Surface Processes

Many areas are threatened, or at least affected, by the hazards associated with the internal geologic processes discussed before. Every place on earth is subject to one or more of the various kinds of *surface processes* . These are the geologic processes with causes and effects at or near earth's surface. They involve principally the actions of water, ice, wind, and gravity. Local climate plays a major role in determining the relative importance of these processes. This is one reason for interest in possible future changes in global and local climate.

The earth's surface is, geologically, a very active place. It is here that we see the interplay of the internal heat of the earth (which builds mountains and shifts the land), the external heat from the sun (which drives the wind and provides the energy behind the hydrologic cycle), and the inexorable force of gravity (which constantly tries to pull everything down to the same level).

Streams and Flooding

Water is the single most important agent sculpturing the earth's surface. Mountains may be raised by the action of plate tectonics and volcanism, but they are shaped primarily by water. Streams carve valleys, level plains, and move tremendous amounts of sediment from place to place.

Floods are probably the most widely experienced catastrophic geologic hazards. On the average, in the United States alone, floods annually take 140 lives and cause well over $6 billion in property damage. The 1993 flooding in the Mississippi River basin took 48 lives and caused an estimated $15–20 billion in damages.

Some floods are the result of unusual events, such as the collapse of a dam, but the vast majority are a perfectly normal, and to some extent predictable, part of the natural functioning of streams.

Factors Governing Flood Severity

Many factors together determine whether a flood will occur. The quantity of water involved and the rate at which it enters the stream system are the major factors. When the water input exceeds the capacity of the stream to carry that water away downstream within its channel, the water over flows the banks.

Worldwide, the most intense rainfall events occur in Southeast Asia, where storms have drenched the region with up to 200 centimeters (80 inches) of rain in less than three days. In the United States, several regions are especially prone to heavy rainfall events: the southern states, vulnerable to storms from the Gulf of Mexico; the western coastal states, subject to prolonged storms from the Pacific Ocean; and the midcontinent states, where hot, moist air from the Gulf of Mexico can collide with cold air sweeping down from Canada. Streams that drain the Rocky Mountains are likely to flood during snowmelt, especially when rapid spring thawing follows a winter of unusually heavy snow.

The rate of surface runoff is influenced by the extent of infiltration, which, in turn, is controlled by the soil type and how much soil is exposed. Soils, and rocks, vary in *porosity* and *permeability*.
A very porous and permeable soil allows a great deal of water to sink in relatively fast. If the soil is less permeable or is covered by artificial structures, the proportion of water that runs off over the surface increases. Once even permeable soil is saturated with water, any additional moisture is necessarily forced to become part of the surface runoff.

Topography also influences the extent or rate of surface runoff: The steeper terrain, more readily water runs off over the surface and the less it tends to sink into the soil. Water that infiltrates the soil, like surface runoff, tends to flow down gradient, and may, in time, also reach the stream. However, the subsurface runoff water, flowing through soil or rock, generally moves much more slowly than the surface runoff. The more gradually the water reaches the stream, have better chances that the stream discharge will be adequate to carry the water away without flooding. Therefore, the relative amounts of surface runoff and subsurface (groundwater) flow, which are strongly influenced by the near-surface geology of the drainage basin, are fundamental factors affecting the severity of stream flooding.

Vegetation may reduce flood hazards in several ways. The plants may simply provide a physical barrier to surface runoff, decreasing its velocity and thus slowing the rate at which water reaches a stream. Plant roots working into the soil loosen it, which tends to maintain or increase the soil's permeability, and hence infiltration, thus reducing the proportion of surface runoff. Plants also absorb water, using some of it to grow and releasing some slowly by evapotranspiration from foliage. All of these factors reduce the volume of water introduced directly into a stream system.
Meteorologic fluctuations local flood hazard may vary seasonally or as a result of meteorologic fluctuations. Just as soil already saturated from previous storms cannot readily absorb more water, so the solidly frozen ground of cold regions prevents infiltration; a midwinter rainstorm in such a region may produce flooding with a quantity of rain that could be readily absorbed by the soil in summer. The extent and vigor of growth of vegetation varies seasonally also, as does atmospheric humidity and thus evapotranspiration.

