
Chapter 13 Streams and Floods

Learning Objectives

After reading this chapter, completing the exercises within it, and answering the questions at the end, you should be able to:

- Explain the hydrological cycle and its relevance to streams and what *residence time* means in this context.
- Describe a drainage basin and explain the origins of different types of drainage patterns.
- Explain how streams become graded and how certain geological and anthropogenic changes can result in a stream losing its gradation.
- Describe the formation of stream terraces.
- 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.
- Explain the origins of natural stream levées.
- Describe the process of stream evolution and the types of environments where one would expect to find straight-channel, braided, and meandering streams.
- Describe the annual flow characteristics of typical streams in Canada and the processes that lead to flooding.
- Describe some of the important historical floods in Canada.
- 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.



Figure 13.0.1 A small waterfall on Johnston Creek in Banff National Park, AB.

Streams are the most important agents of erosion and transportation of sediments on Earth's surface. They are responsible for the creation of much of the topography that we see around us. They are also places of great beauty and tranquility, and of course, they provide much of the water that is essential to our existence. But streams are not always peaceful and soothing. During large storms and rapid snowmelts, they can become raging torrents capable of moving cars and houses and destroying roads and bridges. When they spill over their banks, they can flood huge areas, devastating populations and infrastructure. Over the past century, many of the most damaging natural disasters in Canada have been floods, and we can expect them to become even more severe in the near future as the climate changes.

Media Attributions

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13.1 The Hydrological Cycle

Water is constantly on the move. It is evaporated from the oceans, lakes, streams, the surface of the land, and plants (transpiration) by solar energy (Figure 13.1.1). It is moved through the atmosphere by winds and condenses to form clouds of water droplets or ice crystals. In response to the pull of gravity it comes back down as rain or snow and then flows through streams, into lakes, and eventually back to the oceans. Water on the surface and in streams and lakes infiltrates the ground to become groundwater. Groundwater slowly moves through the rock and surficial materials. Some groundwater returns to other streams and lakes, and some goes directly back to the oceans.

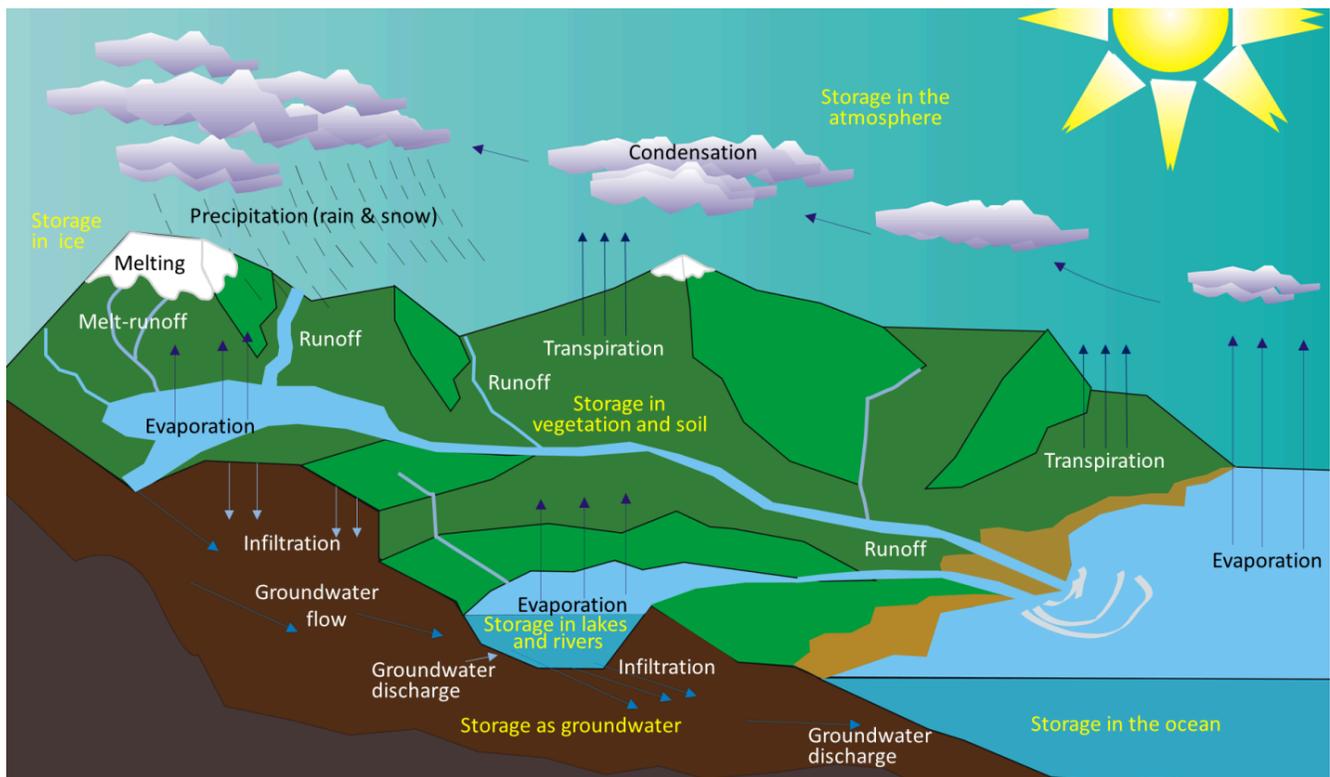


Figure 13.1.1 The various components of the water cycle. Black or white text indicates the movement or transfer of water from one reservoir to another. Yellow text indicates the storage of water.

Even while it's moving around, water is stored in various reservoirs. The largest, by far, is the oceans, accounting for 97% of the volume. Of course, that water is salty. The remaining 3% is fresh water. Two-thirds of our fresh water is stored in ice and one-third is stored in the ground. The remaining fresh water—about 0.03% of the total—is stored in lakes, streams, vegetation, and the atmosphere. To put that in perspective, let's imagine putting all of Earth's water into a 1 litre jug (Figure 13.1.2). We start by almost filling the jug with 970 millilitres of water and 34 grams of salt. Then we add one regular-sized (roughly 20 millilitres) ice cube (representing glacial ice) and two teaspoons (roughly 10 millilitres) of groundwater. All of the water that we see around us in lakes and streams and up in the sky can be represented by adding three more drops from an eyedropper.

Although the proportion of Earth's water that is in the atmosphere is tiny, the actual volume is huge. At any given time, there is the equivalent of approximately 13,000 cubic kilometres (km^3) of water in the air in the form of water vapour and water droplets in clouds. Water is evaporated from the oceans, vegetation, and lakes at a rate of 1,580 km^3 per day, and just about exactly the same volume falls as rain and snow every day—over both the oceans and land. The precipitation that falls on land goes back to the ocean in the form of stream flow (117 km^3/day) and groundwater flow (6 km^3/day). Most of the rest of this chapter is about that 117 km^3/day of streamflow. The average discharge of the Fraser River into the ocean is approximately 0.31 km^3/day , or 0.26% of the total flow of all rivers.



