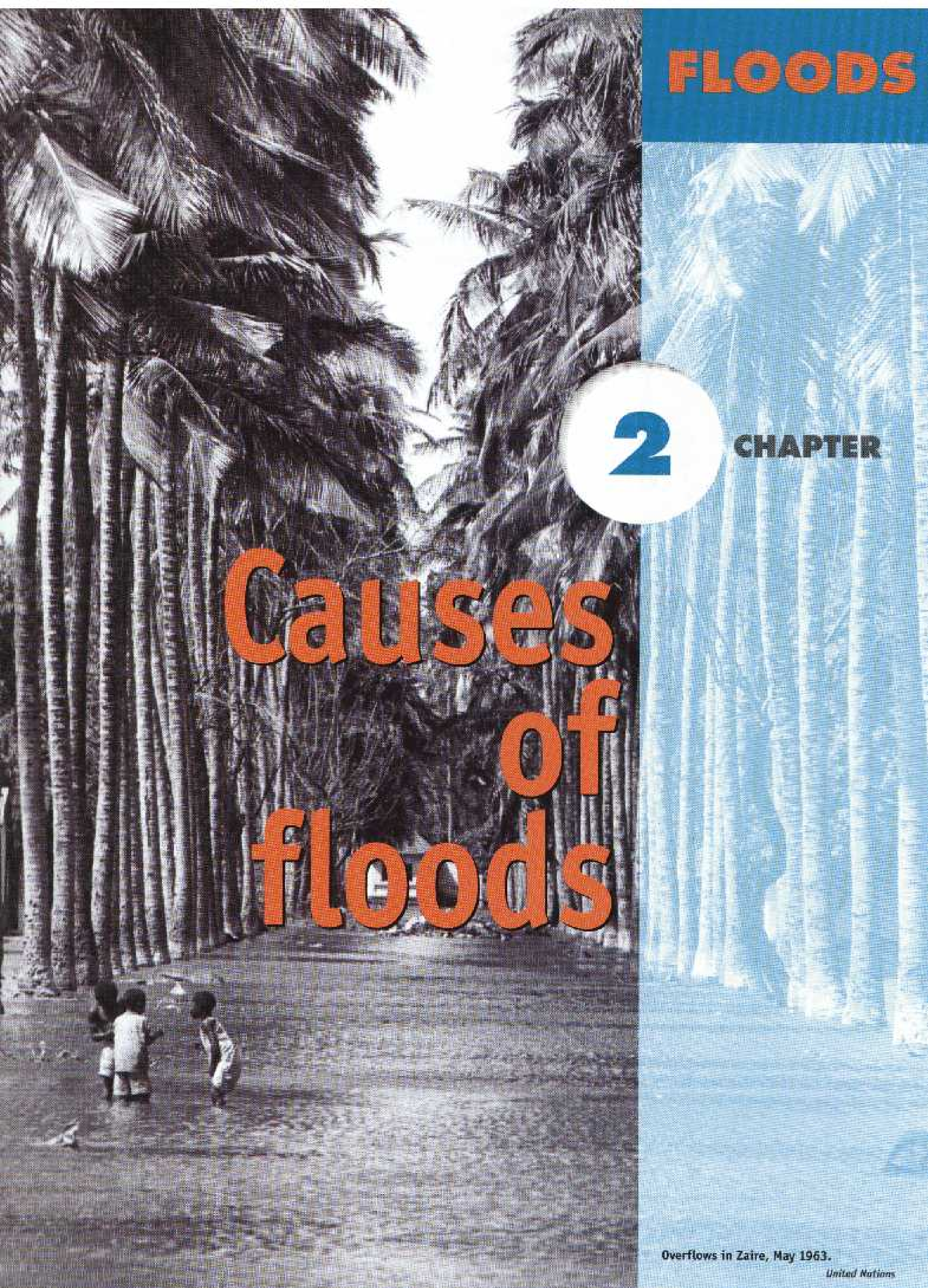
2 CHAPTER

Causes of floods



Overflows in Zaire, May 1963.

