# FLOODING

Flooding occurs as an overflow of water in a specific area, and it can happen for a variety of reasons, including:  severe weather, tsunamis, and hurricanes.  In this chapter, we are going to focus on flooding that occurs due to excessive run-off from rain or snowmelt, rather than those caused by earthquakes (tsunamis) or storm surges (hurricanes), in rivers.  Rivers can be called by many names:  streams, creeks, rivulet, tributaries, etc.  Regardless of the name, they are one of the most important movers of water and sediment on the surface of Earth.  Though they vary in  size, streams can become overwhelmed by excess water and turn into dangerous, flows of water that can destroy any obstacle in its path.  Historically, floods were also the most fatal disaster events, but deaths have been declining nationally due to steps taken to prepare for and recover from flooding.  Globally there is still cause considerable loss of life in impoverished countries, and huge losses to infrastructure in more affluent societies.

Flooding in Australia
Figure 6.1 Flooding in Australia. NASA, Public Domain.

Learning Objectives

After this chapter, you should be able to:

Explain the hydrological cycle and its relevance to streams
Describe a drainage basin and its importance in flooding events
Describe the processes by which sediments are moved by streams and the flow velocities that are necessary to erode them from the stream bed and keep them suspended in the water
Describe the annual flow characteristics of typical streams and the processes that lead to flooding
Describe some of the important historical floods in the United States
Determine the probability of a flood of a particular size based on the flood history of a stream
Explain some of the steps that we can take to limit the damage from flooding.

6.1 Distribution of Earth's Water
Water, Water, Everywhere!
Water is composed of two atoms of hydrogen and one atom of oxygen bonded together. Despite its simplicity, water has remarkable properties. Water expands when it freezes. It has high surface tension because of the molecules' polar nature that tend to stick together. Without water, life might not exist on Earth, and it certainly would not have the tremendous complexity and diversity that we see (1). Video 6.1.1. explains the polarity and the properties that arise.

Video 6.1.1. Water is both essential and unique. Many of its particular qualities stem from its polarity, thanks to two hydrogen atoms and one oxygen. (3:51)

Where does all the Earth’s water come from? Primordial Earth was an incandescent globe of magma, but all magmas contained water in them. Water was released as water vapor from magma and it accumulated in Earth’s atmosphere. When the temperature decreased, the water vapor condensed and precipitated as rain, accumulating on the surface as liquid water. Volcanic activity kept, and still keeps, introducing water into the atmosphere, thus increasing the surface- and groundwater volume of the Earth (2).

An image showing the relative amounts of Earth's water in comparison to the size of the Earth.
Figure 6.1.1. An image showing the relative amounts of Earth’s water compared to the size of the Earth. USGS, Public Domain.

Earth’s oceans contain 97% of the planet’s water, and just 3% is freshwater with relatively low concentrations of salts. Most freshwater is trapped as ice in the vast glaciers and ice sheets of Greenland and Antarctica. A storage location for water such as an ocean, glacier, pond, or even the atmosphere is called a reservoir. A water molecule may pass through a reservoir quickly or may remain for much longer. As you can see from the graph below, Rivers account for 0.49% of surface/ other freshwater or 0.0001% of the overall water on the planet (1).

An estimation of where the Earth's water exists on, within, and around the Earth.
Figure 6.1.2. An estimation of where the Earth’s water exists on, within, and around the Earth. “Distribution of the Locations of Water on Earth” by the United States Geologic Survey Public Domain

Hydrologic Cycle

Because of the unique properties of water, water molecules can cycle through almost any-where on Earth. The water molecule found in a glass of water today could have erupted from a volcano early in Earth’s history. In the intervening billions of years, the molecule probably spent time in a glacier or far below the ground. The molecule surely was high in the atmosphere and maybe deep in the belly of a dinosaur.

Water is the only substance on Earth that is present in all three states of matter—as a solid, liquid, or gas. Along with that, Earth is the only planet where water is present in all three states. Because of the ranges in temperature in specific locations around the planet, all three phases may be present in a specific location or region. The three phases are solid (ice or snow), liquid (water), and gas (water vapor) (Dastrup, 2020).

Video 6.1.2. Block diagram animations of the water cycle (1:22)

The water cycle has no starting point. But we'll begin in the oceans, since that is where most of Earth's water exists. The sun, which drives the water cycle, heats water in the oceans. Some of it evaporates as vapor into the air. Ice and snow can sublimate directly into water vapor. Rising air currents take the vapor up into the atmosphere, along with water from evapotranspiration, which is water transpired from plants and evaporated from the soil. The vapor rises into the air where cooler temperatures cause it to condense into clouds (USGS).

Air currents move clouds around the atmosphere, cloud particles collide, grow, and fall out of the sky as precipitation. Some precipitation falls as snow and can accumulate as ice caps and glaciers, which can store frozen water for thousands of years. Snowpacks in warmer climates often thaw and melt when spring arrives, and the melted water flows overland as snowmelt (USGS).

