# RIVERS – Tutorial Script

97% of all the water on Earth's surface is in the ocean. The remaining roughly 3% is fresh and found on land. Of that freshwater, 69% is trapped in glaciers and ice caps, and 30% can be found in pores and cracks, soaked into the ground (known as **groundwater**). The remaining 1% of freshwater supplies includes water in the atmosphere or in plants or the biosphere, and water pooling or running across the surface. The water in lakes makes up 0.26% of all freshwater supplies; and rivers, streams, and creeks make up only 0.006% of freshwater on the planet.

**How does water move around between all the different reservoirs in which it's found?** Heat from the sun evaporates water (turns it into water vapor), moving it up into the atmosphere. This atmospheric water will get moved around the planet by winds. When that air later cools, water vapor will condense back into liquid water and drop downward as rain, otherwise known as precipitation. Some of that rain lands directly in the oceans. Some lands in glacial or ice sheet areas. Some drops directly into the ground and soaks into it. Where grounds are saturated with water and can hold no more, any rain that falls there will run along the surface into rivers, streams, and lakes. Eventually most of this running water will make its way back to the ocean. What about ocean water that soaks into the sediment and cracks on the seafloor? When this crust eventually sinks into the mantle at subduction zones, that water is squeezed out and because it's less dense, rises upwards. Since the addition of water to the asthenosphere drops its melting point, magmas form. The magmas produced are rich in water and rise upwards to produce volcanoes that release the water back into the atmosphere as a gas. Through continued evaporation and precipitation, running water, subduction, and volcanism, Earth's water continually cycles in and out of the various reservoirs, processes collectively known as the hydrologic or water cycle.

Now let's focus on the 0.006% of freshwater found in rivers. Despite being such a minor component of water storage, running water is the most powerful erosional agent at work on Planet Earth. Running water weathers, erodes, and deposits material across Earth's surface and produces a multitude of unique and varied landforms. Even in deserts, where water runs on the surface for only a few weeks a year, that running water is still the most powerful of the forces at work sculpting that landscape.

**How does water get into a river?**
A river's **drainage basin or watershed** is the area of land in which all the rain that falls will ultimately makes its way into that river. The line between two drainage basins or watersheds is called a **divide**. The continental divide in the United States, for example, is a divide that runs along the top of the Rocky Mountains. Water that falls on one side of this divide will travel east and south into the Mississippi River Basin; and water that runs on the other side will travel west into different basins, such as the basin of the Colorado River. We call the waters at the highest elevation of a drainage basin the **headwaters**. As water moves downhill it will be joined by more water from the ground or from other streams. Each of the small streams and rivulets that join together are called **tributaries**. The lowest point of a river, where it enters a lake or the ocean, is called the **mouth**.

Tectonics and isostatic uplift push the land up – erosional agents such as running water carve it down. As water moves downhill, it will carve out rock from the high country and carry it to the low country. Its work is done when the river has carved the land flat. **Base level** is the lowest level to which a river will erode – **Ultimate base level** for most rivers in the world is the ocean, unless a river is draining into an interior basin lower than sea level and with no outlet to the ocean. An example of this can be found in Death Valley, California, where the lowest point is 282 feet below sea level. A lake might be a local or intermediary base level. In that local area, the rivers that feed into that lake will erode down only to the level of lake. Then their work is done until the lake drains downward and the rivers are back at work again.

**Why is running water such a powerful eroder or sculptor of the land?**
First let's review a few terms. **Weathering** is the process of physical or chemical breakdown of rock. **Erosion** is the transport of weathered debris or sediment from one location to another. **Deposition** is the dropping of the sediment into piles.

Rivers physically weather or break down rock through two primary methods: **hydraulic pressure** and **abrasion**. As water moves downhill, the weight and velocity of the water puts pressure on the rocks over which it flows. When cracks exist in those rocks, this pressure can gradually expand the crack. Also, the sediment carried along the base of a river, pushed downhill by the force of the weight of the running water (also known as **bed load**) will move across rock surfaces and scrape and abrade those surfaces. Chemical weathering as discussed in the Weathering video tutorial is aided by water, so when rivers put water in continual contact with solid rock, they increase the rate at which that rock will chemically break down, primary methods being that minerals will dissolve, oxidize, or turn into clays.