Consequences of Development in Floodplains

Why would anyone live in a floodplain? One reason might be ignorance of the extent of the flood hazard. Someone living in a stream's one-hundred- or two-hundred-year floodplain may be unaware that the stream could rise that high, if historical flooding has all been less severe. In mountainous areas, floodplains may be the only flat or nearly flat land on which to build, and construction is generally far easier and cheaper on nearly level land than on steep slopes. Around a major river like the Mississippi, the one-hundred- or two-hundred-year floodplain may include a major portion of the land for miles around, and it may be impractical to leave that much real estate entirely vacant. Farmers have settled in floodplain since ancient times because flooding streams deposit fine sediment over the lands flooded, replenishing nutrients in the soil and thus making the soil especially fertile. Where rivers are used for transportation, cities may have been built deliberately as close to the water as possible. And, of course, many streams are very scenic features to live near. Obviously, the more people settle and build in floodplains, the more damage flooding will do. What people often fail to realize is that floodplain development can actually increase the likelihood or severity of flooding.

Effects of development on flood Hazards:

As mentioned earlier, two factors affecting flood severity are the quantity and rate of surface runoff. The materials extensively used to cover the ground when cities are built, such as asphalt and concrete, are relatively impermeable and greatly reduce infiltration. Therefore, when considerable area is covered by these materials, surface runoff tends to be much more concentrated and rapid than before, increasing the risk of flooding.

Buildings in a floodplain also can increase flood heights (figure 6.20). The buildings occupy volume that water formerly could fill, and a given discharge then corresponds to a higher stage (water level). Floods that occur are more serious.

Filling in floodplain land for construction similarly decreases the volume available to stream water and further aggravates the situation. Measures taken to drain water from low areas can likewise aggravate flooding along a stream. In cities, storm sewers are installed to keep water from flooding streets during heavy rains, and, often, the storm water is channeled straight into a nearby stream. This works fine if the total flow is moderate enough, but by decreasing the time normally taken by the water to reach the stream channel, such measures increase the probability of stream flooding. The same is true of the use of tile drainage systems in farmland. Water that previously stood in low spots in the field and only

slowly reached the stream after infiltration instead flows swiftly and directly into the stream, increasing the flood hazard for those along the banks.
Both farming and urbanization also disturb the land by removing natural vegetation and, thus, leaving the soil exposed. The consequences are twofold. As noted earlier, vegetation can decrease flood hazards somewhat by providing a physical barrier to surface runoff, by soaking up some of the water, and through plants' root action, which keeps the soil looser and more permeable.
Vegetation also can be critical to preventing soil erosion. When vegetation is removed and erosion increased, much more soil can be washed into streams. There, it can fill in, or "silt up," the channel, decreasing the channel's volume and thus reducing the stream's capacity to carry water away quickly.

Strategies for Reducing Flood Hazards

1-Restrictive Zoning and Flood proofing

Short of avoiding floodplains altogether, various approaches can reduce the risk of flood damage. Many of these approaches— restrictive zoning, special engineering practices are similar to strategies applicable to reducing damage from seismic and other geologic hazards. A first step is to identify as accurately as possible the area at risk. Careful mapping coupled with accurate stream discharge data should allow identification of those areas threatened by floods of different recurrence intervals. Land that could be inundated often by twenty five year floods, perhaps might best be restricted to land uses not involving much building. The land could be used, for example, for livestock grazing-pasture or for parks or other recreational purposes.
Unfortunately, there is often economic pressure to develop and build on floodplain land, especially in urban areas. Local governments may feel compelled to allow building at least in the outer fringes of the floodplain, perhaps the parts threatened only by one-hundred- or two-hundred-year floods. In these areas, new construction can be designed with the flood hazard in mind.
Buildings can be raised on stilts so that the lowest floor is above the expected two-hundred-year flood stage, for example. While it might be better not to build there at all, such a design at least minimizes interference by the structure with flood flow and also the danger of costly flood damage to the building. A major limitation of any flood plain zoning plan, whether it prescribes design features of buildings or bans buildings entirely, is that it almost always applies only to new construction. In many places, scores of older structures are already at risk.