Most precipitation falls back into the oceans or onto land, where, due to gravity, the precipitation flows over the ground as surface runoff. A portion of runoff enters rivers in valleys in the landscape, with streamflow moving water towards the oceans. Runoff, and groundwater seepage, accumulate and are stored as freshwater in lakes. Not all runoff flows into rivers, though. Much of it soaks into the ground as infiltration. Some water infiltrates deep into the ground and replenishes aquifers (saturated subsurface rock), which store huge amounts of freshwater for long periods of time (USGS).

Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean) as groundwater discharge, and some groundwater finds openings in the land surface and emerges as freshwater springs. Over time, though, all of this water keeps moving, some to reenter the ocean, where the cycle continues (USGS).

And, of course, it's complicated….
Video 6.1.3. This animation uses Earth science data from a variety of sensors on NASA Earth observing satellites and cartoons to describe Earth's water cycle and the continuous movement of water on, above and below the surface of the Earth (5:52).

People also depend on water as a natural resource. Not confined to only take fresh water directly from streams or ponds, humans create canals, aqueducts, dams, and wells to collect water and direct it to where they want it, which further complicates the already dynamic system.

Figure 6.1.3. Annual Precipitation data 1981-2010, Arizona State University School of Geographical Sciences and Urban Planning. Used with permission.
Backyard Geology: Arizona's water cycle

Arizona is the sixth largest state in the US, and it encompasses diverse climates and topography.

Precipitation: Much of the state is characterized as arid to semi-arid with total annual precipitation ranging from less than 3 inches in the southwest to around 40 inches in the White Mountains in east central Arizona. Precipitation is highly variable from year to year, with statewide average precipitation ranging from a low of 6.04 total inches in 1956 to a high of 22.77 inches in 1905.

Evaporation: It is estimated that more than 95% of rainfall that falls in the non-mountainous regions of Arizona evaporates quickly. The largest natural lake in Arizona is Mormon Lake, near Flagstaff, AZ, and has been known to be completely dry.

Runoff (Streams): This is extremely variable, and generally related to weather patterns and rainfall through storms. Most streams in Arizona either infiltrate into the groundwater, evaporate, or flow to the Colorado River. All major streams have at least one dam on them, and very little water flows all the way to the ocean.

## 6.2 Streams and River Systems

### Streams

Streams are bodies of water that are in constant motion. Geologists recognize many categories of streams depending on their size, depth, speed, and location. Creeks, brooks, tributaries, bayous, and rivers might all be lumped together as streams. In streams, water always flows downhill, but the form varies with rock type, topography, and many other factors (1).

Stream Landscape

Figure 6.2.1 Stream Landscape. Wikimedia Commons, Public Domain.

### Path of a Stream

A stream originates at its sources of water, which may be from precipitation, such as high mountains where snows collect in winter and melt in summer, or a spring. It is common for a stream to have more than one source.

image

Figure 6.2.2. Water starts collecting on the top of mountains from small streams. The stream grows by receiving the flow of more streams and it turns into a river. Rivers collect water from other rivers as they flow towards the ocean. “River Source” by Tony Ferrie CC-BY.

Figure 6.2.3. The Ohio river meets the Mississippi River. The Ohio is considered the tributary of the Mississippi River. NASA Landsat Science, Public Domain.

Where multiple streams combine, the smaller stream is called a tributary. In Figure 6.2.3, the Ohio and Mississippi Rivers meet, and the Ohio River is considered a tributary at this junction. Streams will eventually run down the landscape and the water molecules could infiltrate into the ground, evaporate into the atmosphere, or continue to run-off until it intersects with a large body of water, like an ocean or a lake.

image

Figure 6.2.4. A river delta is the place where the river encounters a larger body of water, such as a lake or, more typically, the ocean. “Mouths of the Amazon River” by NASA, Public Domain.

Divides and Drainage Basins

A drainage basin is all of the land that is drained by one stream, including its tributaries.  A divide is a topographically high area that separates a landscape into different water basins. The rain that falls on the north side of a divide flows into the northern drainage basin, and rain that falls on the south side flows into the southern drainage basin. On a much grander scale, entire continents have divides, known as continental divides.(1).

image

Figure 6.2.5. North America Water Divides Pfly, CC-BY-SA

According to Fig. 6.2.5, the State of Arizona is bracketed by the Great Divide to the east, and the Great Basin to the west.

Discharge and Stream Stage

Along the path of the stream, the water volume and velocity may change, depending on the amount of water input and the overall shape and gradient of the stream as it winds through the landscape. This is referred to as stream discharge. Discharge measures stream flow at a given time and location, and specifically is a measure of the volume of water passing a particular point in a period of time. It is found by multiplying the area (width multiplied by depth) of the stream channel by the velocity of the water, and is often in units of cubic feet per second (cfs). Discharge increases downstream in most rivers, as tributaries join the main channel and add water.

