Flash Flood Science

A flash flood is generally defined as a rapid onset flood of short duration with a relatively high peak discharge (World Meteorological Organization). The American Meteorological Society defines it as a “…flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area.” The U.S. National Weather Service employs a more detailed definition:

A rapid and extreme flow of high water into a normally dry area, or a rapid water level rise in a stream or creek above a predetermined flood level, beginning within six hours of the causative event (e.g., intense rainfall, dam failure, ice jam). However, the actual time threshold may vary in different parts of the country. Ongoing flooding can intensify to flash flooding in cases where intense rainfall results in a rapid surge of rising flood waters.

Regardless of which definition is applied, the distinctive characteristics of flash flooding mean that forecasting processes are quite different for this hazard than for other types of hydrometeorological hazards. Flash floods can be triggered by a variety of events including intense rainfall, failure of a natural (e.g., glacial lake debris) or manmade (e.g., dam, levee) structure that is impounding water, or the sudden impoundment of water upstream of a river ice jam.

While the causes can be variable, this document only addresses the most common cause of flash floods, intense rainfall.

What Is in This Chapter?

This chapter should be read by persons who require a basic understanding of the hydrology associated with flash floods caused by heavy rain. The chapter briefly discusses how soil characteristics, basin features, stream density, and land use affect the development and intensity of flash floods.

Flash Flood Processes

Flash floods are rapid-onset hydrologic events that can be difficult to forecast. A combination of a high rainfall rate with rapid and often efficient runoff production processes is common to most flash flood events. Therefore, the nature of the rainfall and the anticipated runoff processes are key elements in the forecast process. The following figure (Fig. 2.1) describes the overall flood prediction process and how flash floods relate to that larger process.
In general, the greater the precipitation intensity, the more likely it is that significant surface runoff will be generated. Higher precipitation intensity can result in more runoff because the ground cannot absorb the water quickly enough. Although prior ground saturation increases the flash flood risk, many flash floods occur when the ground is not saturated. Flash floods can and do occur with dry soils and drought conditions.

Hydrologic influences of the ground surface can have a major impact on the timing, location, and severity of flash flooding. Although rainfall is often considered the most important factor for forecasting floods, what happens to the rain once it is on the ground can sometimes be of greater importance. In some cases, runoff production processes may be more important than rainfall characteristics.
Hydrologic Influences

Soil Influences

There are three critical soil properties to consider when assessing the risk of flash flooding: (1) soil moisture, and in particular the degree of saturation, (2) soil permeability, including soil surface alterations, such as compaction, paving, and fire, and (3) soil profile. Soil moisture is considered to be the most important soil factor for rapid runoff and flash flooding, especially in humid areas with deep soils. If soil is saturated it will not permit additional rainfall to infiltrate, and all rainfall becomes runoff regardless of other environmental conditions. On the other hand, many flash floods do occur in areas with sub-saturated soils. Dry soil has a specific rate at which it can absorb rainfall, called the infiltration capacity. If the rainfall rate exceeds the infiltration capacity, runoff will occur. This process, called infiltration excess overland flow, leads to rapid and efficient production of surface runoff even during dry conditions.

The rate of rainfall infiltration also can be affected by soil permeability. A commonly used indicator of soil permeability is soil texture. Soil texture is a soil property used to describe the relative proportion of different grain sizes of mineral particles in a soil. Some other soil properties that might determine the soil’s permeability rate are crust formation, soil compaction, soil contraction and expansion, microbial activity, soil hydraulic conductivity, and root distribution. As indicated in Figure 2.2, clay, and to a lesser extent silt, can result in low infiltration rates and rapid runoff during intense rainfall. Sandy soils, in contrast, permit greater infiltration because of the wider spaces between particles. As a general rule, runoff from intense rainfall is likely to be more rapid and greater with clay soils than with sand.

But surface alterations such as pavement, compaction, and fire can have an even greater influence than soil texture and result in very rapid runoff even in dry conditions. Wildfires can alter soil properties so that burn areas become hydrophobic, i.e. tending to repel and not absorb

![Infiltration Variations by Soil Texture](image)

**Figure 2.2** Infiltration variations by soil texture
water, for weeks or even years following a fire; indeed, the greatest flash flood risks occur after high-intensity fires in coniferous forests.

In addition to soil moisture and soil permeability, soil profiles can also influence flash flood hydrologic processes. However, depending on the intensity of rainfall and spatial and temporal scales of a flash flood event, the influence of soil profile can be small compared to soil moisture and soil permeability. Soil profile refers to the vertical organization of the different soil layers and the depth of the soil column. Soil profile characteristics are tightly related to the capacity of the soil to store water and to the infiltration rate. For instance, although sandy soils have greater infiltration rate, rapid runoff can still occur when there is only a thin layer of sandy soil. If, for example, there is an impermeable layer of rock beneath a thin layer of soil, that soil layer can saturate quickly resulting in large amounts of runoff. Figure 2.3 depicts how soil profiles can influence runoff and the occurrence of flash floods.