Figure 13.1.2 Representation of the Earth's water. The 1 litre jug is filled with salty sea water (97%). The ice-cube is glacial ice (2%). The 2 teaspoons represent groundwater (1%), and the three drops represent all of the fresh water in lakes, streams, and wetlands, plus all of the water in the atmosphere.

Exercise 13.1 How long does water stay in the atmosphere and oceans?

The residence time of a water molecule in the atmosphere (or any of the other reservoirs) can be estimated by dividing the amount that is there by the rate at which it is transferred in and out. For the atmosphere, we know that the reservoir size is 13,000 km^3 , and the rate of flux is 1,580 km^3 per day. That's the amount that goes into or comes out of the atmosphere in a day. If we divide 13,000 by 1,580, we get 8.22 days. This means that, *on average*, a molecule of water stays in the atmosphere for just over eight days. "Average" needs to be emphasized here because obviously some molecules stay in the air for only a few hours, while others may stay up there for weeks.

The volume of the oceans is 1,338,000,000 km^3 and the flux rate is approximately the same (1,580 km^3 per day). What is the average residence time of a water molecule in the ocean?

See Appendix 3 for [Exercise 13.1 answers](#).

Media Attributions

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- Figure 13.1.2: © Steven Earle. CC BY. Based on data from [The Water Cycle: Freshwater Storage](#).

13.2 Drainage Basins

A **stream** is a body of flowing surface water of any size, ranging from a tiny trickle to a mighty river. The area from which the water flows to form a stream is known as its **drainage basin**. All of the precipitation (rain or snow) that falls within a drainage basin eventually flows into its stream, unless some of that water is able to cross into an adjacent drainage basin via groundwater flow. An example of a drainage basin is shown in Figure 13.2.1.

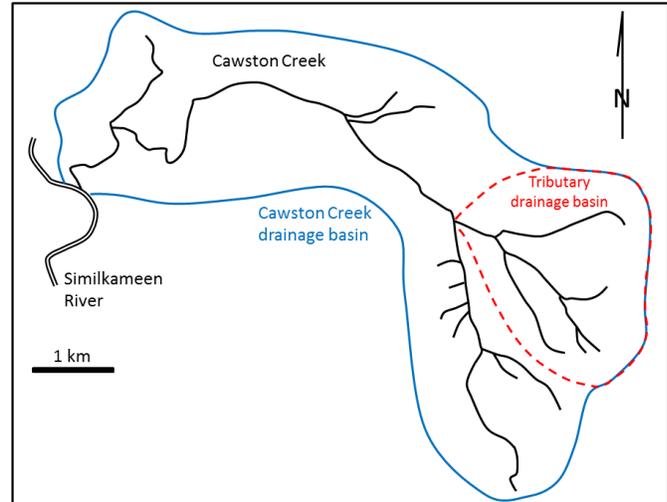


Figure 13.2.1 Cawston Creek near Keremeos, B.C. The blue line shows the extent of the drainage basin. The dashed red line is the drainage basin of one of its tributaries. [\[Image Description\]](#)

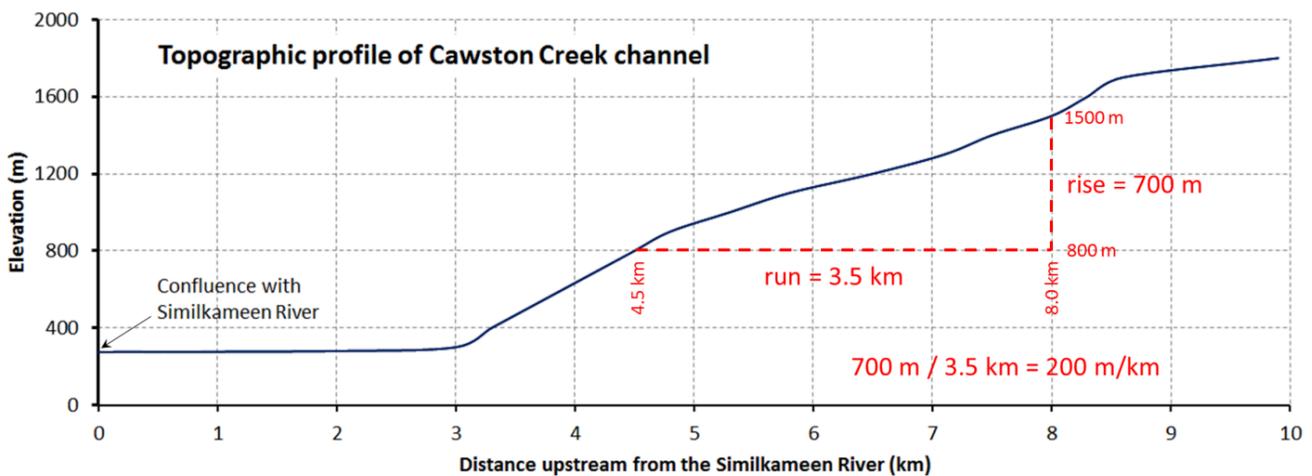


Figure 13.2.2 Profile of the main stem of Cawston Creek near Keremeos, B.C. The maximum elevation of the drainage basin is about 1,840 metres, near Mount Kobau. The base level is 275 metres, at the Similkameen River. As shown, the gradient of the stream can be determined by dividing the change in elevation between any two points (rise) by the distance between those two points (run). [\[Image Description\]](#)

Cawston Creek is a typical small drainage basin (approximately 25 square kilometres) within a very steep glaciated valley. As shown in Figure 13.2.2, the upper and middle parts of the creek have steep **gradients** (averaging about 200 metres per kilometre but ranging from 100 to 350 metres per kilometre), and the lower part, within the valley of the Similkameen River, is relatively flat (less than 5 metres per kilometre). The shape of the valley has been controlled first by tectonic uplift (related to plate

convergence), then by pre-glacial stream erosion and mass wasting, then by several episodes of glacial erosion, and finally by post-glacial stream erosion. The lowest elevation of Cawston Creek (275 metres at the Similkameen River) is its **base level**. Cawston Creek cannot erode below that level unless the Similkameen River erodes deeper into its flood plain (the area that is inundated during a flood).

