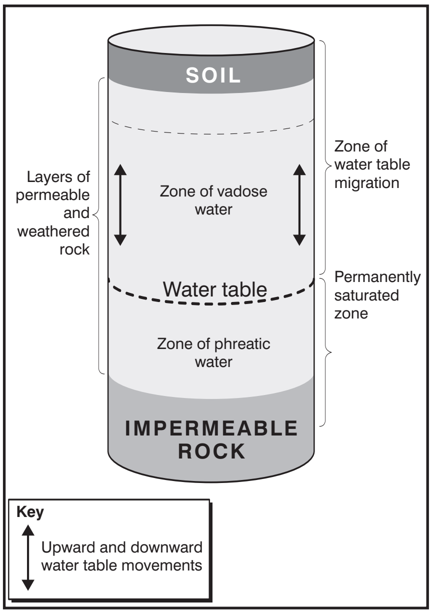


Figure 3: Cross-section showing groundwater and the water table



which soak up and hold water. As the stores fill, just like the pores of a sponge, so they absorb less and, when saturated, release any additional water quickly and in larger volumes. There are six types of river basin store: interception, surface, channel, soil moisture, groundwater and deep storage.

Interception storage is the first stage in any new precipitation inputs. In economically developed countries, most of the precipitation is intercepted by buildings, roads or vegetation before reaching the ground. Calculations have put this at as much as 50% in woodland areas in summer months. However, it is important to recognise that the storage capacity of trees not only varies with the seasons but is also dependent on tree density, leaf shape and size and patterns of branching. Surface storage occurs in natural areas such as lakes and wetlands and in artificial areas such as reservoirs, ponds, drainage ditches and canals. Urban environments also store water in puddles on pavements or rooftops.

As well as being a conduit for water flow channels also store water. When inputs exceed the capacity of the channel to store water flooding occurs. Water can also be stored as soil moisture; when the soil is dry water is absorbed and held by the soils capillary pores. In finely textured soil, such as clay, the numerous capillary pores mean that storage capacity is greater than sandy textured soils, which are free draining. Soil structure also affects storage and soils that have been compacted, for example from intensive farming, have reduced capacity.

Most water in the river basin is held in groundwater stores. Globally, 99% of freshwater is held as groundwater or frozen as ice. Groundwater is present in permanently saturated soil known as the water table (Figure 3). Water can also be stored beneath the water table in the bedrock's cracks and fissures. Deep stores extend into the Earth's surface up to 10,000 metres and may total up to 7 million cubic km of water. Waters in these stores can be thousands of years old. Such stores play little part in the hydrological cycle and the water which seeps down to them is often viewed as an output.

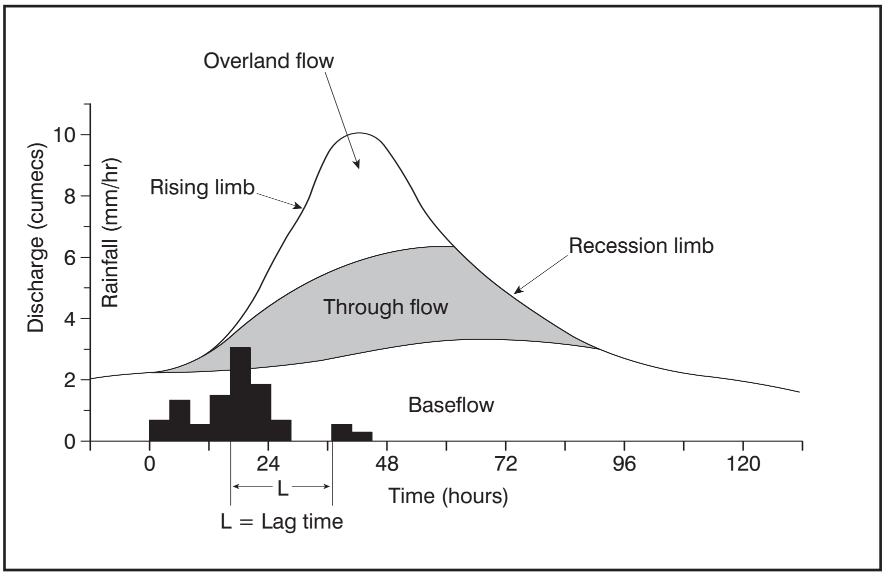
Linking each of the stores is a system of flows which begins to transport water soon after rain falls. The earliest is known as **stem and drip flow** where water that is intercepted by trees and leaves finds its way to the ground by dripping from leaves or running down trunks or branches. Sloping roofs, guttering and drain pipes have a similar effect. The second flow type is known as **infiltration and percolation**. As rainwater infiltrates into the soil the rates and capacity of movement are affected by land use. Fastest rates occur in old permanent pasture and slowest in land covered by weeds or cereals. Paradoxically, where land is bare and baked hard there will be very little penetration.