Once rocks have broken down through any activity, the river itself, gravity, glaciers, wind, humans, waves, etc., the river will pick up those weathered pieces and transport them to a new location. **Discharge** is the term we use to describe the volume of water a river transports past a given point every second. It's measured in cubic meters per second ($cm^3/s$). The higher the discharge, the more sediment load a river can carry. The maximum sediment load a river can carry is called its **capacity**. As discharge increases, so too does capacity. New sediment can be carried by a river only if it hasn't yet reached its capacity. Rivers that are at capacity will run across sediment but not have room to pick it up. Similarly, when a river's discharge decreases, like in the days after a storm, its capacity will shrink, and it has to drop sediment it can no longer carry.

Additionally, the ability to pick up and carry a sediment grain of a particular weight or size depends on the river's velocity. The greater the velocity, the greater the power and hence the larger the grain size it can carry. We call the maximum grain size that a river can carry, its **competence**. Competence goes up as velocity goes up. Similarly, as velocity goes down, competence goes down. Result? When velocity drops, all the largest grains are dropped at the same place in a pile, creating a pile of well-sorted grains which means similarly sized.

Piles of sediment dropped by rivers are called **alluvium**, and they are easily recognizable by their excellent sorting and also by the rounding produced by the continual knocking about with other grains as they were transported by the river and as the river continues to move over them once they were deposited.

Now that we know under what conditions rivers pick up sediment and under what conditions they drop it, where are we most likely to see both happening in a river? Let's start by looking closer at velocity. Where along a river does velocity increase? Or decrease? The **slope or gradient** of a river is the ratio of vertical to horizontal distance that a river moves down a hill. How does gradient impact the velocity? We would expect rivers to move faster down steeper slopes and slower on gentler ones. Where rivers move from the steep mountains onto the flat plains, gradient flattens out considerably, slowing the river. The slower-moving river has a lower competence and has to drop sediment grains too big to carry. The alluvial deposits that form in these circumstances are referred to as an **alluvial fan**. Why flatter slopes at the base of the mountains? That's where all the sediment from erosion of those mountains piles up. The remaining water that runs down must now make its way across this pile of sediment and thus can split into many different rivulets or braids as it weaves it way through the pile. We call the pattern of such a river a **braided river**. In contrast, rivers high in the mountains typically have straight channels with a V-shape cross-section, as rivers erode downward as directly as possible, and gravity carries the slope material on either side downhill.

Where rivers go from flatter slopes to steeper slopes, like when they spill over waterfalls, the velocity speeds up and the river can pick up larger particles. How do waterfalls form? When you have a resistant layer of rock that is difficult for rivers to erode, they will find cracks and erode downward through those cracks to less resistant rocks below. As the river erodes the less resistant rock underneath, it will undercut the top layer. Over time the continued undercutting will make the top layer unstable, and the overlying cliff will crack and fall.

Another factor that impacts velocity is **friction** – the stickiness of the river bed that drags on the water within. Friction and drag are affected by the shape of the channel as well as the material over which the river runs. Shallow channels or deep narrow channels have increased surface area so increased drag. A deep and broad channel, like a perfect semicircle, has the least amount of surface area to volume of water and the least drag. Large boulders like what's found in the mountains in shallow streams produce high drag. Smooth rock surface or fine muds cause very little drag. Less friction or drag, faster river.

What about the width of the river? Just like with your finger on the end of a hose, when the channel of the river flow is constricted or narrows, velocity speeds up. Erosion increases, and the narrows can be eroded quite deep. Where channels widen, velocity drops, and depositions occurs.

The discharge of a river also affects speed – the higher the discharge, the higher the velocity. So what makes discharge increase or decrease? As already mentioned, discharge in a river is a function of how much water rains down in the drainage basin. Eventually all the tiny streams in the basin will join to the main river. So discharge should be highest the closer we get to the mouth of the river. Discharge will also change throughout the seasons as the amount of rain and snow melt varies. If we can erode through a drainage divide and increase the area of a drainage basin, that should also lead to greater discharge.

What happens at dams? Dams across a river will stop the flow of the river. That stop in velocity means sediment is dropped at the mouth of the river as it enters the lake. We call sediment dropped at the mouth of a river where it enters another body of water, a **delta**. That delta sediment over time will cause the lake level to rise, so in summer the lake might need to be drained, and the sediment removed. Meanwhile, downriver, the water that spills over the dam has no sediment within and is dropping from great height with great velocity. It will pick up and erode sediment from the areas immediately below the dam.