Metro Vancouver's water supply comes from three large drainage basins on the north shore of Burrard Inlet, as shown in Figure 13.2.3. This map illustrates the concept of a drainage basin divide. The boundary between two drainage basins is the height of land between them. A drop of water falling on the boundary between the Capilano and Seymour drainage basins (a.k.a., watersheds), for example, could flow into either one of them.

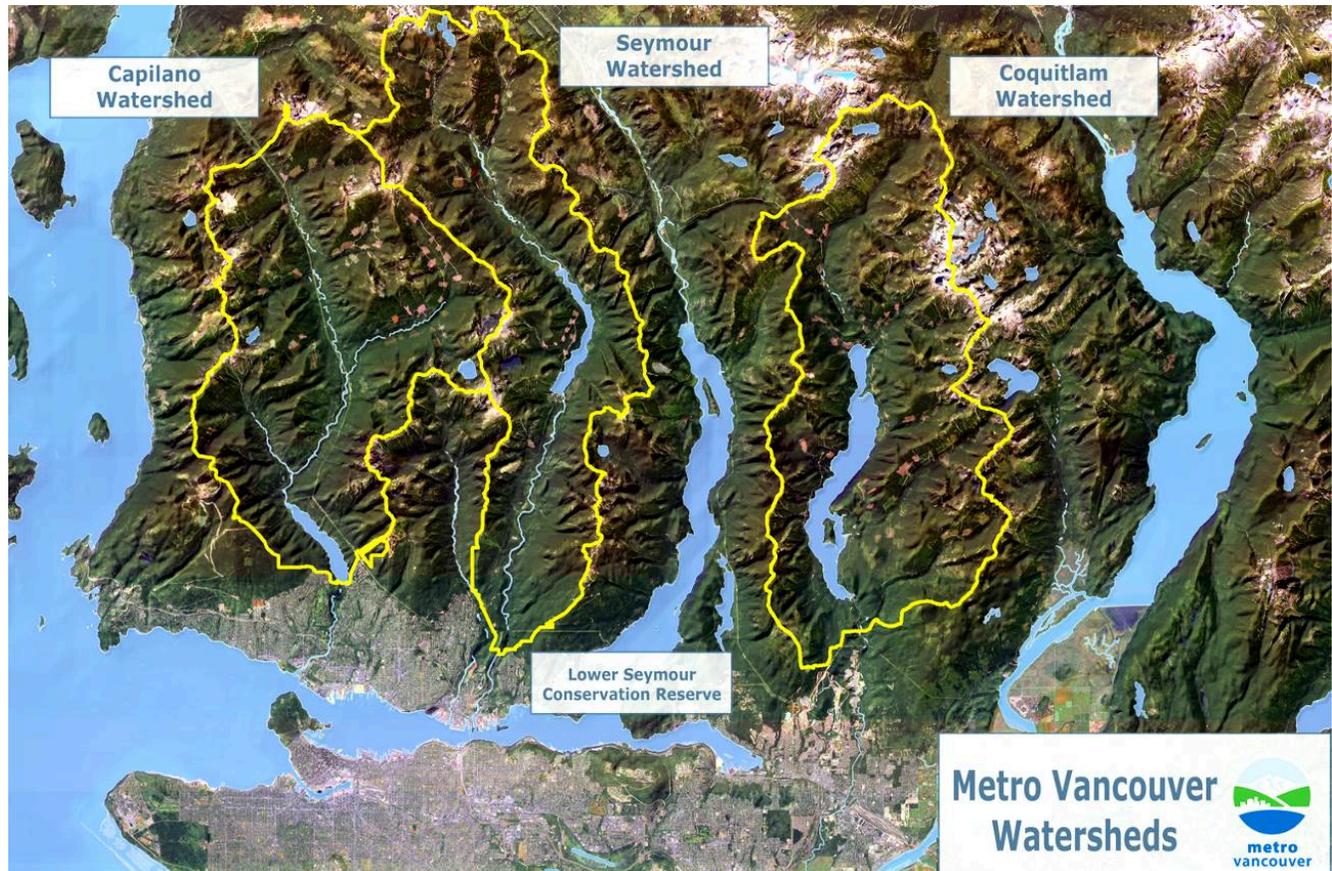


Figure 13.2.3 The three drainage basins that are used for the Metro Vancouver water supply.

The pattern of tributaries within a drainage basin depends largely on the type of rock beneath, and on structures within that rock (folds, fractures, faults, etc.). The three main types of drainage patterns are illustrated in Figure 13.2.4. **Dendritic** patterns, which are by far the most common, develop in areas where the rock (or unconsolidated material) beneath the stream has no particular fabric or structure and can be eroded equally easily in all directions. Examples would be granite, gneiss, volcanic rock, and sedimentary rock that has not been folded. Most areas of British Columbia have dendritic patterns, as do most areas of the prairies and the Canadian Shield. **Trellis** drainage patterns typically develop where sedimentary rocks have been folded or tilted and then eroded to varying degrees depending on their strength. The Rocky Mountains of B.C. and Alberta are a good example of this, and many of the drainage systems within the Rockies have trellis patterns. **Rectangular** patterns develop in areas that have very little topography and a system of bedding planes, fractures, or faults that form a rectangular network. Rectangular drainage patterns are rare in Canada.

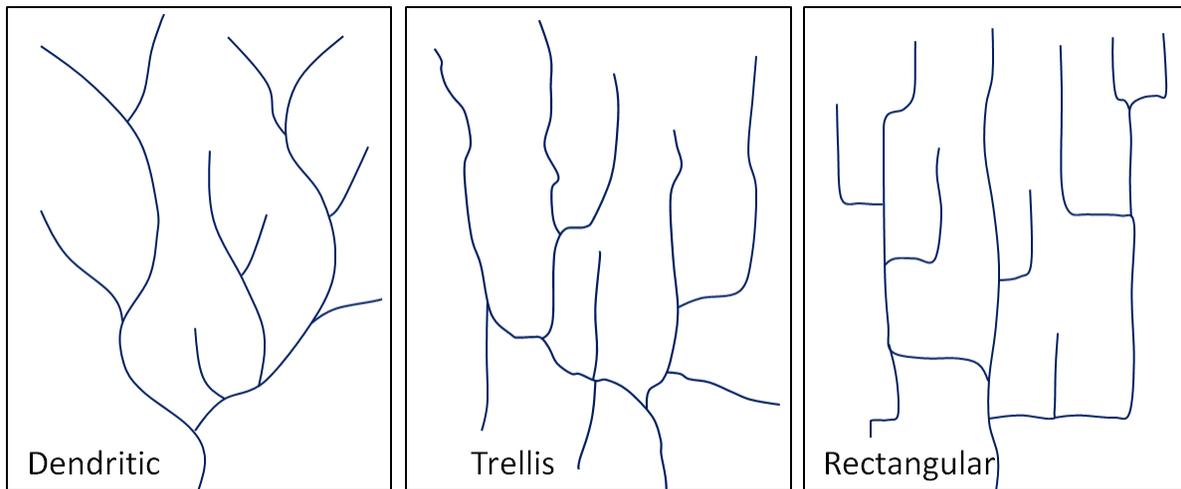


Figure 13.2.4 Typical dendritic, trellis, and rectangular stream drainage patterns. [\[Image Description\]](#)

In many parts of Canada, especially relatively flat areas with thick glacial sediments, and throughout much of Canadian Shield in eastern and central Canada, drainage patterns are chaotic, or what is known as **deranged** (Figure 13.2.5, left). Lakes and wetlands are common in this type of environment.