Overland flow is the fastest flow type. This occurs when rainwater is forced to flow across the surface. This happens because the soil is saturated or, as in the example above, because of an impermeable layer or hardpan. In particularly heavy storms the rate of infiltration may be insufficient to cope with the deluge of water and so overland flow begins before all the stores are full. Usually this type of flow takes the form of small rivulets known as rills. Sometimes during heavy storms these combine to form sheets of water.

Figure 4: Annual regime for River Severn, 1921-1998

Month -	1921-1998 (78 years) Flow (cumecs)	1921-1967 (47 years) Flow	% of 78-yr average	1968-1998 (31 years) Flow	% of 78-yr average	1988-1998 (11 years) Flow	% of 78-yr average
J	115.2	115.2	100	115.2	100	121.7	106
F	99.9	103.3	103	94.7	95	99.3	99
M	74.7	71.0	95	80.1	107	80.5	108
A	53.1	52.0	98	54.8	103	53.5	101
M	38.5	39.4	102	37.2	97	27.2	71
J	29.2	30.6	105	27.1	93	25.3	87
J	22.8	25.1	110	19.3	85	18.1	79
A	27.6	30.7	111	23.0	83	19.5	71
S	34.3	38.7	113	27.4	80	27.5	80
O	51.7	54.9	106	46.7	90	35.6	69
N	92.7	102.6	111	77.2	83	67.0	72
D	101.4	101.4	100	101.5	100	103.2	102

Figure 5: The flood hydrograph



Source: Burton 1995

Where water percolates through the soil and regolith its flow is slowed and becomes THROUGHLO. This type of flow can be vertical and lateral, sometimes utilising natural channels, or percolines, made by earthworms or root systems. Throughflow makes a significant contribution to the water flowing in river channels. As water makes its way into the deeper stores, flows are characterised by ASLO and INTRLO . ASLO can contribute to water in a river channel but only if the water table is higher than the level of the river. This produces the necessary hydraulic gradient. Baseflow provides the inputs into river channels when there have been long periods without rainfall. NTRLO is the discharge of water below the water table. Finally, deep outflow moves groundwater not into the river channel, but directly into the sea or lake that the river discharges into.

Outputs include evapotranspiration, water, sediment and energy. Evaporation from water on the soil or in stores is combined with water released from the pores of leaves (transpiration) to produce APOTRANSPIRATION The river channel moves water, sediment and energy out of the system. Some channels do this more efficiently than others and this in turn affects the hydrograph. River flow is measured as DISCHARG, the volume of water passing a point per unit time (cubic m per second, or 'cumecs').

The annual hydrograph

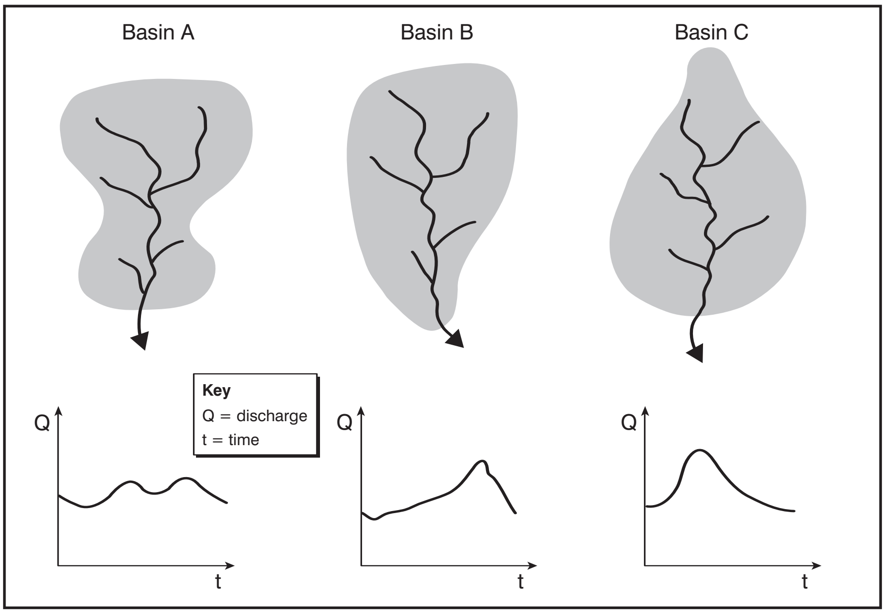
This describes a river's fluctuations in discharge over a year (Figure 4). The pattern of flow is also known as the river regime. In the annual hydrograph seasonal patterns are evident, reflecting variations in inputs and outputs. For example, rivers affected by snowmelt in the northern hemisphere will show a spring peak in discharge with lower flows following and preceding this, although the precipitation inputs will be at the highest in winter.