Figure 6.2.6. The most common method used by the USGS for measuring velocity is with a current meter. However, a variety of advanced equipment can also be used to sense stage and measure streamflow. In the simplest method, a current meter turns with the flow of the river or stream. The current meter is used to measure water velocity at predetermined points (subsections) along a marked line, suspended cableway, or bridge across a river or stream. The depth of the water is also measured at each point. These velocity and depth measurements are used to compute the total volume of water flowing past the line during a specific interval of time. Usually a river or stream will be measured at 25 to 30 regularly spaced locations across the river or stream. USGS, Public Domain

Stream stage, sometimes called gage height, is the height of the water at the surface of the stream.  Stage zero would be the dry streambed, and stage 1 would be 1 feet above zero. Every stream in every part of the world has a unique calculation of stage and discharge that is related to its unique features.

A stream gage showing water depth in the Colorado River.  USGS.  Public Domain

Figure 6.2.7. A stream gage showing water depth in the Colorado River.  USGS, Public Domain
Backyard Geology:  The Colorado River Drainage Basin

Figure 6.2.7. Colorado River Drainage Basin, USGS. Public Domain
Path of the Stream: The Colorado River is nearly 1,450 miles long, beginning with snowmelt, rainwater, and springs in Colorado and Wyoming.

Drainage Basin: The entire basin covers approximately 246,000 square miles and includes all of Arizona (Fig. 6.2.7).

Discharge: The average discharge of the river is highly variable, because it is regulated through a series of dams along the river, as well as extensive use for agriculture. In it's natural state, the discharge would still be highly variable due to climate but would average about 22,500 cfs, but very little of it typically makes it to the Gulf of California.

## 6.3 Stream Erosion and Transportation

Flowing water is a primary mechanism for erosion, transportation, and deposition. There are many factors that can control how quickly or how much water will flow within a stream, but it is primarily related to the stream's gradient, or slope, as well as the shape of the stream.  All of the water that reaches a stream contains sediment that has been carried from the entire drainage basin.

### Stream Erosion

Erosion is the geological process in which materials are worn away and transported by natural forces such as wind or water, and streams are very efficient agents of erosion.  The faster the water is flowing, the larger the particles that can be kept in suspension and transported within the flowing water. However, as Swedish geographer Filip Hjulström dis-covered in the 1940s, the relationship between grain size and the likelihood of a grain being eroded, transported, or deposited is not as simple as one might imagine (Fig. 6.3.1). Consider, for example, a 1 mm grain of sand. If it is resting on the bottom, it will remain there until the velocity is high enough to erode it. However, once it is in suspension, that same 1 mm particle will remain in suspension as long as the velocity does not drop below 10 centimeters per second (cm/s.) For a 10 mm gravel grain, the velocity is 105 cm/s to be eroded from the bed but only 80 cm/s to remain in suspension (3).

The Hjulström-Sundborg diagram showing the relationships between particle size and the tendency to be eroded, transported, or deposited at different current velocities.
Figure 6.3.1. The Hjulström-Sundborg diagram showing the relationships between particle size and the tendency to be eroded, transported, or deposited at different current velocities. Steven Earle. CC-BY 4.0
On the other hand, a 0.01 mm silt particle only needs a velocity of 0.1 cm/s to remain in suspension but requires 60 cm/s to be eroded. A tiny silt grain requires a higher velocity to be eroded than a grain of sand that is 100 times larger. For clay-sized particles, the discrepancy is

even more significant. In a stream, the most easily eroded particles are small sand grains between 0.2 mm and 0.5 mm. Anything smaller or larger requires a higher water velocity to be eroded and entrained in the flow. The main reason for this is that those small particles, especially the tiny grains of clay, have a strong tendency to stick together, so they are challenging to erode from the stream bed (3).

Stream Transportation

Streams transport large quantities of materials from the headwaters all the way to the mouth of the stream where it intersects a lake or ocean. There are three types of sediment that are carried:

Large particles rest on the bottom, typically anything larger than sand, is called bedload, and may only be moved during rapid flows under flood conditions. They can be moved by saltation (bouncing) and by traction (being pushed along by the force of the flow).

Smaller particles may rest on the bottom some of the time, where they can be moved by saltation and traction, but they can also be held in suspension in the flowing water, especially at higher velocities. They are referred to as suspended load.

Stream water also has a dissolved load, representing roughly 15 percent of the mass of material transported, and includes ions such as calcium dissolved load and chloride in solution. The solubility of these ions is not affected by flow velocity (Earle, 2019).

image

Figure 6.3.2. Particles in Suspension and Ions in Solution. Steven Earle CC-BY.

Stream Deposition

Because streams carry a tremendous amount of sediment, they also deposit that sediment. Flooding events typically deposit dissolved and suspended sediments onto floodplains, but larger particles can also be deposited depending on water discharge.

Backyard Geology: Colorado River Sediment Carry

One of the more spectacular examples of Colorado River erosion is the formation of the Grand Canyon. Millions of visitors a year visit this beautiful landscape that highlights stream movement through a dynamic landscape.

Grand Canyon Overlook

Figure 6.3.3. Grand Canyon Overlook, Merry Wilson CC-BY-NC-SA.

Stream Erosion: Between 5-6 million years ago, the Colorado River and its tributaries began carving through the underlying rocks.