A fourth type of drainage pattern, which is not specific to a drainage basin, is known as **radial** (Figure 13.2.5, right). Radial patterns form around isolated mountains (such as volcanoes) or hills, and the individual streams typically have dendritic drainage patterns.

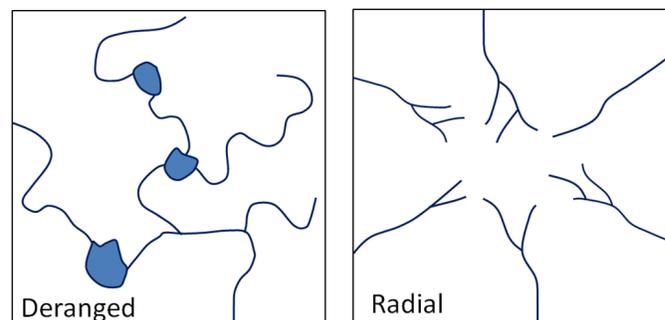


Figure 13.2.5 Left: a typical deranged pattern; right: a typical radial drainage pattern developed around a mountain or hill. [\[Image Description\]](#)

Over geological time, a stream will erode its drainage basin into a smooth profile similar to that shown in Figure 13.2.6. If we compare this with an ungraded stream like Cawston Creek (Figure 13.2.2), we can see that graded streams are steepest in their headwaters and their gradient gradually decreases toward their mouths.

Ungraded streams have steep sections at various points, and typically have rapids and waterfalls at numerous locations along their lengths.

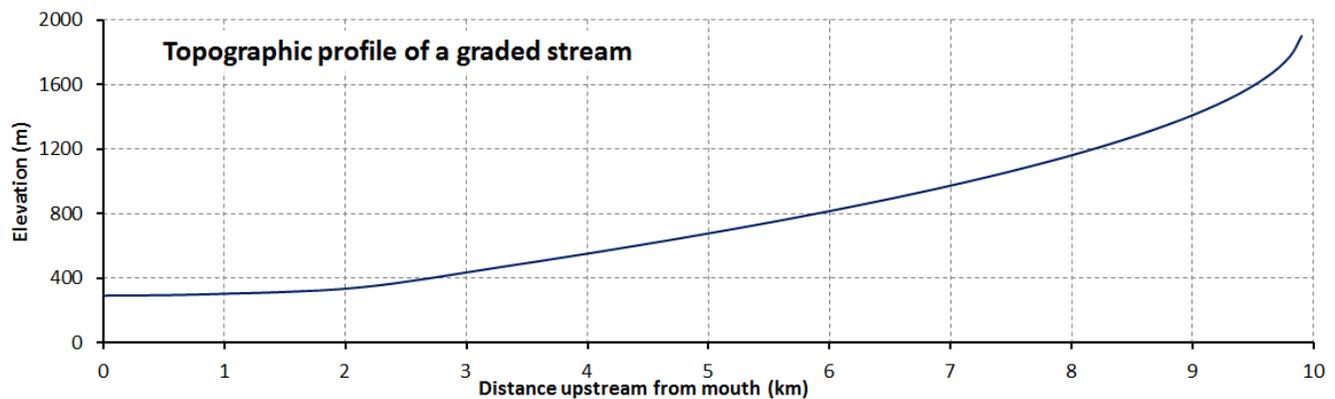


Figure 13.2.6 The topographic profile of a typical graded stream. [\[Image Description\]](#)

A graded stream can become ungraded if there is renewed tectonic uplift, or if there is a change in the base level, either because of tectonic uplift or some other reason. As stated earlier, the base level of Cawston Creek is defined by the level of the Similkameen River, but this can change, and has done so in the past. Figure 13.2.7 shows the valley of the Similkameen River in the Keremeos area. The river channel is just beyond the row of trees. The green field in the distance is underlain by material eroded from the hills behind and deposited by a small creek (not Cawston Creek) adjacent to the Similkameen River when its level was higher than it is now. Sometime in the past several centuries, the Similkameen River eroded down through these deposits (forming the steep bank on the other side of the river), and the base level of the small creek was lowered by about 10 metres. Over the next few centuries, this creek will seek to become graded again by eroding down through its own alluvial fan.



Figure 13.2.7 An example of a change in the base level of a small stream that flows into the Similkameen river near Keremeos. The previous base level was near the top of the sandy bank. The current base level is the river (hidden behind the trees) which has eroded down into the sandy deposit.

Another example of a change in base level can be seen along the Juan de Fuca Trail on southwestern Vancouver Island. As shown in Figure 13.2.8, many of the small streams along this part of the coast flow into the ocean as waterfalls. It is evident that the land in this area has risen by about 5 metres in the past few thousand years, probably in response to deglaciation. The streams that used to flow directly into the ocean now have a lot of down-cutting to do to become regraded.



Figure 13.2.8 Two streams with a lowered base level on the Juan de Fuca Trail, southwestern Vancouver Island.

The ocean is the ultimate base level, but lakes and other rivers act as base levels for many smaller streams. We can create an artificial base level on a stream by constructing a dam, as illustrated in Exercise 13.2.

Exercise 13.2 The effect of a dam on base level

When a dam is built on a stream, a reservoir (artificial lake) forms behind the dam. This temporarily (for many decades at least) creates a new base level for the part of the stream above the reservoir.

How does the formation of a reservoir affect the stream where it enters the reservoir, and what happens to the sediment it was carrying?

The water leaving the dam has no sediment in it. How does this affect the stream below the dam?

See Appendix 3 for [Exercise 13.2 answers](#).



Figure 13.2.9 Revelstoke Dam and Revelstoke Lake on the Columbia River at Revelstoke, BC.

Sediments accumulate within the flood plain of a stream, and then, if the base level falls, or if there is less sediment to deposit, the stream may cut down through those existing sediments to form terraces. A terrace on the Similkameen River is shown in Figure 13.2.7 and some on the Fraser River are shown in Figure 13.2.10. The Fraser River photo shows at least two levels of terraces.



