Geo Factsheet

Number 71

Floods

This Factsheet summarises the causes, consequences and means of control of flooding.

Floods are one of the most common of all environmental hazards. This is because so many people live in fertile river valleys and in low lying coastal areas. The nature and scale of flooding varies greatly. For example, less than 2% of the population of England and Wales and in Australia live in areas exposed to flooding, compared to 10% of the US population. The worst problems occur in Asia where floods damage about four million hectares of land each year and affect the lives of over seventeen million people. Worst of all is China where over five million people have been killed in floods since 1860.

Some environments are more at risk than others. The most vulnerable include the following:

1. Low lying parts of active flood plains and river estuaries, for example in the lower Thames in London or in Bangladesh, where 110 million people live relatively unprotected on the flood plain of the Ganges/Brahmaputra/Meghna. Floods caused by the monsoon regularly cover 20-30% of the flat delta. In very high floods, up to half of the country may be flooded. In 1988 46% of the land was flooded and over fifteen hundred people were killed.
2. Small basins subject to flash floods. These are especially common in arid and semi-arid areas. In tropical areas some 90% of lives lost through drowning are the result of intense rainfall on steep slopes.
3. Areas below unsafe or inadequate dams. In the USA there are thirty thousand sizeable dams and 2000 communities at risk from dams. In Europe one of the most well-known, spectacular failures was that of the Vaiont dam in Italy in 1963.
4. Low lying inland shorelines such as along the Great Lakes and the Great Salt Lake in the USA.
5. Alluvial fans in semi-arid areas are prone to flash floods
6. Urban areas - here human activity is increasing the frequency and intensity of flooding (Table 1)

Table 1. Potential hydrological effects of urbanisation

Urbanising influence	Potential hydrological response
Removal of trees and vegetation	Decreased evapotranspiration and interception; increased stream sedimentation
Initial construction of houses, streets and culverts	Decreased infiltration; increased storm flows and decreased base flows during dry periods
Complete development of residential, commercial and industrial areas	Decreased porosity, reducing time of runoff concentration, thereby increasing peak discharges and compressing the time distribution of the flow; greatly increased volume of runoff and flood damage potential
Construction of storm drains and channel improvements	Local relief from flooding; concentration of floodwaters may aggravate flood problems downstream

Key Definitions

Bankfull discharge	The discharge measured when a river is at bankfull stage
Bankfull stage	A condition in which a rivers channel fills completely, so that any further increase in discharge results in water overflowing the banks
Channel	The passageway in which a river flows
Channelisation	Modifications to river channels, consisting of some combination of straightening, deepening, widening, clearing or lining of the natural channel
Discharge	The quantity of water that passes a given point on the bank of a river within a given interval of time.
Drainage Basin	The total area that contributes water to a river
Flash Flood	A flood in which the lag time is exceptionally short - hours or minutes A discharge great enough to cause a body of water to overflow its channel and submerge surrounding land
Flood frequency curve	Flood magnitudes that are plotted with respect to the recurrence interval calculated for a flood of that magnitude at a given location
Floodplain	The part of any stream valley that is inundated during floods
Load	The particles of sediment and dissolved matter that are carried along by a river.
Natural Hazards	The wide range of natural circumstances, materials, processes and events that are hazardous to humans, such as locust infestations, wildfires, or tornadoes, in addition to strictly geologic hazards
Risk assessment	1. The process of establishing the probability that a hazardous event of a particular magnitude will occur within a given period 2. Estimating its impact, taking into account the locations of the buildings, facilities, and emergency systems in the community 3. Estimating the potential exposure to the physical effects of the hazardous situation or event, and the community's vulnerability when subjected to those physical effects

In most developed countries the number of deaths from floods is declining, although the number of deaths from flash floods is changing very little. By contrast, national flood damage has increased. The death rate in developing countries is much greater, partly because warning systems and evacuation plans are inadequate. It is likely that the hazard in developing countries will increase as more people migrate and settle in low lying areas and river basins. Often, new migrants are forced into the more hazardous zones.