Stream Transportation: Sediment transport in the Colorado River at the Grand Canyon has been extensively studied. Because the water flow is now tightly controlled through a series of dams, sediment transport has dramatically been affected. It is estimated that the River would have carried over 500,000 tons of sediment through the Grand Canyon daily before the construction of the Glen Canyon Dam.

Stream Deposition: Lake Mead, the largest lake on the Colorado River, is formed by the Hoover Dam, built in 1935. Due to the sediments that fill the lake over time, it was estimated that Hoover Dam would only last 200 years before it was overtopped with sediment. With the construction of Glen Canyon Dam upstream, Hoover is now expected to last a thousand years. However, Glen Canyon Dam sedimentation is now the focus of analysis (National Park Service).

## 6.4 Types of Floods and Flood Features

Floods, an overflow of water in one place, are a natural part of the water cycle, but they can be terrifying forces of destruction. Floods can occur for a variety of reasons, and their effects can be minimized in several ways. Perhaps unsurprisingly, floods tend to affect low-lying areas most severely, although they can occur anywhere. Floods usually occur when precipitation falls more quickly than that water can be absorbed into the ground or carried away by rivers or streams. Waters may build up gradually throughout weeks when an extended period of rainfall or snowmelt fills the ground with water and raises stream levels. The discharge levels of streams are highly variable depending on the time of year and on specific variations in the weather from one year to the next (1).

Video 6.4.1. What is a flood? Why do floods occur at Mount Rainier National Park, and how are floods changing the landscape? (5:38).

### Types of Floods

Flash floods are sudden and unexpected, taking place when very heavy rains fall over a very brief period. A flash flood may do its damage miles from where the rain falls if the water travels far down a dry streambed so that the flash flood occurs far from the location of the original storm. These floods can turn a dry stream channel into a raging river in a matter of minutes (Dastrup, 2020).

While flash floods can occur anywhere, they are more likely in mountainous regions and areas with small drainage basins that a sudden, intense influx of water can easily overcome. In the dry, desert southwest, the lack of vegetation and clay-rich soils also play a role. Densely vegetated lands are less likely to experience flooding, because plants slow down water as it runs over the land, giving it time to enter the ground. Even if the ground is too wet to absorb more water, plants still slow the water's passage and increase the time between rainfall and the water's arrival in a stream; this could keep all the water falling over a region to hit the stream at once. While clay-rich soils can hold huge amounts of water, they don't absorb that water quickly, so water is more likely to run off/

Video 6.4.2. Post-fire flash flood. The flow event resulted from rain higher up in the basin, which includes the Montezuma Pass overlook area in Arizona (2:32).

Historic Flooding: Flash Floods

While typically smaller, flash floods are often unexpected and can be deadly events. Here are some examples:

Big Thompson Canyon, Colorado, 1976. Within a few hours of the initial rainfall, water accumulated in a dry wash in the middle of the night and killed 144 people.
Antelope Canyon, AZ, 1997. A beautiful tourist destination became deadly to 11 hikers that could not get out of the steep walled-canyon when waters came rushing through from an unseen cloudburst in the distance.
Verde River, Payson, AZ, July 2017. A family of 10 was swept and drowned by a flash flood in a tributary of the East Verde River while on playing in a popular swimming area. Monsoonal rains 29 miles away had raced down an area that had burned down during a recent forest fire.

Regional Floods

When flooding occurs after an extended period of rainfall, the increase in volume of water within a stream and its tributaries will eventually overflow with water into the adjacent floodplain. This is the classic vision of flooding and is also the most common type of flooding event. This is sometimes referred to as riverine flooding. Along major rivers with very large drainage basins, the timing and size of floods can be predicted in advance with considerable accuracy. Generally, the smaller the drainage basin, the more difficult it is to forecast the flood. Prolonged seasonal rainfall and associated snowmelt often causes these types of floods, but they can be heightened by storm events as well. Global water circulation patterns are also often to blame.

For example, El Nino is a global weather event that causes the trade winds to weaken and subsequently push warm, wet air across the Gulf Coast and southeastern United States. Both flash and regional flooding can occur from the storms generated by this event.

El Nino Weather Event

Figure 6.4.1. El Niño weather pattern brings warm wet air to some areas that can increase flooding. NOAA, Public Domain.

Historic Flooding: Regional Floods

Heavy rainfall of extended periods of time can overwhelm large drainage basins.

Mississippi River, 1927. Considered the most destructive regional flood in the history of the US. Over 500 people were killed.
Ohio River, 1937. This flood event was so widespread, people were left homeless up to 30 miles away from the river.
Mississippi River, 1993. This was the second costliest on flood event on record, partly due to the amount of time that areas were flooded. The waters stayed at flood stage for 81 consecutive days.

Arizona, 1993. The El Nino event caused 3 months of abnormally high precipitation across most of Arizona. The combination of rain and snow generated the largest floods on record for many rivers in the state.

Flood recurrence

Floods naturally happen regularly on streams. If you've ever heard someone talking about the "100-year flood", this means that on average we can expect a flood of this size or greater to occur within a 100-year period. There are also 5-year, 10-year, and up to 1000-year floods. While this doesn't tell us exactly which year the flood event will occur in, it gives us an idea of the size and frequency to expect.