Figure 13.2.10 Terraces on the Fraser River at High Bar. [\[Image Description\]](#)

In the late 19th century, American geologist William Davis proposed that streams and the surrounding terrain develop in a cycle of erosion (Figure 13.2.11). Following tectonic uplift, streams erode quickly, developing deep V-shaped valleys that tend to follow relatively straight paths. Gradients are high, and profiles are ungraded. Rapids and waterfalls are common. During the mature stage, streams erode wider valleys and start to deposit thick sediment layers. Gradients are slowly reduced and grading increases. In old age, streams are surrounded by rolling hills, and they occupy wide sediment-filled valleys. Meandering patterns are common.

Davis's work was done long before the idea of plate tectonics, and he was not familiar with the impacts of glacial erosion on streams and their environments. While some parts of his theory are out of date, it is still a useful way to understand streams and their evolution.

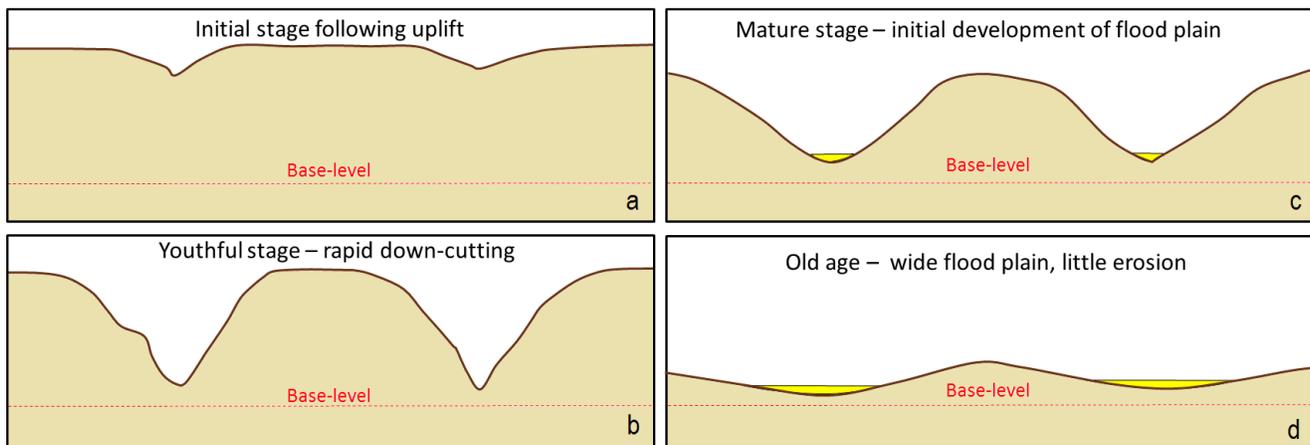


Figure 13.2.11 A depiction of the Davis cycle of erosion: a: initial stage, b: youthful stage, c: mature stage, and d: old age. [\[Image Description\]](#)

Image Descriptions

Figure 13.2.1 image description: Cawston Creek is a drainage basin made up of a number of small streams that flow into the Similkameen River. The Cawston Creek drainage basin also has a smaller tributary drainage basin that flows into it. [\[Return to Figure 13.2.1\]](#)

Figure 13.2.2 image description: The graph shows the topographical profile of the Cawston Creek channel. Starting at 10 kilometres from the Similkameen River, the channel is at an elevation of 1800 metres. It flows downhill towards the river at a steady decline for seven kilometres. At three kilometres from the Similkameen River at an elevation of 275 metres, the channel levels out and stays at that elevation until it joins with the Similkameen River. This is conveyed in the following table.

Distance from the Similkameen River (kilometres)	Elevation (metres)
10	1,800
9	1,750
8	1,500
7	1,300
6	1,125
5	950
4	600
3	280
2	275
1	275
0	275

To determine the gradient of the stream, you must divide the change in elevation (rise) by the change in distance (run). For example, the elevation at 4.5 kilometres from the river is 800 metres and at 8.0 kilometres from the river, the elevation is 1500 metres. That means that in 3.5 kilometres (run), elevation increased by 700 metres (rise). To determine the gradient, you must divide rise (700 metres) by run (3.5 kilometres), which equals a vertical increase of 200 metres per kilometre.

[\[Return to Figure 13.2.2\]](#)

Figure 13.2.4 image description: Three types of drainage patterns:

- Dendritic: a pattern of drainage channels that resembles the branches in a tree.
- Trellis: a drainage pattern in which tributaries typically flow parallel to one other but meet at right angles.
- Rectangular: a drainage pattern in which tributaries typically flow at right angles to each other and meet at right angles.

[\[Return to Figure 13.2.4\]](#)

Figure 13.2.5 image description: Two types of drainage patterns:

- Deranged: a pattern of drainage channels that is chaotic.
- Radial: a pattern of streams radiating out from a central point, typically an isolated mountain.

[\[Return to Figure 13.2.5\]](#)

Figure 13.2.6 image description: The topographic profile of a typical graded stream. While the topographical profile of Cawston Creek fell at a steady rate and then leveled out for the last three kilometres, the topographical profile of a typical graded stream starts out steep, but the slope (or gradient) gradually decreases towards the bottom to form a soft curve. [\[Return to Figure 13.2.6\]](#)

Figure 13.2.10 image description: The Fraser River snaking through a channel that it has worn down over the years. The sides of the bank rise steeply, level out, and then rise again to produce terraces.

[\[Return to Figure 13.2.10\]](#)

Figure 13.2.11 image description: William Davis's cycle of erosion.

1. Initial stage: A tectonic uplift forms two sharp valleys on each side.
2. Youthful stage: Streams flowing through those valleys erode the surrounding earth quickly and cut deep to form sharp V's.
3. Mature stage: The streams become wider and the banks more gradual. This marks the initial development of a flood plain.
4. Old age: Streams form a wide flood plain where little erosion occurs.

[\[Return to Figure 13.2.11\]](#)

Media Attributions

- Figures 13.2.1, 13.2.2, 13.2.4, 13.2.5, 13.2.6, 13.2.7, 13.2.8, 13.2.9, 13.2.11: © Steven Earle. CC BY.
- Figure 13.2.3: Image by Metro Vancouver. Used with permission.
- Figure 13.2.10: Image by Marie Betcher. Used with permission.

13.3 Stream Erosion and Deposition

As we discussed in Chapter 6, flowing water is a very important mechanism for erosion, transportation and deposition of sediments. Water flow in a stream is primarily related to the stream's gradient, but it is also controlled by the geometry of the stream channel. As shown in Figure 13.3.1, water flow velocity is decreased by friction along the stream bed, so it is slowest at the bottom and edges and fastest near the surface and in the middle. In fact, the velocity just below the surface is typically a little higher than right at the surface because of friction between the water and the air. On a curved section of a stream, flow is fastest on the outside and slowest on the inside.

