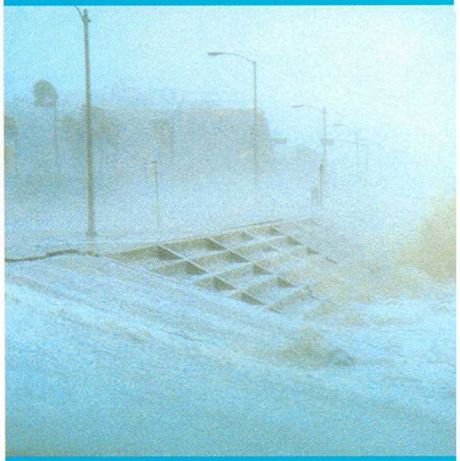
that the dam be designed to withstand the so-called Probable Maximum Flood (PMF). Other cases where PMF may be required could include the protection of some particularly dangerous industrial plant, such as a nuclear power station or a chemical works. The decision as to whether PMF, or any other procedure, should be used is based on political and social issues and in many countries recommended or even obligatory standards have been developed to guide the engineer in his or her decision.



Hurricane Allen, Texas 1983.
Black Star. H. Kokojan

The general procedure for estimating the Probable Maximum Flood is to estimate the Probable Maximum Precipitation (PMP) that could occur at the site and then to route that precipitation through a hydrological model of the catchment to produce a design runoff hydrograph. PMP estimation techniques are well developed for mid-latitudes, but less so for the tropical regions. Storm rainfall is produced by wet air converging towards the storm and being lifted and cooled, causing condensation and rain. PMP is determined by analysing severe rainstorms that have occurred in the general region to determine the water content of the air, the convergence and uplift. The storm is then maximized by increasing all the rainfall-producing factors to their maximum values and computing the precipitation that would result. A hydrological model of the basin is then used to calculate the river flow that would result from the PMP. This is the probable maximum flood and is not just a single value, but a flood hydrograph that shows the variation of flow with time. There are several approximations in this estimation procedure and the judgement of the meteorologist computing the PMP is important in several steps and as a result PMP and PMF are only estimates of the largest precipitation and flood that could occur. Routing the PMP through a hydrological model involves further approximations, especially as the model would be working well outside the range of flows for which it was calibrated. For some hydrologists these uncertainties make the PMP unacceptable as a basis for design. They argue that the use of the term "probable maximum" is misleading and may engender a false sense of security. It is also argued that the flood so estimated contains no information on the risks incurred by using it for design. A design flood estimated on the basis of some very low probability does include an estimate of this risk. Both methods of selecting a design flood involve, inevitably, considerable extrapolation from normal experience and, properly handled, both can be satisfactory. The use of PMP/PMF for design of critical dams will be considered further in chapter 6.

Storm surges

The discussion so far has centred on river flooding. However, many floods in coastal areas and in river estuaries are due to storm surges which result from the sea being driven onto the land by meteorological forces. There are two physical forces which act together. A storm with intense low pressure will cause the level of the sea to rise because of barometric effects and the strong winds associated with this storm, if they are directed onshore, will drive the sea on to the land. Storm surges are commonly associated with tropical cyclones: Bangladesh is particularly prone to storm surges. Two that struck the country in recent decades rank among the deadliest of natural disasters recorded. The cyclone of November 1970 crossed the coast north of Chittagong and caused 300,000 deaths. On 29-30 April 1991 a more intense tropical cyclone crossed the coast near the same point at approximately the time of astronomical high tide and produced a surge six metres high associated with winds up to 220 km per hour. It caused nearly 140,000 deaths and considerable material damage. The lower death toll, compared to 1970, despite the tropical cyclone being more intense and the population in the affected area being higher, is attributed to warnings being issued in time for people to reach cyclone shelters.

Storm surges can occur with any intense storm: a surge of over three metres in the North Sea in 1953 caused the collapse of flood defences in Britain and the Netherlands leading to some 2,200 deaths and considerable damage to property. As a result of this incident, both countries improved their sea flood defences leading to the construction of the Thames Barrier to protect London and the giant Haringvliet storm gates across the Rhine Delta. A number of North Sea storm surges of similar magnitude have occurred since with much smaller consequences, because of the extra protective measures.

The storm that produces the surge can also give rise to heavy rainfall inland so that the estuary region can be subject simultaneously to river flooding and the storm surge. Because of this correlation between storm surge and river flow, detailed studies of their interaction in the estuary are needed to determine the frequency of floods in estuaries. Forecasting of floods in estuaries also requires that the combined effects of the river flood and the storm surge be taken into account.

Increases in flooding

In recent decades, the frequency and severity of floods has been observed to rise in many countries. As the weather, particularly rainfall, has not yet shown a similar change the increase in flooding is due to changes in the river catchment. Modern development in almost all countries has led to the destruction of forest cover, the draining of natural wetlands and the spread of towns across the countryside. These and many other human interventions have reduced infiltration and increased the speed with which water runs off, leading to more frequent and higher floods. Soil and water conservation measures that can help reduce these effects are described further in chapter 5. As well as these already existing causes of increasing flooding, the prospect of climate change raises the possibility of further increases in flooding.

The major cause of climatic change is the so-called "greenhouse effect" due to increases in the level of carbon-dioxide (CO_2) in the atmosphere from the burning of fossil fuels such as coal and oil. Until now, studies of climate change have produced little firm information on the likely effects on the hydrological cycle and water resources. This is largely because the global circulation models used in climate studies are not yet able to give sufficiently detailed results at the regional level. However, one result that is observed is that heavy rainfall will become more frequent. Simulations of the climate that would result from doubling the concentration of CO_2 in the atmosphere show fewer days with light rain and an increased frequency of days with heavy precipitation, that is to say less frequent, but more violent rainfall. This will inevitably lead to heavier flooding, including flash flooding. The predicted rise in sea levels will also lead to increased danger from storm surge flooding, with serious consequences for low-lying countries including Bangladesh, the Netherlands and eastern parts of England.