The flood hydrograph

The flood hydrograph expresses the sequence of relationships that occur between run-off, water flows and other components of the basin hydrological system, together with their adjustments to the physical characteristics of the basin. The flood hydrograph is a graphical measure of changes in discharge over time and can be drawn for individual flood events by converting rainfall into channel runoff or streamflow (Figure 5). The shape of the hydrograph starts with a RISING LIM in which discharge increases rapidly with time. This culminates in a PA DISCHARG which is the maximum flow of the particular flood event (Qp). There is a measurable gap in time between PA RAINALL and PA STRAM LO and this is known as the LAG TIM (tp, or time to peak). The lag time is related to the condition of stores in the basin and the types of flow between them. It measures the time taken for droplets of rainfall to make their way into the river channel. The final shape of the hydrograph is known as the RCSSION LIM which shows the flood subsiding but usually at a slower rate than it builds up. The shape of the graph is therefore shallower than the rising limb. At the base of the storm hydrograph is the discharge known as ASLO which contributes to the 'normal' flow of the river and explains why a river channel contains water even if there has been no rain for several months. When the recession limb has ended discharge returns to the level of baseflow. Rivers that flow constantly are termed PRNNIAL STRAMS while those that 'dry up', having little or no base flow during dry spells, are called PHMRAL STRAMS.

H STORMLO HYDROGRAPH IS TH SUTRACTION O ASLO ROM THROUGHLO AND ORLAND LO . The shape of the hydrograph changes with storms of differing duration being flatter and with a lower peak for storms lasting for a long period of

Figure 6: Basin shape and effect on flood hydrograph



Source: Burton 1995

time. The intensity of rainfall changes the response of the basin as will the length and intensity of previous rainfall events which may have filled stores to their capacity. Even then, a low intensity storm of around 6mm/hour is less likely to produce a peak discharge that exceeds bankfull or channel capacity than a high intensity storm of 70mm/hour.

Physical and human factors affecting hydrographs

There are various physical factors controlling the propensity of a river to flood and it is possible to divide these into those which are 'transient' and those which are 'permanent'. **Permanent controls** include the physical characteristics of the drainage basin such as size, shape, slope, drainage density and permeability. **Transient controls** are made up of climatic factors that vary seasonally and daily. Permanent controls such as the shape of the basin will affect the shape of the flood hydrograph (Figure 6). A circular basin is likely to produce a sharp peak in a hydrograph as the distance water has to flow to discharge is equal in all directions and water will arrive from all sources at roughly the same time. In a stretched out, or elongated, basin the arrival of water will be more staggered because the distance from source of water to the discharge point varies considerably and so the angle of the limbs on the hydrograph are much gentler.

Human factors play an important role in modifying the natural system. Just about every component, store and flow can be changed by people. For example, deforestation and afforestation can affect lag time. Felling trees and clearing land will increase rates of overland flow and reduce lag time making rivers 'flashier' and thus more likely to flood. Conversely, planting forests will increase interception and increase lag time reducing the slope of the rising limb and lowering the peak flow. Farming methods and the types of crops planted can also have an effect. Intensive arable farming systems characterised by large fields and reduced hedgerows will also speed overland flow. Hedge planting, where vegetation acts as a barrier to sheet flow can reduce flood risks. Urbanisation has a major impact on increasing rates of overland flow by speeding up the passage of rainfall into the channel through rooftop guttering, pavement drains and culverts. More significant is the colonisation and urbanisation of the flood plain by people and the subsequent modification of river channels known as 'channelization'. Both processes have tended, often unintentionally, to increase the risk of flooding by changing the shape of the hydrograph. The building of reservoirs or dams can change both annual and flood hydrographs. Dams can increase storage capacity and regulate flow reducing the risk of flooding. However, evidence shows that the downstream risks of flooding may actually increase as a result of changes in the energy dynamics of the river channel.

Managing the flood hydrograph

Management involves the use of a variety of measures to change the shape of the hydrograph by increasing lag time, lowering the flood peak and the gradient of the rising limb. There may also be attempts to modify the channel to increase efficiency and reduce the tendency for bankfull conditions to be reached early. In addition efforts may be made to increase bankfull capacity by building levees which effectively raise and strengthen the banks of the river.

Bibliography

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FOCUS QUESTIONS

1. Using the data in Figure 4 draw out the annual hydrograph for the River Severn.

2. Carry out an internet search on a UK river of your choice. Produce a report on the river's annual and flood hydrographs, and identify the main physical and human factors affecting discharge.

3. Design a programme of fieldwork that would provide students with practical investigation into the components and processes at work in a drainage basin of your choice.

4. Research and write an essay to answer the question: 'Critically evaluate measures to manage the river basin system and flood hydrograph and , drawing on contrasting examples from economically more and less developed countries, assess their success in reducing flood risks.'