Floods

J A Hubbart and J R Jones, University of Missouri, Columbia, MO, USA

Definition of Flood

A flood is loosely defined as river discharge exceeding bankfull limitations. It is also considered a temporary rise of the water level, as in a river or lake or along a seacoast or wetland, resulting in its spilling over and out of its natural or artificial confines onto land that is normally dry. Floods are sometimes described according to their statistical occurrence. For example, a 50-year flood is a flood having a magnitude that is reached in a particular location on average once every 50 years. This is often referred to as a return interval (Tr), and is calculated as follows:

$$\mathrm{Tr} = (n + 1)/m$$

where n is the total number of events, and m is the specific event number in question. With this calculation, probability (p) of event occurrence is calculated by

$$p = 1/\mathrm{Tr}$$

A helpful way to visualize the difference in flow between a flood and normal runoff is to visualize the flood channel width, which is the floodplain portion that will discharge the 50-year flood (**Figure 1**). In this example, the flood zone is centered over the main channel, an unusual situation in natural systems where the flood zone can be offset or split into several zones depending on the topography.

Forecasting annual flows and the magnitude and frequency of flood events is a challenge. Hydrologic data from unaltered, wildland systems show great variation in annual floods (coefficients of variation ≥ 1.0), making it difficult to predict when the floodplain will be inundated. Human land use changes further complicate flood forecasting because impermeable surfaces reduce infiltration and accelerate runoff. Ultimately, both natural and anthropogenic processes can result in watershed morphological changes that may modify flow. It is noteworthy that even minor changes in flood magnitude, duration or frequency, although statistically undetectable, should not be misinterpreted as ecologically or culturally benign.

Causes and Effects of Floods

All rivers and streams are subject to fluctuations in flow. During a rainstorm, the amount, intensity, duration, area, and path of the storm all influence the runoff reaching the stream. Multiple land form and use factors affect the ability of land to absorb precipitation and therefore affect the rate of runoff. Area and path of the storm relate to the area of the basin receiving rainfall, which in turn, represents the area contributing runoff. Area and the runoff rate determine the volume of water that will pass a given point downstream.

Modification of runoff rates occurs by variations in topographic relief, soil infiltration processes, vegetative cover, and surface retention (e.g., ponding) within a given catchment or watershed. The key physical mechanism controlling runoff and flooding processes is precipitation. River flow is largely determined by the precipitation regime (i.e., amount and type of precipitation). Precipitation type is determined by factors such as elevation (rain, snow) and orographic uplift, and whether it is on the leeward or windward side of mountains. Orographic uplift often results in heavier precipitation on the crests and windward slopes of mountain ranges. It also accounts for much heavier precipitation than in surrounding lowlands. The same process also causes rain shadow effects on leeward sides of mountains. The nature and condition of the drainage basin, and variable climates also affect streamflow, and therefore flood potential. Vegetative cover also affects the rate at which surface water flows to a main channel by slowing and spreading out runoff. The passage of water is similarly ameliorated in basins with natural storage areas, including lakes and wetlands. Consequently, smaller peak flows are produced in basins with dense vegetation and lakes, reservoirs and wetlands than those without.

Snowmelt: In high elevations and northern latitudes, most precipitation is snow. During snowmelt, large quantities of water are released. Snowmelt induced runoff floods are the most common type of flooding in these areas and generally occur in the spring but also occur during sudden winter thaws and as a consequence of rain-on-snow events. Heavy runoff results from rapid melting of snow under the combined effect of sunlight, winds, warmer temperatures, and rain. When there is an above average snow depth, a sudden thaw, or both, the potential for high volumes of runoff and subsequent flooding increases. This process is made more severe when the rising snowmelt runoff is compounded by runoff from heavy rainfall. Because climatic factors influencing the rate of snowmelt are often widespread, snowmelt runoff flooding conditions can exist over vast areas

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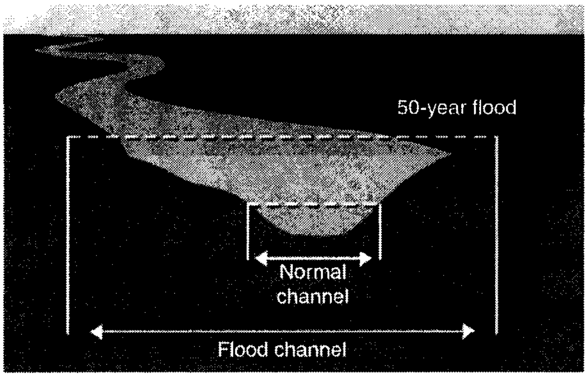

Figure 1 Example 50-year flood event.

and mobilize and transport a great deal of debris and sediment.