![Figure 2.3 Influences of depth to bedrock on runoff](image-url)
Basin Influences

A drainage basin is an area having a common outlet for its surface runoff. The physical properties of a basin and its streams influence the amount and the timing of runoff and therefore the likelihood of flash flooding in the basin’s outlet. Any factor that increases the speed and efficiency of runoff production processes can make a particular basin more prone to flash flooding. Fewer stream meanders, steep slopes, less surface roughness, high stream density, urbanization, and deforestation are all factors that can increase the susceptibility of a basin to flash floods.

It is important to consider basin size when evaluating flash flood risk. The size of the contributing area of the rainfall in a basin has a direct influence on the total volume of runoff that drains from that basin. Consider two similarly shaped basins but different-sized basins (see Figure 2.4 below). Runoff starting from most upstream point of the larger basin will take longer to reach the basin outlet than runoff traveling from the farthest point in the smaller basin, since it needs to travel a longer distance. In addition, a single thunderstorm (i.e., heavy rainfall event) will probably impact only a portion of the large basin at any given time, but it could envelop the entire small basin. Indeed, most flash floods occur in small basins, less than 77 square kilometers, with many less than 38 square kilometers.

Figure 2.4 Influence of basin size on runoff.
Basin shape also has an influence on magnitude and timing of the peak flow at the basin outlet. Consider two basins of equal area where one is long and narrow, and the other is more round (see Figure 2.5). Then consider runoff traveling from the farthest point in each basin to their respective outlets. The runoff in the more round basin will arrive more quickly at the basin outlet. In addition, runoff from multiple locations in this basin is more likely to arrive at the outlet at the same time, resulting in a greater peak flow. By contrast, in a longer, narrower basin, water from multiple locations is less likely to arrive at the same time.

Slope is another important factor to consider in a basin. Not only does slope affect the timing of runoff, but it also affects the amount of infiltration. The greater the slope, the lower the infiltration rate, since gravity pulls less water into the land surface and more water across that surface. Both effects increase runoff. In general, the steeper the slope and the steeper the drainage channels, the quicker the flow response and the higher the peak discharges.

Surface roughness also affects runoff rates. The presence of rocks, vegetation, and debris creates turbulence, slowing runoff and increasing infiltration. Conversely, reducing channel roughness results in faster streamflow velocities and less infiltration. If concrete-lined channels (Figure 2.6) are used to direct streamflow, there is no infiltration and very high velocity – and increased flash flood hazard.

Figure 2.5 Influence of basin shape on peak flow
Stream density is one of the most important characteristics for evaluating potential runoff. Stream density is the length of all channels within the basin divided by the area of the basin. A drainage basin with a large number of tributaries has a higher stream density than a basin with very few tributary streams. Higher stream density allows the landscape to drain more efficiently following a storm event. More efficient drainage means that water moves into streams and creeks faster, causing peak storm flows to be larger and to occur sooner. Urbanization artificially increases stream density. This is because the road grid and storm drain network act as pathways, or tributaries, that move water rapidly to low lying areas and the nearby stream channels. A basin with a lower stream density usually indicates a deep, well-developed soil. In this case, water is more likely to infiltrate into the soil rather than become surface runoff and enter into the channel network.

Land cover and land use are other essential influences on runoff. Urbanization, devegetation, and frozen ground are special cases that need to be considered. Urbanization has several major impacts, including:

- Greater runoff volumes due to increased percentage of impermeable surfaces and compacted soils.
- Faster runoff due to road grids, storm sewer networks, alterations to the natural vegetation, and sometimes channelization of streams.

All of this greatly enhances the movement of runoff to and within stream channels. As a result, when compared to rural conditions, urban streams will flood faster, more frequently, and with a
greater peak flow given the same rainfall. In fact, in an urban environment flood conditions can occur with much less rainfall than that necessary for rural or “pre-urban” conditions.

Deforestation and wildfires can also increase the flash flood risk by increasing the runoff volume and the potential for sediment transport within the runoff. As mentioned earlier in the section on soil influences, wildfires can alter soil properties so that burn areas become hydrophobic, i.e., tending to repel and not absorb water, for weeks or even years following a fire; indeed, some of the greatest flash flood risks occur after high-intensity fires in coniferous forests.

Finally, flash floods typically occur with intense warm-season convective rainfall so frozen soil is typically not a problem. However, in situations where intense rainfall may occur on impervious frozen ground, efficient runoff could result in flash flooding.

### Important Things to Remember About Flash Flood Science

- A combination of high rainfall rate and very efficient runoff production is common to most flash flood events.
- In some situations the runoff characteristics can be as or more important than the rain rate.
- Soil moisture, soil permeability, soil surface alterations, and vertical soil profile are important soil characteristics that affect runoff production and hence help define flash flood prone areas.
- Basin characteristics, (e.g., size, shape, slope, land cover) influence runoff and hence flash flood occurrence potential.
- Urbanization and fire can greatly increase flash flood potential by increasing both the potential volume of runoff as well as the speed with which the runoff occurs.