**How is material transported by a river?** In addition to the bed load already discussed (the sediment pushed along the bottom of the river due to the pressure of the water moving downhill), rivers also carry particles in suspension, buoyed up by the energy of the water. This **suspended load** make the river look cloudy or opaque. We can remove suspended load by letting a jar or bucket of river water sit for a few days still. The lack of energy gives the particles time to settle out and deposit in a layer on the bottom of the bucket. The finest muds might take more than a day to fully settle out. Also carried by a river are the dissolved ions produced through chemical weathering of the rocks up river. This **dissolved load** can be removed only if the water is evaporated, allowing the ions to find each other again and crystallize.

Let's look more closely at what happens when rivers flood. **Meandering rivers** no longer have any downward-eroding work to do, as they move across flat plains close to sea level. However, they are now eroding horizontally, as they meander across the landscape, bending around obstructions, avoiding resistant rocks, and carving out new channels during floods. Most of the year, the river sits in its channel. But when the discharge increases and the river's level rises during heavy rains, they can overtop their banks and spill out into the surrounding land. That means a fast-moving river chuck-full of sediment will overtop its banks and immediately slow down as it spreads across the flat plain on either side of the channel. These plains are known as the **flood plains**. The drop in velocity means deposition – the largest gravels depositing along the banks of the river creating structures called **levees**. The finer sands and muds deposit behind the levees across the flood plain.

Rivers use their flood plains every time they flood, which is an annual process. Some floods are heavier or more intense than others, and the heavier the flood, the more sediment is deposited in the flood plains. Also, the heavier the flood, the more water in the river, and the faster the river runs. That makes it more erosive and more likely to carve out a new channel or path.

For example, in meandering rivers, the outside of the meanders or bends experience the fastest most erosive water, the inside the calmest. Therefore, sediment piles up on the inside of these bends, and erosion increases on the outside. Over time, the bends get more and more extreme until during a flood, the pressure of the water can cut a new path right across a bend. The cut-off bend now becomes a lake, known as an **oxbow lake**, while the river has straightened itself out a bit. After the flood, the water that remains in the channel also slows down and deposits any sediment that it can no longer carry on the bottom of its bed. That causes the river bed to rise, which also makes the river level rise, so the natural levees will also rise during the next flood, as will the flood plains. Over time, the entire region gets a thicker and thicker pile of sediment as the mountains continue to erode, and the sediment continues to pile up at the coast.

What happens when we build homes on the flood plains and build levees to keep the water out of those flood plains during floods? When the river tries to overtop its levees, it can't. This puts extra pressure on other areas of the river, and if it can't find anywhere to overtop, then after the flood, the sediment that it carried will be deposited on the bottom of the river bed only. So the river itself will continue to rise, and the levees have to continually be built up to keep the river back, and that makes the flood plain level considerably lower than the river bed so when the river does eventually break through over top the levees or break through the leveess, the water that makes it into the flood plains will have to be pumped out, as the area is now lower than the river level. This is true in the New Orleans area on the Mississippi River. The area of homes built on the flood plain are now sitting under the level of the river, and pumps are working 24-7 in some locations to ensure that water doesn't migrate underground and turn these areas into lakes. After a flood breaks through the levees, it can take weeks or months before all the water is pumped back out.

Rivers flood when there's more water entering the river than the channel can contain. This happens during heavy rains over long periods of time once the ground has been saturated and can hold no more water. What happens when we cover natural forested land with agriculture? The runoff is faster because there are no tree limbs and roots to soak up the water. What about when we cover agricultural land with urban land, especially concrete? The rain runoff will go directly into the river with none soaking into the ground, so the rivers can reach flood stage much faster.

The river channel and floodplain are part of the same system, together representing the path that the river will take at various stages in its seasons and journey. Detailed mapping of the flood plain around meandering rivers shows that throughout the history of the river, its path has migrated back and forth across the plains as sediments continue to deposit and build over time. Building communities on the flood plains of rivers is a challenging feat that requires artificial levees to keep the river in its path and constant maintenance to ensure the river stays in its channel. It requires dredging the bottom of the river to keep the bed from rising and it requires significant flood plains to be accessible elsewhere to release the pressure of the rising river.

All natural rivers systems flood every year or two on average. The intensity of flooding varies, and often floods are described as 100-year events, 50-year events, 10-year events, and so on. The goal of these terms is to consider the building requirements and risks for various levels of flooding. The higher the year provided, the more intense the flood will be. For example, 100-year floods are so intense they happen on average only once every 100 years. What that means for those who choose to live in the flood plains of a river is that we need to be prepared to handle the consequences of any of these events.

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