United Nations

Causes of floods

This chapter gives a brief scientific introduction to flooding. It covers hydrology, including factors influencing runoff, storm surge effects and the frequency of flooding. The concepts introduced here will be used in later chapters to explain the purpose of various flood reduction measures. Several technical terms are introduced and they are printed in italics when first defined.

Hydrology

Flooded streets Haiti.

Still Pictures. M. Edwards

The ultimate source of all river flow is rainfall or snowmelt, collectively termed *precipitation*, over the catchment area of the river. The catchment area or river basin is the area that the river drains. Some rain and snow can be intercepted by vegetation, particularly trees, and re-evaporated. Rain (and water from melting snow) reaching the soil surface can infiltrate into the soil or run off directly into streams and rivers. Soils have an *infiltration capacity* (the maximum rate at which they can absorb rainfall), and once this has been exceeded the excess water runs off as *direct*, or *fast-response, runoff* or *overland flow*. The infiltration capacity depends on the soil type (sandy soils can absorb more than heavy clays) and the amount of water already held by the soil. During the course of a storm the soil may become fully saturated and any further rain would then all form direct runoff. The infiltrated water can be absorbed by plant roots and transpired by the plants or may percolate deeper, below the root zone. Both these processes remove water from the top layers of soil, enabling the soil to absorb more rain or snowmelt from later storms. The water that is not transpired may make its way down slope through the soil to the nearest stream, as *interflow*, or may percolate even deeper to groundwater aquifers. The geology of the underlying rocks has a direct control on this deep percolation and may indirectly control infiltration because the soils are often derived from the rocks below. If the underlying rocks are highly pervious, for example limestones, the deep percolation will be large and the river basin will respond sluggishly to rainfall. Less pervious rocks give a more rapid, flashy reaction to rain. Depending on the soils and geology and the slope of the terrain, the direct runoff may reach the river within hours to days, the interflow within days to weeks while seepage out of the aquifers can take months to years to reach the river and forms the baseflow that sustains the river during long dry periods.

At several points in this cycle, water is evaporated. The interception by vegetation, the transpiration by plants and any direct runoff caught in surface depressions can all be evaporated in a process termed *evapotranspiration*. This process requires energy to be available, which comes largely from solar radiation. During winter there is little, if any, energy available for evapotranspiration and thus the soils become highly charged with water, increasing the proportion of precipitation that runs off directly.

These processes all form part of the hydrological cycle. Water evaporated from the ocean and other water bodies falls as precipitation on the land, is partly evaporated or moves to rivers and streams either overland or through the soil as described above and is eventually returned to the ocean.

Precipitation in the form of snow does not immediately produce runoff or infiltrate into the soil, but waits until the snow melts, which means that several months of precipitation can accumulate above the soil surface. Rain on the snowpack, or water from melting snow can be held within the pack until the high liquid water content finally causes the pack to collapse, releasing water catastrophically and causing a very large runoff very rapidly. Warm rain after a long cold spell may cause the snowpack to melt while the underlying ground is still frozen, which prevents any infiltration. Because of these reasons, snowmelt floods, typical of the spring thaw, can be very large.

It will be appreciated that the direct runoff is the major cause of floods. The interflow may also contribute to flooding, but generally to a lesser degree. Human influences frequently reduce infiltration, causing more direct runoff and thus increase the likelihood of floods. Deforestation is a major influence in many countries. The trees hold the soils of the forest floor together and make a deep litter of fallen leaves etc. Both these factors encourage infiltration. Once the trees are lost, the litter and the soils are soon eroded resulting in increased runoff of sediment-laden water. The resulting erosion of hillsides is very deleterious and also leads to increased sediment loads in rivers and silting up of reservoirs downstream. Overgrazing leads to loss of grass cover on hillsides, which again causes faster runoff and erosion. Soil and water conservation need to be considered together to prevent soil erosion, conserve water resources and reduce floods.