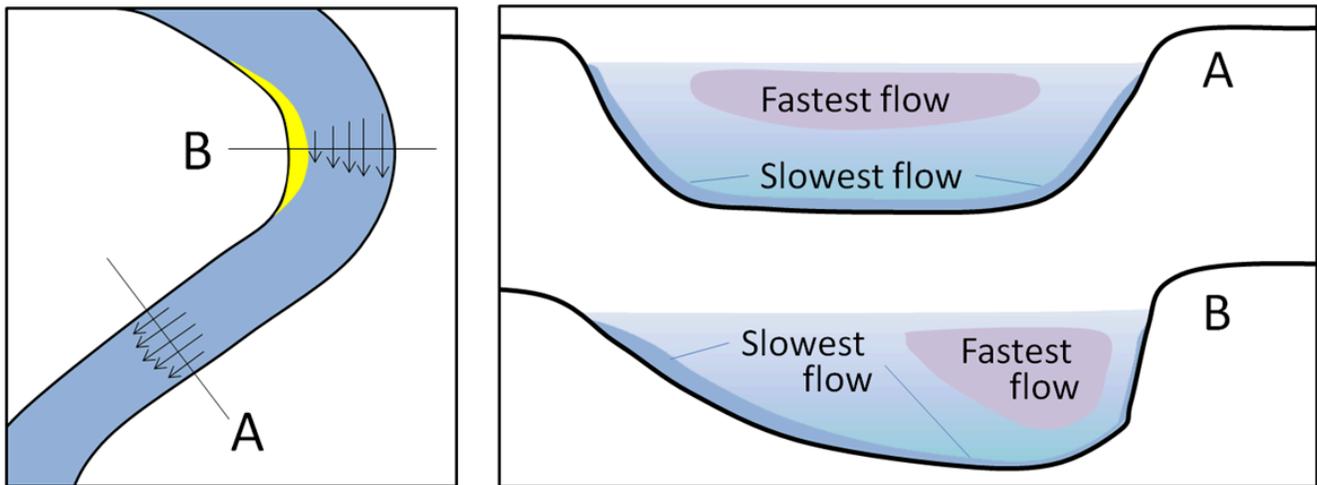


Figure 13.3.1 The relative velocity of stream flow depending on whether the stream channel is straight or curved (left), and with respect to the water depth (right). [\[Image Description\]](#)

Other factors that affect stream-water velocity are the size of sediments on the stream bed—because large particles tend to slow the flow more than small ones—and the **discharge**, or volume of water passing a point in a unit of time (e.g., cubic metres (m^3) per second). During a flood, the water level always rises, so there is more cross-sectional area for the water to flow in, however, as long as a river remains confined to its channel, the velocity of the water flow also increases.

Figure 13.3.2 shows the nature of sediment transportation in a stream. Large particles rest on the bottom—**bed load**—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. As you know from intuition and from experience, streams that flow fast tend to be turbulent (flow paths are chaotic and the water surface appears rough) and the water may be muddy, while those that flow more slowly tend to have laminar flow (straight-line flow and a smooth water surface) and clear water. Turbulent flow is more effective than laminar flow at keeping sediments in suspension.

Stream water also has a dissolved load, which represents (on average) about 15% of the mass of material transported, and includes ions such as calcium (Ca^{+2}) and chloride (Cl^-) in solution. The solubility of these ions is not affected by flow velocity.

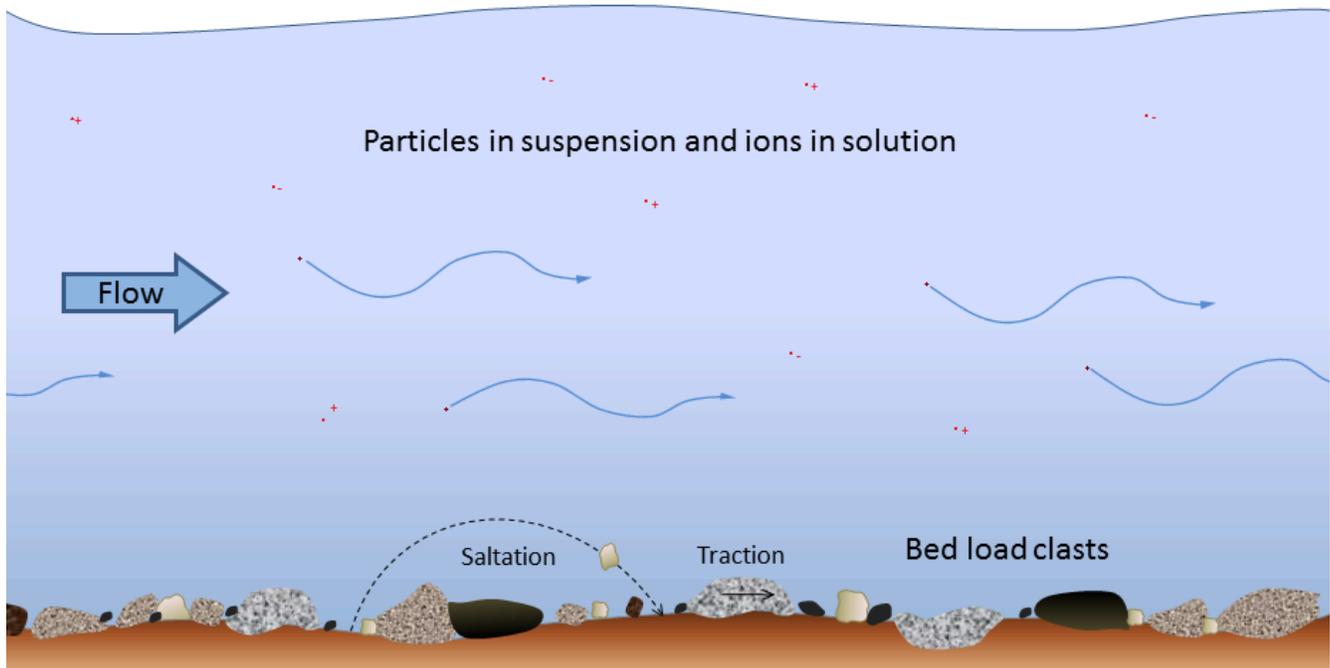


Figure 13.3.3 Modes of transportation of sediments and dissolved ions (represented by red dots with + and - signs) in a stream.