Since World War II there has been a change in the understanding of the flood hazard, in the attitude towards floods, and policy towards reducing the flood hazard. The focus of attention has shifted away from **physical control (engineering structures)** towards **reducing vulnerability through non-structural approaches**. Three overlapping stages have been identified:

- The structural era 1930s to 1960s (reservoirs, levees, channel improvements)
- The unified flood plain management era 1960s to 1980s (flood warning, land use planning, insurance)
- Post flood hazard mitigation era 1980s onwards (property acquisition and land use control).

The causes of floods

A flood is a high flow of water which overtops the bank of a river. The primary cause of floods are mainly the result of external climatic forces whereas the secondary flood intensifying conditions tend to be drainage basin specific. Most floods in Britain are associated with deep depressions (low pressure systems) in autumn and winter, which are both long in duration and wide in aerial coverage. By contrast in India, up to 70% of the annual rainfall occurs in one hundred days in the summer south west monsoon. Elsewhere, melting snow is responsible for widespread flooding.

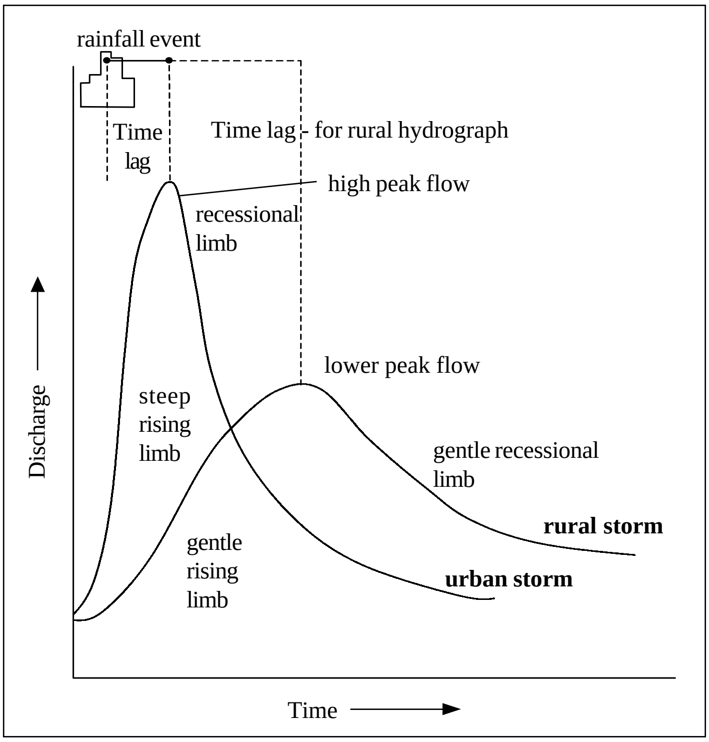
Flood intensifying conditions cover a range of factors which alter the drainage basin response to a given storm. These factors include topography, vegetation, soil type, rock type and characteristics of the drainage basin.

The potential for damage by flood waters increases exponentially with velocity and speeds above 3m per second and can undermine the foundations of buildings. The physical stresses on buildings are increased even more, when rough, rapidly flowing water contains debris such as rock, sediment, debris and trees. Other conditions which intensify floods include changes in land use. Urbanisation, for example, increases the magnitude and frequency of floods in at least three ways:

- Creation of highly impermeable surfaces, such as roads, roofs, pavements
- Smooth surfaces served with a dense network of drains, gutters and underground sewers increase drainage density
- Natural river channels are often constricted by bridge supports or riverside facilities, reducing their carrying capacity. Due to increased storm runoff, many sewage systems cannot cope with the resulting peak flow

The result is to create a greater flood, and one that occurs more rapidly, compared with neighbouring rural areas (Fig 1).