The U.S. Geological Survey has thousands of gages on streams throughout the country in order to track flow and calculate recurrence intervals, like the 100-year flood. The amount of actual water in the channel is related specifically to the stream being assessed, as the discharge of every stream is variable. Geologists use statistical probability (chance) to put a context to floods and their occurrence. If the probability of a particular flood magnitude being equaled or exceeded is known, then risk can be assessed. To determine these probabilities, all the annual peak streamflow values measured at a gage are examined and every stream had a different magnitude calculation for floods. So, the 100-year flood magnitude for the Salt River, which flows through central Phoenix is calculated to be 300,000cfs, although very few floods have been recorded and measurements have only been taken since the late 1890's. However, the same 100-year flood calculation for the Mississippi River (the largest stream in the United States), is nearly 1,800,000cfs!

Flood Features

A stream typically reaches its greatest velocity when it is close to flooding over its banks. This is known as the bank-full stage, as shown in the figure below. As soon as the flooding stream overtops its banks and occupies the wide area of its flood plain, the water has a much larger area to flow through and the velocity drops significantly. At this point, sediment that was being carried by the high-velocity water is deposited near the edge of the channel, forming a natural bank or levée. As numerous flooding events occur, these ridges buildup under repeated deposition. These levees are part of a larger landform known as a floodplain. A floodplain is the relatively flat land adjacent to the stream that is subject to flooding during times of high discharge and are popular sites for development due to their rich soils, access to waterways, and nice scenery (1).

The development of natural levées during flooding of a stream. The sediments of the levée become increasingly fine away from the stream channel, and even finer sediments — clay, silt, and fine sand — are deposited across most of the flood plain. [SE]

Figure 6.4.2 The development of natural levées during flooding of a stream. The sediments of the levée become increasingly fine away from the stream channel, and even finer sediments — clay, silt, and fine sand — are deposited across most of the flood plain. Steven Earle, CC-BY.

Because floodplains are flat areas that have had regular deposits of silt and clay over time, they become fertile and are often used for agriculture.  The U.S. Federal Emergency Management Agency (FEMA) estimates that in 2018, as many as 13 million Americans live on the floodplain in the 100-year flood zone, although the number is likely much higher due to the amount of time it takes to update flood maps in highly populated areas.

## 6.5 Flood Mitigation

Flooding occurs in every U.S. state and territory, and kills more people each year than tornadoes, hurricanes, or lightning and costs on average $5 billion per year to (NOAA, 2021). Flooding is inevitable when living near a stream, and there are many hazards associated with flooding. Hazard mitigation is any sustainable action that reduces or eliminates long-term risk to people and property from future disasters. Mitigation planning breaks the cycle of disaster damage, reconstruction and repeated damage. Hazard mitigation includes long-term solutions that reduce the impact of disasters in the future (FEMA, 2021).

### Flood Control Structures

We construct flood control structures to protect residential areas, businesses, and agricultural lands from the potential devastation of large flood events. Sometimes these structures allow water to flow more slowly through the watershed, allowing flood waters to recede to a less dangerous stage. Other times the block water entirely from entering an area. When they work well, flood control structures can allow people and rivers to interact in a predicable patter, but when they fail, they can often be devastating events.

Video 6.5.1. How do large-scale flood control structures work in rivers? (11:17).

### Dams

A dam is a structure that is built to stop river water flow. These are built as flood control features and are also used to store water in reservoirs for irrigation, public consumption, and to produce hydroelectric electricity. People try to protect areas that might flood with dams, and dams are remarkably effective. Dams are also used to control regional flooding events by slowing the release of water, so that it does not overwhelm a single trunk stream all at one time. When a dam breaks along a reservoir, flooding can be catastrophic. High water levels have also caused small dams to break, wreaking havoc downstream (1).

Glen Canyon Dam, Page, Arizona

Figure 6.5.1. The Glen Canyon Bridge & Dam, Page, Arizona controls the flow of the Colorado River and was designed to provide hydro-electricity and recreation. Thad Roan, CC-BY.

### Historic Flooding:  Dam Failure

While dam failure is infrequent, the results can be devastating.

Johnstown, PA, 1889. The deadliest flood in U.S. history. Several days of extremely heavy rain overwhelmed a small drainage basin and caused dam collapse, killing 2,200 people.
Rapid City, South Dakota, 1972. A flash flood filled a dam with debris and caused it to fail. 238 people died.

Levees

People may also line a riverbank with levees, high walls that keep the stream within its banks during floods. Sometimes these are earthen structures, made of mud and sand, and sometimes they are made of concrete. A levee in one location may force the high water up or downstream and cause flooding there. The photo below is of a broken levee after a flood in Kansas City, along the Missouri River, in 2011. That year, record rain and snowmelt overwhelmed more than 850 miles of open river between North Dakota and the Mississippi River in St. Louis. Dams along the Missouri tried to regulate the water in the river, but calculations did not allow enough water release and large-scale flooding ensued. Sometimes levees are breached intentionally in order to flood less populated areas and save more urban areas from extensive damages.