Buildings and roads and other paved areas are effectively waterproof and cause very rapid runoff. To remove this rapid runoff from the city streets drains will be built that lead the storm water directly to streams and rivers, thus increasing again the rapidity of the onset of the flood downstream. The storm water from urban areas is also very polluted, containing sediments, oil and other contaminants from the streets. Other hydrological interventions that increase flooding include land drainage and channel improvements to increase capacity. These both reduce runoff delay times with the effect also of increasing the magnitude of floods downstream. Figure 2.1 summarizes how these human interventions increase flooding.

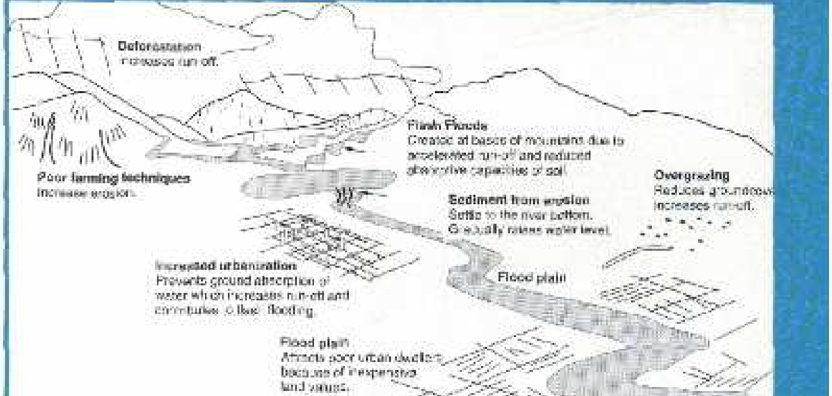


Figure 2.1
UHA. DMTP, Introduction to Hazards

Flash floods are defined in the WMO/UNESCO International Glossary of Hydrology as floods of short duration with a relatively high peak discharge. They arise from local precipitation of extremely high intensity, typical of thunderstorms. The high concentration of rainfall on a small area can have devastating effects as the river flow can rise to several hundred times the normal flow in the space of a few hours. Flash floods are common in arid and semi-arid areas. In these areas what little rainfall there is usually falls in short, intense storms. The intensity of the storms and the poor absorptive capacity of arid zone soils lead to much of the annual runoff occurring as flash floods which carve out the ephemeral wadi channels that are typical of desert regions. Flash floods can also occur following thunderstorms in more humid regions. Mountainous areas are prone to thunderstorms and the steep terrain and thin soils in the mountains assure high runoff with a short delay time. Because of the short delay time it is difficult to forecast flash floods in time for action to be taken. In September 1992, 300 mm of rain fell in three hours on the slopes of Mt. Ventoux (1900 m) in southern France. The River Ouvèze rose rapidly and engulfed the town of Vaison-la-Romaine. A large number of

Floods in Camargue, January 1994.
Agence Vu. E. Franceschi

After the flood. Joyeuse River, Vaucluse.
WWP. J.-L. Vantiohen

houses and other buildings were destroyed and camp-sites in the valley bottom were devastated. The death toll reached 38 and there was considerable damage to communications, roads and power lines throughout the region, with insured losses of over US$ 300 million. The damage to communications lines meant that the local authorities (municipality and police) were unable to inform the outside world of the town's plight, thus delaying the civil defence response to the disaster for several hours.

From the above brief discussion it can be seen that the flood-producing potential of a river basin depends on its natural setting (climate, soils, geology, steepness), on the land cover (forests, crops, roads, buildings) and on the land-use (agriculture, forestry, towns and cities). Many human interventions have the effect of increasing flood potential by reducing infiltration capacity. Sensitive land-use practices can repair some of the damage. These include reforestation, particularly on land that is too steep for agriculture; terracing and contour ploughing to increase infiltration, delay runoff and reduce erosion; and the construction of small farm dams, which not only catch surface runoff but can also provide water for stock and minor irrigation schemes. Urban runoff remains a major problem. In many countries new urban developments are required to provide detention basins to catch and delay the runoff from buildings and paved areas and these can be an effective solution.