Fig 1. Urban v Rural hydrograph



Deforestation increases flood runoff and, because of increased deposition within the channel, decreases channel capacity. However, there is little evidence to support any direct relationship between deforestation in the Himalayas and changes in flooding and increased deposition of silt in parts of the lower Ganges-Brahmaputra. This is believed to be due to the combination of high monsoon rains in the Himalayas, steep slopes, and the seismically unstable terrain which ensure that runoff is rapid and sedimentation is high irrespective of the vegetation cover.

Human causes of floods

Economic growth and population movements throughout the twentieth century have caused many flood plains to be built on. However, in order for people to live on flood plains there needs to be flood protection. These range from loss-sharing adjustments to event-modifications.

Loss sharing adjustments include disaster aid and insurance. Disaster aid refers to any aid, such as money, equipment, staff and technical assistance that are given to a community following a disaster. However, there are many taxpayers who argue that they should not be expected to fund losses which should have been insured.

In developed countries insurance is an important loss sharing strategy. However not all flood-prone households have insurance and many of those that are insured may be under insured. In the floods of central England in 1998 many of the affected households were not insured against losses from flooding because the residents did not believe that they lived in an area that was likely to flood. Hence they had very limited flood insurance.

Event modification adjustments include environmental control and hazard resistant design. Physical control of floods depends on two measures – flood abatement and flood diversion.

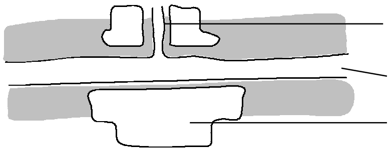
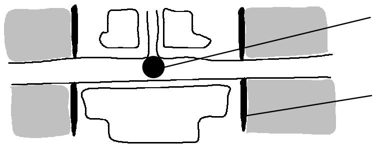
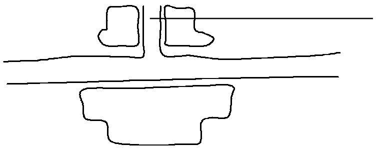
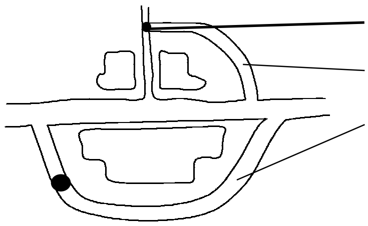
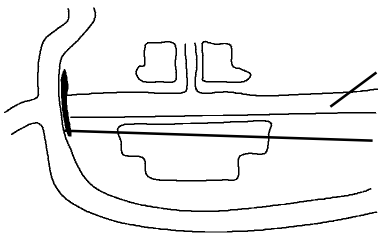
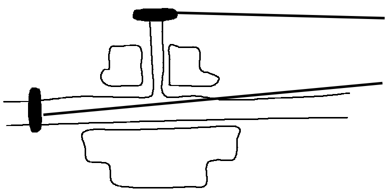
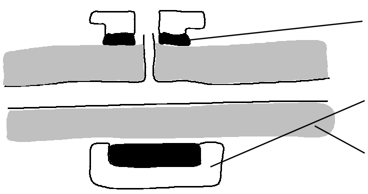
Flood abatement involves decreasing the amount of runoff, thereby reducing the flood peak in a drainage basin. This can be achieved by weather modification and/or watershed treatment, for example, to reduce flood peak over a drainage basin. There are a number of strategies including:

- Reforestation
- Reseeding of sparsely vegetated areas to increase evaporative losses
- Mechanical land treatment of slopes such as contour ploughing or terracing to reduce the runoff co-efficient
- Protection of vegetation from wild fires, overgrazing, clear-cutting of forests, or any other practices likely to increase flood discharge and sediment load.
- Clearance of sediment and other debris from headwater streams
- Construction of storm water and sediment holding areas
- Preservation of natural water detention zones

Flood diversion measures, by contrast, include the construction of levees, reservoirs, and the modification of river channels (Fig 2).