Programs to move threatened structures off floodplains are few, and also costly when many buildings are involved. Usually, any moving occurs *after* a flood disaster, when individual structures or, rarely, whole towns are rebuilt out of the floodplain.

2-Retention Ponds

If open land is available, flood hazards along a stream may be greatly reduced by the use of **retention ponds** (figure 6.22). These ponds are large basins that trap some of the surface runoff, keeping it from flowing immediately into the stream. They may be elaborate artificial structures; old, abandoned quarries; fields dammed by dikes of piled-up soil. The latter option also allows the land to be used for other purposes, such as farming, except on those rare occasions of heavy runoff when it is needed as a retention pond.

Retention ponds are frequently a relatively inexpensive option, provided that ample undeveloped land is available, and they have the added advantage of not altering the character of the stream.

3- Diversion Channels

A similar strategy is the use of *diversion channels* that come into play as stream stage rises; they redirect some of the water flow into areas adjacent to the stream where flooding will cause minimal damage. The diversion of water might be into farmland or recreational land and away from built-up areas, to reduce loss of life and property damage.

4-Channelization

Channelization is a general term for various modifications of the stream channel itself that are usually intended to increase the velocity of water flow, the volume of the channel, or both. These modifications thus increase the discharge of the stream and hence the rate at which surplus water is carried away. The channel can be widened or deepened, especially where soil erosion and subsequent sediment deposition in the stream have partially filled in the channel. Care must be taken, however, that channelization does not alter the stream dynamics too greatly elsewhere. [Dredging of Missouri's Blackwater River in 1910 enlarged the channel and somewhat increased the gradient, thereby increasing stream velocities. As a result, discharges upstream from the modifications increased. This, in turn, led to more stream bank erosion and channel enlargement upstream, and to increased flooding below.]

Alternatively, a stream channel might be rerouted for example, by cutting off meanders to provide a more direct path for the water flow. A meandering stream, however, often tends to keep meandering or to revert to old meanders. Channelization is not a one-time effort. Constant maintenance is required to limit erosion in the straightened channel sections and to keep the river in the cutoffs. The erosion problem along channelized or modified streams has in some urban areas led to the construction of wholly artificial stream channels made of concrete or other resistant materials. While this may be effective, it is also costly and frequently unsightly as well.

5-Levees

Some streams form low natural levees along the channel through sediment deposition during flood events (figure 6.23A). These levees may purposely be enlarged, or created where none exist naturally, for flood control (figure 6.23B). Because levees raise the height of the stream banks close to the channel, the water can rise higher without flooding the surrounding country. This is an ancient technique, practiced thousands of years ago on the Nile by the Egyptian pharaohs. It may be carried out alone or in conjunction with channelization efforts, as on the Mississippi.

However, confining the water to the channel, rather than allowing it to flow out into the floodplain, effectively shunts the water downstream faster during high-discharge events, thereby increasing flood risks downstream. An other large problem is that levees may make people feel so safe about living in the floodplain that, in the absence of restrictive zoning, development will be far more extensive than if the stream were allowed to flood naturally from time to time. If the levees have not, been built high enough and an unanticipated, severe flood over tops them, or if they simply fail and are breached during a high-discharge event, far more lives and property may be lost as a result. Problems with levees were abundantly demonstrated in the 1993 Mississippi River flooding.