Hydrologists can simulate the response of a river basin to rainfall using computer-based hydrological models which describe the movement of the water through the soil to the river. Models conceptualize the catchment as a series of soil-water stores together with equations governing the transfer of water between the stores. Precipitation enters the topmost stores and can be evaporated, transferred to lower stores or form runoff according to the equations thus simulating the direct runoff, interflow and baseflow components of river flow. More elaborate models, describing whole river basins, will also have to include components to compute the flow of water in the river channel and thus the propagation of flood waves down the river. The use of hydrological models to forecast future flood flows will be described in chapter 5 below.

Flood frequency

In analysing the statistics of floods, hydrologists usually study the largest flood in each year, the so-called *annual flood*. From the analysis of these annual floods it is possible to estimate the probability that a certain flood would be exceeded in any year. This flood can be expressed either as water level or as discharge, the two being related by the properties of the river channel. Hydrologists prefer to use discharge in flood analyses as it is more readily transferable up and down the river and is unaffected by the construction of flood prevention works such as dykes or levees, which increase the level for any given discharge. The frequency of a flood of a given size is often described by the *recurrence interval or return period*. For example, if a flood of, say, 2,500 m3/s is said to have a return period of 100 years, then there is a 1 per cent chance that the river discharge will be 2,500 m^3/s (or higher) in any year. This definitely does not mean that the flood of a given return period occurs at regular intervals, but is merely a graphic way of describing the rarity of the flood. An important parameter of the flood frequency distribution is the *mean annual flood*, the average of the annual floods. This gives a measure of the magnitude of floods for a particular river basin and is used to scale the floods of different return periods for a catchment. It can be related empirically to the characteristics of the catchment such as area, slope, rainfall statistics, soil types, and land-use. The mean annual flood is a very common flood and has a return period of only 2 to 2.5 years. In many rivers it is approximately the flow that the river channel can carry when running bankful.