> ***Exam Hint -*** *This is topical geography. Learn the basic facts - causes, consequences and means of control and collect any newspaper articles on actual floods. These up-to-the-minute examples, hopefully drawn from different areas, will help gain high marks.*

Fig 2. Solutions to flooding

Key 	
1. 	Flood embankments with sluice gates. The main problem with this is it may raise flood levels up and downstream.
2. 	Channel enlargement to accommodate larger discharges. One problem with such schemes is that as the enlarged channel is only rarely used it becomes clogged with weed.
3. 	Flood relief channel. This is appropriate where it is impossible to modify original channel as it tends to be rather expensive e.g. the flood relief channels around Oxford.
4. 	Intercepting channels. These divert only part of the flow away, allowing flow for town and agricultural use e.g. The Great Ouse Protection Scheme in the Fenlands.
5. 	Flood storage reservoirs. This solution is widely used especially as many reservoirs created for water-supply purposes may have a secondary flood control role, such as the intercepting channels along the Loughton Brook.
6. 	The removal of settlements. This is rarely used because of cost, although many communities were forced to leave as a result of the 1993 Mississippi floods.

- **Levees** - the most common form of river engineering. They can also be used to divert and restrict water to low value land on the flood plain. Over 4,500 km of the Mississippi River has levees.

- **Channel improvements** - such as enlargement to increase the carrying capacity of the river.

- **Reservoirs** - store excess rainwater in the upper drainage basin.

- **Large dams** - are expensive and may well be causing earthquakes and siltation. It has been estimated that some 66 billion metres cubed of storage will be needed to make any significant impact on major floods in Bangladesh!

Hazard resistant design
Flood proofing includes any adjustments to buildings and their contents, which help reduce losses. Some are temporary such as blocking up of certain entrances, use of shields to seal doors and windows, removal of damageable goods to higher levels, and the use of sandbags. By contrast, long term measures include moving the living spaces above the likely level of the flood plain. This normally means building above the flood level, but could also include building homes on stilts.

Forecasting and warning
During the 1970s and 1980s flood forecasting and warning had become more accurate and they are now one of the most widely used measures to reduce problems caused by flooding. Despite advances in weather satellites and the use of radar for forecasting, over 50% of all of unprotected dwellings in England and Wales have less than six hours of flood warning time. In developed countries flood warnings and forecasts reduce economic losses by as much as 40%. In most developing countries there is much less effective flood forecasting. An exception is Bangledesh. Most floods in Bangladesh originate in the Himalayas, so authorities have about seventy-two hours warning.

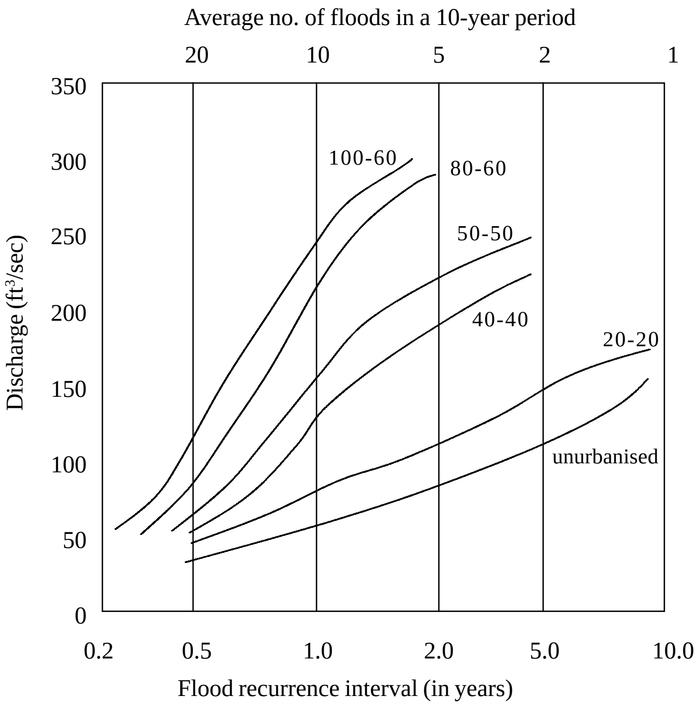
Land use planning
Most land use zoning and land use planning has come in the last thirty to forty years. Land use management has been effective in protecting new housing developments in the USA from losses up to the 1 in 100 year flood (i.e. the floods that we would expect to occur more than once every century).