Rainfall: Heavy rainfall can result in flash flooding. Although thousands of hectares are frequently flooded as a result of flash flooding (for example, northern Queensland, Australia, and the upper Mississippi River drainage, USA), flash floods usually occur in small watersheds as a result of large rain events and are characterized by peak flow within six hours of the onset of rainfall. Flood conditions develop rapidly because heavy rainfall surpasses the infiltration capacity of the soil, resulting in a very high runoff rate. These types of events are generally locally intense and damage is usually restricted to a limited area. Large rivers generally remain unaffected, while smaller streams can overtop their banks, even in a drought year.

Seasonal and inter-annual variability in rainfall and flooding are often a result of El Niño-Southern Oscillation (ENSO). ENSO is a global system of ocean–atmosphere climate fluctuations arising from warmer ocean currents coupled to higher air temperatures. The result is markedly increased evaporation and large-scale interaction between the ocean and the atmosphere. Effects of ENSO are observed by changes in the distribution of rainfall, causing floods in some areas and drought in others. This process leads to drastic alterations to normal weather patterns, including heavy rains and catastrophic flooding in the United States, Asia, and other parts of South and Central America. For example, large areas of Asia receive more than 80% of annual precipitation during the seasonal monsoon season. Conversely, regions in Australia, Indonesia, and India may undergo severe drought because moisture normally dispersed around the world is evaporating too quickly and staying within the Eastern Pacific Ocean. ENSO is the most prominent known source of inter-annual variability in weather and climate around the world (range: 3–8 years).

Ice jams: Ice jams are a major cause of flooding in northern latitudes. In fact, for most northern rivers, the annual peak water levels are due to ice jams resulting from the accumulation of ice fragments, which build up and restrict the flow of water. A rise in water levels may result from spring snowmelt, or a sudden midwinter thaw accompanied by substantial rainfall, resulting in a rapid increase in water levels and severe ice jams. Ice jams can lead to flooding because of two main features. First, ice jam thickness can be considerable, amounting to several meters. Second, the underside of the ice cover is usually very rough. Therefore, the flow depth has to be much greater than for open water, resulting in relatively high water levels with relatively small discharges. This condition leads to a great deal of water and pressure that when released can lead to substantial flooding.

Outburst floods: Outburst floods are also common in northern latitudes, and have some similarities to ice jams. Lakes dammed by glaciers or moraines suddenly drain and large quantities of water, mud, and debris are released. An outburst flood typically occurs when the water level becomes high enough to actually float the ice or when a small channel forms under the ice and causes rapid melting, thus expanding the channel. Another common mechanism is overtopping of the ice dam and the rapid thermal and mechanical erosion of a channel, leading to sudden large scale drainage. The release of water is often sudden and catastrophic.

Coastal storms: Humans living along the shores of major lakes or along ocean coasts are occasionally subject to flooding as a result of high wind and wave action, or the interaction between high estuarine flows and tides. Shoreline flooding may be caused by storm surges often occurring simultaneously with high waves. Surges are caused by sudden changes in atmospheric pressure and by wind stress accompanying moving storm systems. In certain coastal regions, maximum storm surges are produced by severe tropical hurricanes. Along the coasts, severe storms can produce surges of up to 2 m, but in some areas of the world, for example, Bangladesh, severe storms can produce surges in excess of 8 m. Generally, surges in lakes and reservoirs are less, though they have been recorded as high as 2.5 m on Lake Erie. Specific types of coastal flooding events include tsunamis, cyclones, and hurricanes.