Levees alter sedimentation patterns, too. During flooding, sediment is deposited in the floodplain outside the channel. If the stream and its load are confined by levees, increased sedimentation may occur in the channel. This will raise stream stage for a given discharge the channel bottom is raised, so stage rises also and either the levees must be continually raised to compensate, or the channel must be dredged, an additional expense.

6-Flood-Control Dams and Reservoirs

Yet another approach to moderating stream flow to prevent or minimize flooding is through the construction of flood-control dams at one or more points along the stream. Excess water is held behind a dam in the reservoir formed upstream and may then be released at a controlled rate that does not overwhelm the capacity of the channel beyond. Additional benefits of constructing flood control dams and their associated reservoirs (artificial lakes) may include availability of the water for irrigation, generation of hydroelectric power at the dam sites, and development of recreational facilities for swimming, boating, and fishing at the reservoir.
The practice also has its drawbacks, however. Navigation on the river—both by people and by aquatic animals—may be restricted by the presence of the dams. Also, the creation of a reservoir necessarily floods much of the stream valley behind the dam and may destroy wildlife habitats or displace people and their works. If the stream normally carries a high sediment load, further complications arise. The reservoir represents a new base level for the stream above the dam (fi gure 6.25). When the stream flows into that reservoir, its velocity drops to zero, and it dumps its load of sediment. Silting-up of the reservoir, in turn, decreases its volume, so it becomes less effective as a flood control device. Some reservoirs have filled completely in a matter of decades, becoming useless. Others have been kept clear only by repeated dredging, which can be expensive and presents the problem of where to dump the dredged sediment. At the same time, the water released below the dam is free of sediment and thus may cause more active erosion of the channel there. Or, if a large fraction of water in the stream system is impounded by the dam, the greatly reduced water volume downstream may change the nature of vegetation and of habitats there.

Questions for Review

1. Discuss the relationship between flooding and (a) precipitation, (b) soil characteristics, (c) vegetation, and (d) season.
2. Describe two ways in which urbanization may increase local Flood hazards. Sketch the change in stream response as it might appear on a hydrograph.
3. Channelization and levee construction may reduce local flood hazards, but they may worsen the flood hazards elsewhere along a stream. Explain.

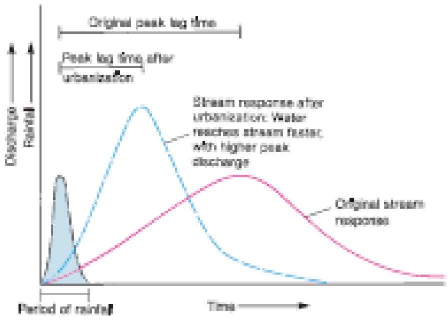


Figure 6.19

Hydrograph reflecting modification of stream response to precipitation following urbanization: Peak discharge increases, lag time to peak decreases.

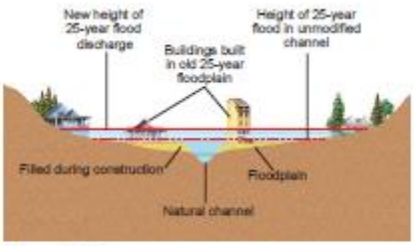


Figure 6.20

How floodplain development increases flood stage for a given discharge.

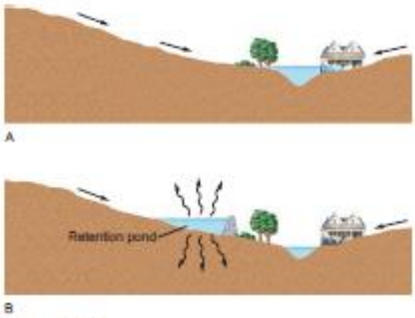


Figure 6.22

Use of retention pond to moderate flood hazard. (A) Before the retention pond, fast surface runoff caused flooding along the stream. (B) The retention pond traps some surface runoff, prevents the water from reaching the stream quickly, and allows for slow infiltration or evaporation instead.