In England and Wales flood plain development has been controlled since 1947 by the **Town and Country Planning Acts**. In Britain there hasn't been the same encroachment on to the flood plain as there has been in the United States. Partly, this is due to population growth, for example between 1952-1982 England and Wales' population grew by 12% compared to 50% in the USA, 73% in Canada and 78% in Australia. Since population growth has been slower in Britain, less new buildings have been required, hence there has been less enroachment onto the flood plains.

One example where partial urban relocation has occurred is at Soldier's Grove on the Kickapoo river in south-western Wisconsin, USA. The town experienced a series of floods in the 1970s, and the Army Corps of Engineers proposed to build two levees and to move part of the urban area. Following floods in 1978 they decided that relocation of the entire business district would be better than just flood damage reduction. Although levees would have protected the village from most floods, they would not have provided other opportunities. Relocation allowed energy conservation measures to be introduced in buildings and an increase in the commercial activity of the area.

Urbanisation, flooding and water quality
Geographers are increasingly aware of the effect of urbanisation on hydrology (Fig 3).

Fig 3. Flood frequency, intensity and urbanisation



(key 100-60 Percentage area sewered - percentage area impermeable)

In urban areas vegetated soils are replaced by impermeable surfaces. These typically cover 20% or more of post-war urban areas. In some central areas, such as city centres, it can be as low as 5%. This change can lead to a number of effects:
- Reduced water storage on the surface and in the soil
- Increased percentage runoff
- Increased velocity of overland flow
- Decreased evapotranspiration because urban surfaces are usually dry
- Reduced percolation to ground water because the surface is impermeable

There are major changes in the drainage density of urban areas. (Drainage density refers to the total length of stream channel per km sq.) The channel network is increased by stormwater sewers, gutters, gullies and drains. Prior to urbanisation, the stream channel network would have been much more limited. The increase in drainage density has a number of effects:

- It reduces the distance that overland flow has to travel before reaching the channel;
- It increases the velocity of flow because sewers are smoother than natural channels;
- It reduces storage in the channel system because sewers are designed to drain as completely and quickly as possible

In addition, there are rapid increases in rates of erosion during periods of construction. During the building of houses, roads and bridges, vegetation is cleared. This exposes the soil to storms and allows increased amounts of overland flow. Heavy machinery disturbs and churns the soil which increases its erodibility. However, some activities may bury the soil under concrete, tar or tiles. This effectively stops any further erosion of soil.

The enroachment on the river channel by embankment reclamation and riverside roads has a number of consequences:
- Channel width is reduced which leads to increased height of floods in the restricted channel
- Bridges in the river can restrict the free discharge of floods and so increase flood levels upstream

The combined effects of all these changes is that the flow regime, the flood hydrology, the sediment balance and the pollution load of streams are radically altered. Urbanisation has increased the peak of the mean annual flood. For example a 243% increase resulted from the construction of Stevenage and an 85% rise followed the building of Skelmersdale. Likewise the peak of the hydrograph (resulting from 25 mm of rainfall) grew three fold and the lag time declined by 40%. Following the paving of 15% of the clay catchment, the total run off increased by almost 60mm and this made it 130% of that of surrounding rural areas. The enlargement of river channels downstream of urban areas as a result of enlarged floods and reduced sediment discharges after the completion of building works have been demonstrated in the UK below Stevenage, Skelmersdale and Woodbury, Devon.