Urban runoff: Urban stormwater runoff can flood local rivers as well as the urban area itself. Urbanization drastically alters the drainage characteristics of natural catchments by increased impervious surface area and thus volume and rate of surface runoff (**Figure 2**). Other effects of increased impervious

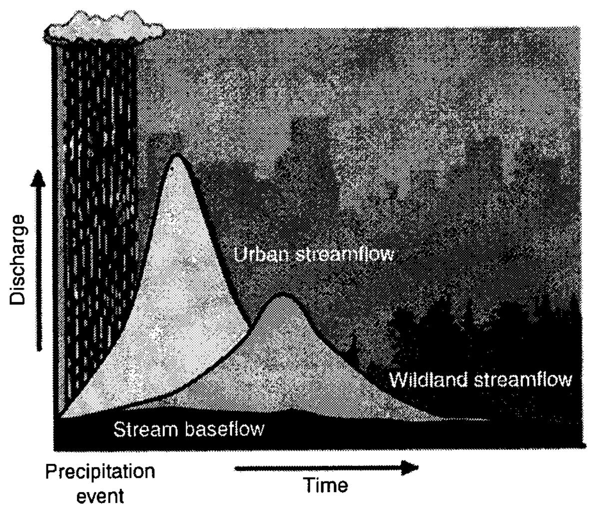

Figure 2 Example of difference between wildland (unaltered) and urban (human modified) event based runoff regimes.

surface area can include decreased water quality, changes to microclimates, habitat degradation and destruction, and diminished stream and landscape aesthetics. Although the impact of urban runoff on major river systems may be minimal, the carrying capacity of small streams may be quickly exceeded, causing flooding and channel erosion problems. Runoff from intense rainfall can exceed the carrying capacity of sewer systems, creating a backup and thus, flooding. In urban settings, streamflow-gauging stations are often used to provide continuous flow records that can be used in the design of new urban infrastructure, including roads, bridges, culverts, channels, and detention structures.

Tropical flooding: Tropical floods are usually caused by cyclones, otherwise known as hurricanes, typhoons, or tropical storms. Cyclones often result in large quantities of rain falling in a short time and can result in a great deal of flooding and sometimes human loss of life. There are two basic types of flood caused by tropical cyclones. Flash flooding occurring in streams and urban areas almost immediately following rainfall and rising water can reach depths of multiple meters. River flooding generally occurs from heavy rains coupled with recent cyclonic activity and can persist for weeks. The impact of tropical floods is locally variable. Water levels that exceed flood stage can constitute minor, moderate, and major flooding over relatively short geographic distances due to topographic variability and ability for the terrain to attenuate flood flows.

Dam failure: Flooding also results from the failure of dams or other hydraulic structures. The suddenness and magnitude of these events often have disastrous results. The failure of dams formed by beaver (*Castor canadensis*) can also result in an outburst flood of impounded water.

Flood Costs and Mitigation

Floods can be disastrous. Often, personal property, businesses, industries, crops, and roads are damaged and human lives can be lost. Floods cost humans many millions of dollars every year in property damage, lost production, lost wages, and lost business. Floods however, are also a natural phenomenon and are often necessary for ecosystem health. The concept of 'environmental flows' was developed in this case to determine how much water needs to be left in a river in order to maintain its ecological health. These flows are critical (especially in dry regions) to provide water for floral and faunal communities, as well as security for human use and socio-economic stability.

Economic development in concert with an increasing population has brought pressure altering the flow regime of surface water systems. Human efforts to constrict the active zone of floodplains that attenuate floods include the construction of dams, dykes, and concrete diversion channels, channel dredging and realignment, and drainage of wetlands. These measures, although perhaps beneficial in the interests of economic development, have resulted in the decline of fish and wildlife habitats, and the disruption of entire ecosystems. Many humans have a false sense of security owing to the size and proclaimed strength of levees protecting their livelihood. Hence, levees may increase the potential for floods by a reduction in flood preparedness and by creating incentives to build structures in areas subject to flooding.

Flood amelioration practices can include materials that are put in place to increase bank stabilization, reduce bank erosion, and stop the meandering of streams and rivers. Common strategies include dikes, loose rock paving, and establishment of plant communities on banks. Often, these practices are successful in reducing bank erosion, but hinder the ability of the channel to widen naturally through flooding, leading to increased flooding by reducing the length of the stream or river, and increasing flow velocity resulting in channel incision. The amount of sediment transported depends mainly on flow volume (**Figure 3**), which also depends on size of the drainage basin, and rate and volume of precipitation. Increases in suspended sediment concentrations above natural levels often have a detrimental impact on fish and invertebrate habitat in streams.