2011 Flood

Figure 6.5.2. Kansas Flood, 2011, US Army Corps of Engineers, Public Domain.

Historic Flooding:  Levee Failure

While we build levees to keep floodwaters away from businesses and homes, when they fail, they can cause more massive flooding that would have occurred without them.

Hurricane Katrina, 2005. The Hurricane itself was only a Category 3 storm when it reached land, but it destroyed New Orleans aging levees, which were holding back large amounts of water. The result was more than 80% of New Orleans was under water, 1800 people died, and this was the costliest natural disaster in US History at the time.
The “Great Mississippi Flood”, 1927. The Mississippi River saw record rain and snowmelt, and the river breached the levees, flooding over 27,000 square miles, killing 250 people, and displacing more than 700,000.

Retention Basins and Canals

Retention basis are small depressions that are constructed to capture storm water that may cause flooding and allow water to be released more slowly.  You’ve probably seen them surrounding shopping malls, or even at a school. When not flooded, sometimes these features are used for recreation and as urban green spaces. The canals seen throughout the Phoenix area are also used as flood control features. While they are also used to transport water throughout the city for irrigation, they collect and manage floodwaters when monsoons do regularly flood the city.

Canals, flood controls stations and water retention basins

Figure 6.5.3. Canals, flood controls stations and water retention basins. World Bank Photo Collection, CC BY-NC-ND.

Backyard Geology: Hohokam Canal System

Modifying river systems is not a new idea. The Hohokam, a prehistoric group of Native Americans that lived in the area that is now Phoenix, built an extensive canal system. Over 700 miles worth of canals, built between the years of 600-1400 AD, serviced over 100,000 acres of desert land. This canal system is considered the largest in the New World, and the oldest in what is now the United States. These were entirely constructed by hand without the benefit of modern survey instruments, machinery, or wheeled vehicles. Their major canals averaged about 8 to 12 miles and were largest at the headwaters and tapered throughout their length so that the velocity was maintained between approximately 1.5 and 3 f/s (ft per second) throughout the system. They also adjusted their construction based on the terrain. The Hohokam developed four different types of distribution systems depending on the terrain. In addition, their system was a dynamic irrigation system. When conditions changed, such as a canal filling with silt, they would abandon the canal and build a new one adjacent to the old one. Around 1450 AD, the Hohokam abandoned the area for unknown reasons, but the leading idea was that they could not keep up with the water needs in the hostile terrain. Hohokam is derived from the Akimel O'odham word for "those who have gone" or "all used up."An irrigation canal runs through the Phoenix area

Figure 6.5.4. A restored Hohokam canal that is currently used for present-day irrigation throughout the Phoenix Area. Wikimedia Commons, CC-BY-SA.

Urbanization and Flooding

The increase in urban society brings many land use changes with it. Vegetation is removed or changed, impermeable surfaces like homes and buildings are constructed, and many changes are made to natural waterways.  All of these changes influence the amount of surface runoff in a given area.  With less natural water storage capacity and more rapid runoff, urban streams have higher, faster peak discharge rates than more rural streams.

Figure 6.5.5. Streamflow in Mercer Creek, an urban stream in western Washington, increases more quickly, reaches a higher peak discharge, and has a larger volume during a one-day storm on February 1, 2000, than streamflow in Newaukum Creek, a nearby rural stream. Streamflow during the following week, however, was greater in Newaukum Creek.

Changing river dynamics can also alter the stream stage, and cause typical rainstorms to become flooding events.  Construction of bridges is a common occurrence in urbanization that can significantly alter stream stage by constricting water flow.

Flood Events

As discussed, flooding occurs when a drainage basin is overwhelmed by water and streams overflow.  Sometimes this can occur very quickly in a flash flood, and sometimes it grows over days, weeks, and months.  All flooding can cause power outages, disrupt travel, damage buildings, create landslide events, and are considered a threat to life. There are some ways to stay safe during floods.

Prepare

Though disasters cannot be stopped, they potential damages can be somewhat mitigated through preparation.  According to FEMA, there are important considerations to prepare for flooding.

Know whether you are located on a floodplain or designated flood zone.
Build a “Go Kit” composed of supplies you may need if you need to move from your location, as well as maintaining supplies if you need to stay several days without power or water.
Find out if your community has a flood warning system, and sign up.
Know the signs that could lead to flash flooding.
During
The general “rule of thumb” regarding floods is to NEVER enter floodwaters.  FEMA advises, “Turn Around, Don’t Drown!”, with an emphasis not to every walk, swim, or drive through flood waters.  The State of Arizona has a law, nicknamed the Stupid Motorist Law, that requires that any motorist that becomes stranded by entering a flooded area can be charged for the cost of their own rescue.

Resident pushing a car through flood waters
Figure 6.5.5. Resident pushing a car through flood waters. FEMA, Public Domain.
Common sense measures can be followed during flood events.