Urban storm water passes directly to open water courses via the storm sewers. By contrast, foul water passes to the sewage works via separate foul sewers or old fashioned combined sewers. However the storm water that washes off the roads and roofs of urban areas is not clean and unpolluted. Studies of urban streams show that during the start of urban run off the quality of water can be worse than foul sewage. Such water may contain high levels of heavy metals, volatile solids and organic chemicals. These have been found in floods of the Silk Stream of London. Between 20 and 40% of storm water sediments are organic in origin and most are biodegradable. By contrast, highway run off has 5-6 times the concentration of heavy metals as roof runoff and the Silk Stream itself is severely polluted with faecal coliform bacteria. Annual run off from 1 km of a single carriageway of the M1 included 1.5 tonnes of suspended sediment, 4 kg of lead, 126 kg of oil and 18 grams of hazardous polynuclear aromatic hydrocarbons.

On all urban impermeable surfaces there is initial wetting of the surface, perhaps some absorption of water by the surfaces, certainly the filling of depressions in irregularities and throughout and after virtually all rainstorms there must be evaporation from the surface into the atmosphere. Roofs are free from the infiltration of water but when the capacity of their gutters is exceeded in a severe storm there is overland flow to the ground. On the other hand, it is argued that after continued heavy rainfall there is no hydrological difference between tar and saturated soil. Beyond a certain threshold, which is hard to determine, the land use has little effect on flood magnitude.

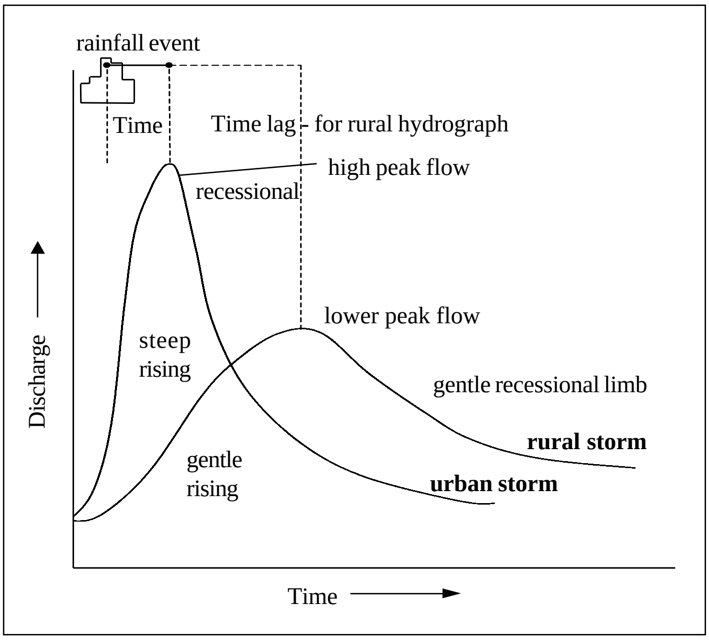
Practice Questions

1. The table shows precipitation and runoff data for a storm on the Delaware River, New York. Plot the storm hydrograph for this storm.

Date	Time	Duration of rainfall	Total (cm)
Sept. 29	6am	12 hours	0.1
Sept. 29	6pm	12 hours	0.9
Sept. 30	6pm	24 hours	3.7
Sept. 30	12pm	6 hours	0.1

Date	Stream runoff (cubic metres/second)
Sept. 28	28.3 (baseflow)
Sept. 29	28.3 (baseflow)
Sept. 30	339.2
Oct. 1	2094.2
Oct. 2	1330.1
Oct. 3	594.3
Oct. 4	367.9
Oct. 5	254.2
Oct. 6	198.1
Oct. 7	176.0
Oct. 8	170.0
Oct. 9	165.2 (baseflow)