High levels of suspended sediment can reduce the effectiveness of drinking water treatment processes

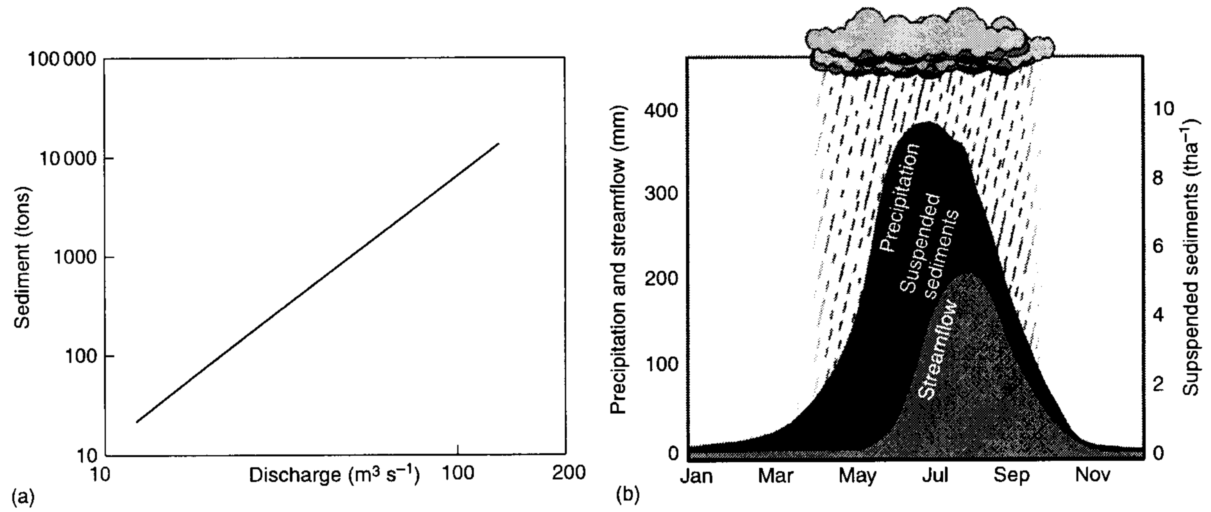

Figure 3 Relationships between (a) sediment flux and stream or river discharge, and (b) precipitation, streamflow and suspended sediment.

and may increase maintenance costs by clogging or reducing the capacity of filtration systems. Suspended sediment and other particulates are aesthetically undesirable for domestic use and can be associated with higher bacterial concentrations. Suspended sediment carried by flood waters can reduce light penetration and temporarily decrease plant productivity in lakes and streams. The same flood waters can also transport nutrients such as phosphorus with the sediment often resulting in an infusion of otherwise nutrient limited waters.

Flood waters are a natural driving force in maintaining the productivity of rivers and floodplain systems. Floods inundate adjacent floodplains and connect river channels with streamside soils and vegetation that result in chemical and faunal exchanges that influence both communities. Peak flows that move or abrade stream substrate can scour attached algae and aquatic macrophytes and reduce or change the community structure of benthic invertebrates and fish populations. Often recovery of these communities to pre-flood conditions is quite rapid. Floods are major contributor to annual inputs of nutrients to lakes and reservoirs. Dissolved nitrogen and phosphorus, delivered with flood inflow, drive aquatic productivity and generally lake systems are more productive during wet years than during periods of drought.

Because of the intricate nature of river ecosystems, water quality sampling and analysis programs are necessary to provide data essential to the understanding and behavior of natural systems and influences of human activity. Thus, simultaneous and continuous sampling of suspended sediment is critical for accurate understanding of pollutant loading of the watershed which is (a) governed by hydrological processes, and (b) closely correlated to chemical pollutant concentrations. These processes are controlled to a large degree by local microclimates.

Ultimately, flooding is a necessary natural process that only has negative effects when humans are involved. Human inhabitation of land that naturally floods causes great losses of life and property. Anthropogenic alterations to these flood-based systems have only worsened the problem in most cases.

See also: Atmospheric Water and Precipitation; Fluvial Export; Fluvial Transport of Suspended Solids; Ground Water; Ground Water and Surface Water Interaction; Streams; Vadose Water.

Further Reading

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