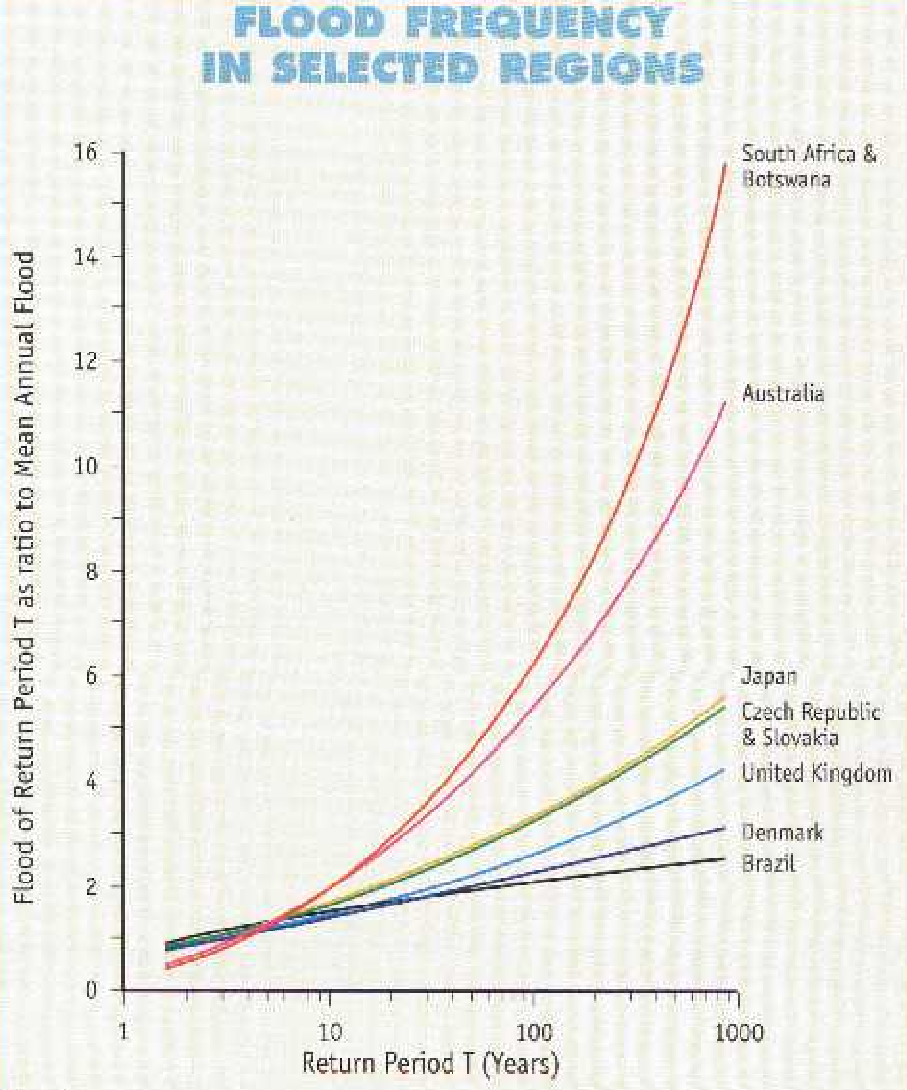
EIGHT HUNDRED YEARS OF FLOODING IN FLORENCE

04-11-1177	●●●●
??-10-1261	●●
01-10-1269	●●●●
15-12-1282	●●●●
02-04-1284	●●●●
05-12-1288	●●●●
??-??-1303	●●
??-01-1305	●●
04-11-1333	●●●●●●
05-12-1334	●●●●
06-11-1345	●●●●
??-11-1362	●●
01-11-1368	●●
21-07-1378	●●
20-10-1380	●●●●
??-05-1406	●●
??-12-1434	●●
18-10-1465	●●●●
16-01-1465	●●●●
19-01-1490	●●
10-06-1491	●●
06-01-1515	●●●●
26-08-1520	●●
15-12-1532	●●●●
??-??-1538	●●
06-11-1543	●●●●
15-11-1544	●●●●
13-08-1547	●●●●●●
08-11-1550	●●
13-09-1557	●●●●●●
31-10-1589	●●●●●●
??-01-1621	●●
09-11-1641	●●
06-11-1646	●●●●
??-01-1651	●●
04-11-1660	●●
11-05-1674	●●
11-10-1676	●●●●
19-02-1677	●●●●
18-05-1680	●●●●
20-04-1683	●●
26-01-1687	●●●●
08-12-1688	●●●●
02-06-1695	●●
??-01-1698	●●
11-10-1705	●●●●
28-02-1709	●●●●
22-10-1714	●●●●
05-09-1715	●●●
??-11-1719	●●●●
03-12-1740	●●●●●●
19-10-1745	●●
01-12-1758	●●●●●●
15-11-1761	●●
03-11-1844	●●●●●●
04-11-1966	●●●●●●

The earliest recorded flood in Florence occurred in 1177, over 800 years ago. The table lists the 56 most serious floods since that date with the dots indicating the severity of the effects of each flood. The water level reached during each flood can no longer be estimated because of changes in the structure and layout of the city. However, we do know that the social impact of flooding in the past was as great as it is today: loss of human lives, urban devastation, economic damage and loss of jobs.

Human settlements affected by floods.

FAO. L. S. Botero



FLOOD FREQUENCY IN SELECTED REGIONS

Figure 2.2

In designing a flood protection scheme it is usual to design against a flood with a specific return period, the «design return period», as this gives a measure of the degree of protection that the scheme will provide. The longer the design return period adopted for a scheme, the more secure it is against flooding. However, longer design return periods also mean higher costs and some compromise has to be adopted based on allowable damage levels and costs. Economic analysis can be used to set the design level to balance the cost of flood protection works with the damage that is avoided. Extra precautions have to be taken when human life would be at risk from overtopping. The United States and Canadian flood plain management systems (see chapter 3, below) both adopted the 100-year flood as the minimum level for design of flood protection works. Much longer return periods are commonly used for dams, up to 10,000 years is not uncommon, while many small urban drainage schemes may be designed for only a ten-year flood. Estimating the magnitude of floods with long return periods is difficult as flow records are often short and even when long records are available it is very likely that the nature of the catchment has changed over the years and this will have altered the flood regime. It is found that the rivers in a region have a similar flood distribution and the flood data from the region can be pooled to give more reliable estimates of the frequency of occurrence of rare floods for the