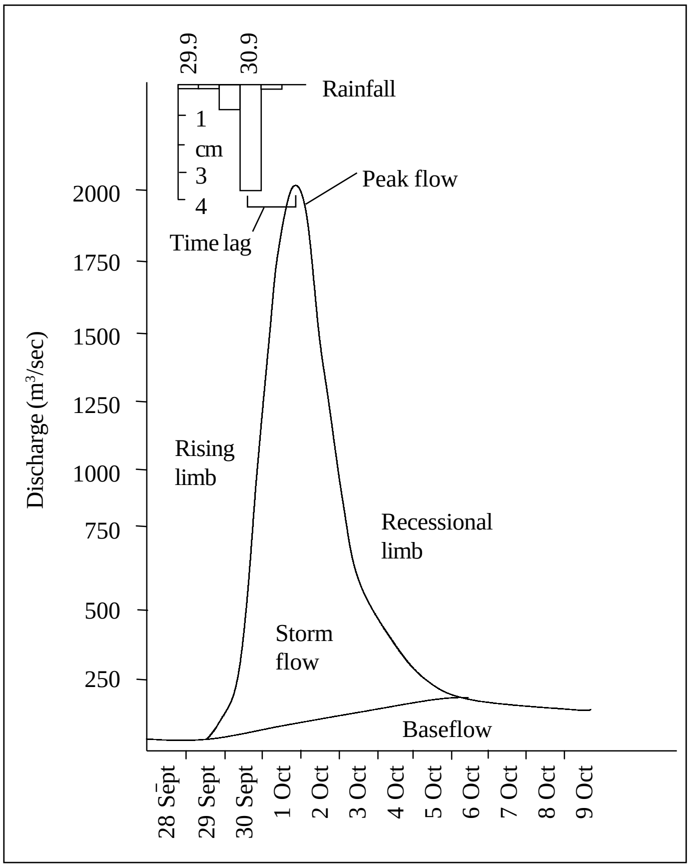
2. (a) Describe and explain the differences in the relationship between discharge and time for an urban hydrograph compared with a rural one, as shown in the figure below.



(b) Describe and explain the relationship between flood frequency, frequency and urbanisation.

Answers
Semicolons indicate marking points

1.



2. (a) In a flood in urban areas there is a higher peak flow (maximum discharge or size of flood), and there is a much shorter time lag between the peak of the storm and the peak of the flood. Moreover, the flood waters recede quickly, i.e. there is a steeper recessional limb.

There are two main reasons why urban hydrographs differ from rural ones. The first is that there is a greater amount of impermeable surface in urban area (up to 95% in city centres and 50% in suburbs) while secondly, there is a much higher drainage density. All of the drains, gutters and sewers help to remove water quickly from the urban area. Hence there is a larger amount of water in the flood and it reaches the river more quickly.

2. (b) In a rural area (unurbanised stream) a very small amount of the land is sewered, and most of the land is permeable to some extent. The average size of flood that occurs most years is approximately 60 cubic feet/second. A flood of over 100 cubic feet/second might occur, on average, every four years, while the five year flood (the maximum amount that would be expected, on average, once every five years) is about 120 cubic feet/second. By contrast, for a stream that occurred on land that was 40 % sewered and 40% impermeable the average one-year flood is about 130 cubic feet/second, and the five year flood is 200 cubic feet/second. A 100 cubic feet/second flood would be expected about every ten months. By contrast, an urban area with all of the area sewered and 60% of the area impermeable would experience 100 cubic feet/second flows approximately every four months. The maximum one-year flood is about 225 cubic feet/second, and the five year flood would be over 300 cubic feet/second (in fact it is off the scale).

The reasons to explain the increasing frequency and size of flood are as in Question 2 – namely an increase in the amount of impermeable surface (so more water gets into the river) and an increase in drainage density (more water is channelled quickly into the main river and there are limited losses due to evapotranspiration and seepage).

Acknowledgements;
This Geo Factsheet was researched and written by Garret Nagle
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