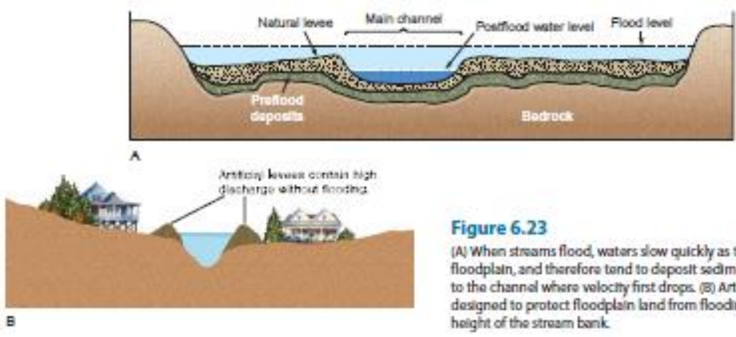


Figure 6.23

(A) When streams flood, waters slow quickly as they flow onto the floodplain, and therefore tend to deposit sediment, especially close to the channel where velocity first drops. (B) Artificial levees are designed to protect floodplain land from flooding by raising the height of the stream bank.

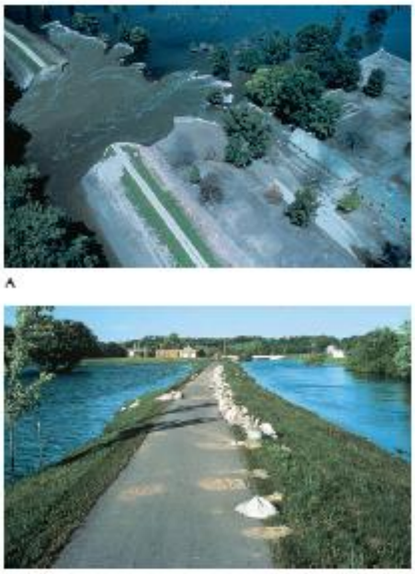
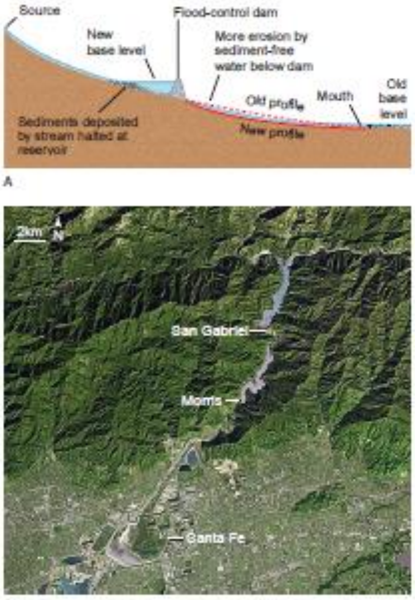


Figure 6.24

The negative sides of levees as flood-control devices. (A) If they are breached, as here in the 1993 Mississippi River floods, those living behind the levees may suddenly and unexpectedly find themselves inundated. (B) Breached or overtopped levees dam water behind them. The stream stage may drop rapidly after the flood crests, but the water levels behind the levees remain high. Sandbagging was ineffective in preventing flooding by the Kishwaukee River, DeKalb, Illinois, in July 1983. By the time this picture was taken from the top of the levee, the water level in the river (right) had dropped several meters, but water trapped behind the levee (left) remained high, prolonging the damage to property behind the levee.



B

Figure 6.25

(A) Effects of dam construction on a stream: change in base level, sediment deposition in reservoir, reshaping of the stream channel. (B) Two of the four large dams and reservoirs that protect Santa Fe from flash floods of the San Gabriel River as it plunges down out of the mountains. Note sediment clouding reservoir water.

Image courtesy NASA/GSFC/METI/ERSDAC/JAROS and the U.S./Japan ASTER Science Team.