Never enter a flooded area.
If told to evacuate, do so immediately.
Stay off bridges, because they could be prone to wash away in fast moving water.
Go to the top floor or roof of a building
After
The size and impact of flooding events vary widely, depending on many factors. In general, it is best to listen to local authorities in order to determine the best course of action after a flood.

Never enter a flooded area, as there could be risk from electrocution, debris, and fast moving water.
Beware that structures could have been compromised and may be unsafe.
Animals, particularly snakes, may have taken refuge in your home.
Costs of Flood
According to the National Centers for Environmental Information, flooding is one of the most universal and costly weather and climate related hazards in the United States. Riverine flooding events cost, on average, $4.6 billion dollars per event. This is independent of flooding events related to tropical cyclones and severe storms, and accounts for over 8% of the total costs of all weather and climate disasters in the United States in the last 40 years (NOAA, 2021).

Billion Dollar Disasters
Figure 6.5.6. NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2021), Public Domain.

6.6 Natural Floodplains and Restoration

Not all the consequences of flooding are negative. Rivers deposit new nutrient-rich sediments when they flood, and so floodplains have traditionally been suitable for farming. Flooding as a source of nutrients was essential to Egyptians along the Nile River until the Aswan Dam was built in the 1960s. Although the dam protects crops and settlements from the annual floods, farmers must now use fertilizers to feed their crops. Places where streams are allowed to flow without human interaction show streams actively move over the landscape.

Rio Negro Floodplain, Patagonia, Argentina
Figure 6.6.1 Rio Negro Floodplain, Patagonia, Argentina. NASA, CC BY-NC.

Natural Floodplains

Floods are also responsible for moving substantial amounts of sediments about within streams. These sediments provide habitats for animals, and the periodic movement of sediment is crucial to the lives of several types of organisms. Plants and fish along the Colorado River, for example, depend on seasonal flooding to rearrange sand bars.

While streams have largely been controlled through flood mitigation, an argument can be made to restore floodplains to their natural states in order to lessen flooding. According to FEMA, there are many benefits to Natural Floodplains, including:

Excess water storage: Except in narrow, steep valleys, floodplains provide a broad area which allows floodwaters to spread out and temporarily store excess water. This reduces flood peaks and velocities and the potential for erosion. Flood storage is particularly important in urban areas where even small floods resulting from a 5- or 10-year storm can cause severe flood damage. One acre of floodplain flooded one foot deep holds approximately 330,000 gallons of water.

Flow rate and erosion reduction: In their natural vegetated state, floodplains slow the rate at which the incoming overland flow reaches the main water body in the area.

Slowing runoff: A natural floodplain has surface conditions favoring local ponding where water slows and pools, plus subsurface conditions favoring infiltration and storage. Slowing runoff across the floodplain allows additional time for the runoff to infiltrate and recharge available groundwater aquifers when there is unused storage capacity. The slowing of runoff provides the additional benefit of natural purification of water as local runoff or overbank floodwater infiltrates and percolates through the floodplain gravels.

Conserving wildlife while reducing flood risk: The nation’s coastal and riverine floodplains and surrounding land areas support large and diverse populations of plants and animals by providing habitat and critical sources of energy and nutrients for these organisms. Many species spend their entire lives in the habitats found in and adjacent to the floodplain. The wide variety of plants and animals supported directly or indirectly by floodplains constitutes an extremely valuable, renewable resource important for our economic welfare, aesthetic enjoyment, and physical well-being.

Restoration

Many communities across the country are recognizing the connection between conserving wildlife and reducing flood risk to their inhabitants, and are engaging in activities that both protect important habitat and help minimize community flood loss.

Backyard Geology:  Rio Salado Habitat Restoration Area
The Salt River flowed freely through Phoenix year-round, but after the river was dammed in 1911 and has experienced high water use for irrigation, it has not continuously flowed for decades.

Rio Salado Habitat Restoration Area
Figure 6.6.2. Rio Salado Habitat Restoration Area, Google Maps, Fair use.
The Rio Salado Habitat Restoration Area, located along the Salt River and managed by Phoenix Parks and Recreation, aims to restore the native wetland and riparian environments that are historic to the area. Utilizing water stored in Tempe Town Lake, the wetland is strategically managed to provide habitat for hundreds of species of migratory birds, as well as recreational and educational opportunities for citizens.

6.7 Attributions and References
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Fig. 6.1.1 Perlman, H., Cook, J., Nieman, A., Shiklamonov (n.d.) The World’s Water.