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 discovered 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 (Figure 13.3.3). Consider, for example, a 1 millimetre grain of sand. If it is resting on the bottom, it will remain there until the velocity is high enough to erode it, around 20 centimetres per second (cm/s). But once it is in suspension, that same 1 mm particle will remain in suspension as long as the velocity doesn't drop below 10 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.

On the other hand, a 0.01 mm silt particle only needs a velocity of 0.1 centimetres per second (cm/s) to remain in suspension, but requires 60 cm/s to be eroded. In other words, a tiny silt grain requires a greater velocity to be eroded than a grain of sand that is 100 times larger! For clay-sized particles, the discrepancy is even greater. 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 small particles, and especially the tiny grains of clay, have a strong tendency to stick together, and so are difficult to erode from the stream bed.

It is important to be aware that a stream can both erode and deposit sediments at the same time. At 100 cm/s, for example, silt, sand, and medium gravel will be eroded from the stream bed and

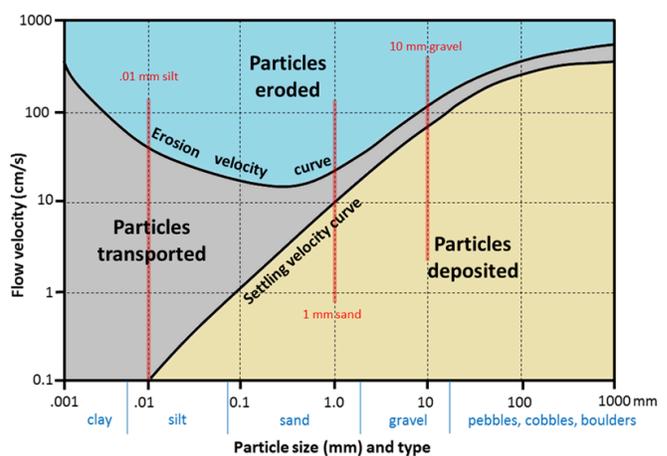


Figure 13.3.3 The Hjulström-Sundborg diagram showing the relationships between particle size and the tendency to be eroded, transported, or deposited at different current velocities. [\[Image Description\]](#)

At 100 cm/s, for example, silt, sand, and medium gravel will be eroded from the stream bed and

transported in suspension, coarse gravel will be held in suspension, pebbles will be both transported and deposited, and cobbles and boulders will remain stationary on the stream bed.

Exercise 13.3 Understanding the Hjulström-Sundborg diagram

Refer to the Hjulström-Sundborg diagram (Figure 13.3.3) to answer these questions.

1. A fine sand grain (0.1 millimetres) is resting on the bottom of a stream bed.
 1. What stream velocity will it take to get that sand grain into suspension?
 2. Once the particle is in suspension, the velocity starts to drop. At what velocity will it finally come back to rest on the stream bed?
2. A stream is flowing at 10 centimetres per second (which means it takes 10 seconds to go 1 metres, and that's pretty slow).
 1. What size of particles can be eroded at 10 centimetres per second?
 2. What is the largest particle that, once already in suspension, will remain in suspension at 10 centimetres per second?

See Appendix 3 for [Exercise 13.3 answers](#).

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 Figure 13.3.4. 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**.

Image Descriptions

Figure 13.3.1 image description: When a stream curves, the flow of water is fastest on the outside of the curve and slowest on the inside of the curve. When the stream is straight and a uniform depth, the stream flows fastest in the middle near the top and slowest along the edges. When the depth is not uniform, the stream flows fastest in the deeper section. [\[Return to Figure 13.3.1\]](#)

Figure 13.3.3 image description:

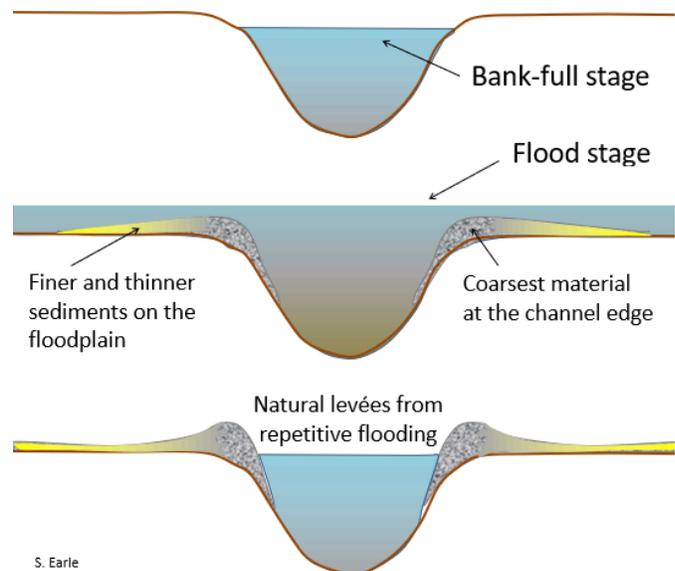


Figure 13.3.4 The development of natural levées during flooding of a stream. The sediments of the levée become increasingly fine away from the stream channel, and even finer sediments—clay, silt, and fine sand—are deposited across most of the flood plain.

- Erosion velocity curve: A 0.001 millimetre particle would erode at a flow velocity of 500 centimetres per second or greater. As the particle size gets larger, the minimum flow velocity needed to erode the particle decreases, with the lowest flow velocity being 30 centimetres per second to erode a 0.5 millimetre particle. To erode particles larger than 0.5 millimetres, the minimum flow velocity rises again.
- Settling velocity curve: A 0.01 millimetre particle would be deposited with a flow velocity of 0.1 centimetre per second or less. As the flow velocity increases, only larger and larger particles will be deposited.
- Particles between these two curves (either moving too slow or being too small to be eroded or deposited) will be transported in the stream.

[\[Return to Figure 13.3.3\]](#)

Media Attributions

- Figure 13.3.1, 13.3.2, 13.3.4: © Steven Earle. CC BY.

13.4 Stream Types

Stream channels can be straight or curved, deep and slow, or rapid and choked with coarse sediments. The cycle of erosion has some influence on the nature of a stream, but there are several other factors that are important.

Youthful streams that are actively down-cutting their channels tend to be relatively straight and are typically ungraded (meaning that rapids and falls are common). As shown in Figures 13.0.1 and 13.4.1, youthful streams commonly have a **step-pool** morphology, meaning that the stream consists of a series of pools connected by rapids and waterfalls. They also have steep gradients and steep and narrow V-shaped valleys—in some cases steep enough to be called canyons.

In mountainous terrain, such as that in western Alberta and B.C., steep youthful streams typically flow into wide and relatively low-gradient U-shaped glaciated valleys. The youthful streams have high sediment loads, and when they flow into the lower-gradient glacial valleys where the velocity isn't high enough to carry all of the sediment **braided** patterns develop, characterized by a series of narrow channels separated by gravel bars (Figure 13.4.2).