An image showing the relative amounts of Earth’s water in comparison to the size of the Earth.
Fig.  6.1.2 USGS (1993) Where is Earth’s Water? Retrieved June 2, 2021 from https://water.usgs.gov/edu/gallery/watercyclekids/earth-water-distribution.html

An estimation of where the Earth’s water exists on, within, and around the Earth.
Video 6.1.2 Met Office – Weather. (n.d.). How does the water cycle work? [Online Video]. Retrieved February 23, 2019, from https://www.youtube.com/watch?v=SvA11IuweNk

An animation to explain the water cycle.
Video 6.1.3. NASA Goddard. (n.d.). NASA | Earth's Water Cycle. [Online Video]. Retrieved February 23, 2019, from https://www.youtube.com/watch?v=oaDkph9yQBs

An animation using Earth science data from NASA satellites to show the continuous movement of water on Earth.
Figure 6.1.3 Arizona State University School of Geographical Sciences and Urban Planning (n.d.) Average Annual Precipitation 1981-2010. Retrieved March 27, 2021 from http://www.public.asu.edu/~aunjs/PrecipMaps.htm

Map showing average annual precipitation in Arizona from 1981-2010.
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Fig. 6.2.1 Wikimedia Commons (n.d.) Stream River Landscape. Retrieved March 27, 2021 from https://pixy.org/src/22/thumbs350/226560.jpg

An image showing stream landscape.
Fig. 6.2.2 Ferrie, Tony (2007) River Source by Retrieved March 27, 2021 from https://upload.wikimedia.org/wikipedia/commons/c/c3/River_source_-_geograph.org.uk_-_380822.jpg

An image showing the headwaters of a river in Sgurr na Ciche, Scotland.
Fig. 6.2.3 NASA (2011) Flooding at the Junction of the Mississippi and Ohio Rivers. Retrieved March 27, 2021 from
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An image showing the muddy waters of the Mississippi River intersecting the cleaner waters of the Ohio River after the flooding event in 1993.
Fig. 6.2.4 NASA (1990) Mouths of Amazon Geocover. Retrieved March 27, 2021 from https://commons.wikimedia.org/wiki/File:Mouths_of_amazon_geocover_1990.png

An satellite image showing the mouth of the Amazon River.
Fig. 6.2.5 Pfly (2010) North America-Water Divides. Retrieved March 27, 2021 from https://commons.wikimedia.org/wiki/File:NorthAmerica-WaterDivides.png

Map showing major continental divides of North America.
Fig. 6.2.6 USGS (2019) Diagram of Channel Cross Section with Subsections. Retrieved March 27, 2021 from https://www.usgs.gov/media/images/diagram-channel-cross-section-subsections

A diagram showing a cross section of a stream and the method used to determine area and discharge of a stream.
Fig. 6.2.7 USGS (2010). Colorado Basin Focus Area Study Map. Retrieved March 27, 2021 from https://www.usgs.gov/media/images/colorado-basin-focus-area-study-map

A map showing all the area covered in the Colorado River Drainage Basin that was the study area of the USGS.
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Fig. 6.3.1 Earle, S. (n.d.) Hjulström-Sundborg diagram. Retrieved March 27, 2021 from https://openeducationalberta.ca/practicalgeology/wp-content/uploads/sites/66/2020/06/hulstrom-2.png

A diagram showing the relationships between particle size and tendency to be eroded, transported, or deposited at different current velocities.
Fig. 6.3.2 Earle, S (n.d.) Modes of transportation of sediments and dissolved ions. Retrieved March 27, 2021 from
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A diagram showing movement of sediments within a stream.
Fig. 6.3.3 Wilson, M (2019) Grand Canyon Overlook

An image from the South Rim of the Grand Canyon looking northwest over Plateau Point and the Inner Gorge.
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Video 6.4.1. National Park Service (2017) Anatomy of a Flood. [Online Video]. Retrieved March 27, 2021 from https://youtu.be/dd0-ZsDAgNw

Video showing causes and effects of flooding around Mt. Ranier
Video 6.4.2. USGS (2011) Post-fire Flash Flood in Coronado National Memorial, Arizona (2011). [Online Video]. Retrieved March 27, 2021 from https://youtu.be/aAR6FWR35BU

Video of a flash flood quickly filling a dry river bed in Arizona.
Fig. 6.4.1 NOAA (n.d.) El Nino weather pattern. Retrieved March 27, 2021 from
https://oceanservice.noaa.gov/facts/ninonina.html#:~:text=El%20Nino%20means%20Little%20Boy,can%20affect%20our%20weather%20significantly.

El Nino causes the Pacific jet stream to move south and spread further east. During winter, this leads to wetter conditions than usual in the Southern U.S. and warmer and drier conditions in the North.
Fig. 6.4.2 Earle, S. (n.d.) Natural levees. Retrieved June 2, 2021.

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Image of the Glen Canyon Dam, Arizona.
Fig. 6.5.2 Army Corp of Engineers (2011) Kansas Flood. Flickr, Public Domain.

Fig. 6.5.3 World Bank (2019, May 2) Canals, flood controls stations and water retention basins. Retrieved June 2, 2021 from
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Image of a canal
Fig. 6.5.4 Wikimedia Commons (2019) Hohokam Canal. Retrieved June 2, 2021 from
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Image of a modern day canal that follows the path of the Hohokam canal system
Fig. 6.5.5 FEMA (2008) Driver pushing a car through flood waters. Retrieved June 2, 2021 from
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Image of a man pushing a car through flood waters in Brownsville, TX, after Hurricane Dolly in 2008.
Fig. 6.5.6 NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2021). https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73

Infographic showing the relative costs of natural disasters in the United States from 1980-2020.
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