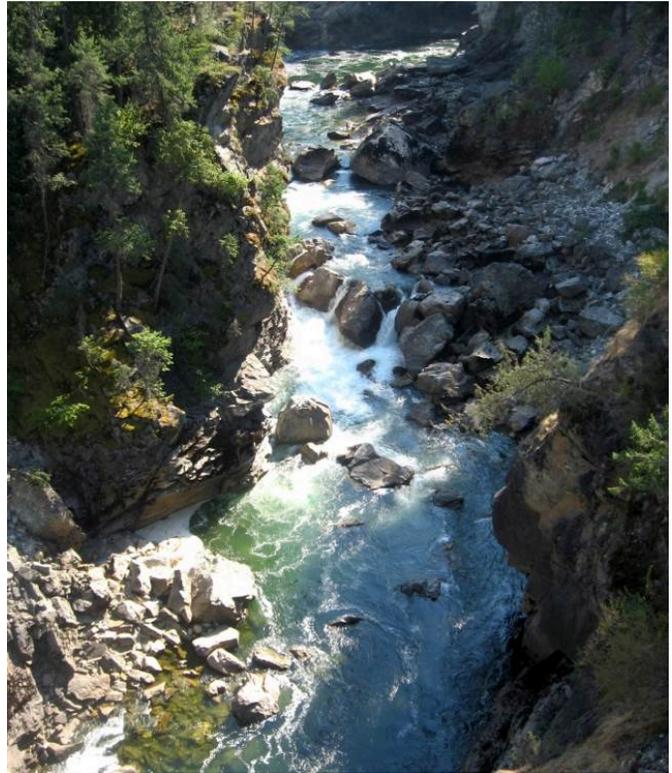


Figure 13.4.1 The Cascade Falls area of the Kettle River, near Christina Lake, B.C. This stream has a step-pool morphology and a deep bedrock channel.

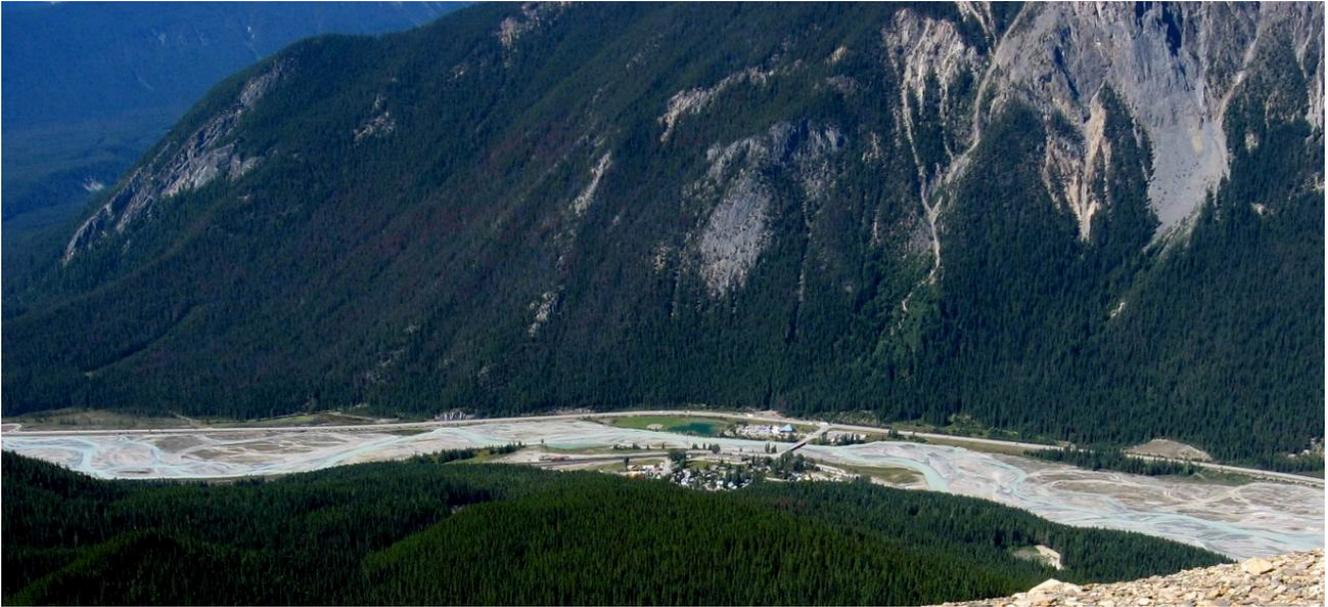


Figure 13.4.2 The braided channel of the Kicking Horse River at Field, B.C.

Braided streams can develop anywhere there is more sediment than a stream is able to transport. One such environment is in volcanic regions, where explosive eruptions produce large amounts of unconsolidated material that gets washed into streams. Streams in the volcanic Mt. Meager area of southwestern British Columbia are good examples of this (Figure 13.4.3).

A stream that occupies a wide, flat flood plain with a low gradient typically carries only sand-sized and finer sediments and develops a sinuous flow pattern. As you saw in Figure 13.3.1, when a stream flows around a corner, the water on the outside has farther to go and tends to flow faster. This leads to erosion of the banks on the outside of the curve, deposition on the inside, and formation of a point bar (Figure 13.4.4). Over time, the sinuosity of the stream becomes increasingly exaggerated, and the channel migrates around within its flood plain, forming a **meandering** pattern.



Figure 13.4.3 The braided channel of Meager Creek in the Mt. Meager area



Figure 13.4.4 The meandering channel of the Bonnell Creek, Nanoose, B.C. The stream is flowing toward the viewer. The sand and gravel point bar must have formed when the creek was higher and the flow faster than it was when the photo was taken.

A well-developed meandering river is shown in Figure 13.4.5. The meander in the middle of the photo has reached the point where the thin neck of land between two parts of the channel is about to be eroded through. When this happens, another **oxbow** lake will form like the others in the photo.



Figure 13.4.5 The meandering channel of the Nowitna River, Alaska. Numerous oxbow lakes are present and another meander cutoff will soon take place. [\[Image Description\]](#)

Exercise 13.4 Determining stream gradients

Gradient is the key factor controlling stream velocity, and of course, velocity controls sediment erosion and deposition. This map shows the elevations of Priest Creek in the Kelowna area. The length of the creek between 1,600 metres and 1,300 metres elevation is 2.4 kilometres, so the gradient is $300/2.4 = 125$ metres per kilometre.

1. Use the scale bar to estimate the distance between 1,300 metres and 600 metres and then calculate that gradient.
2. Estimate the gradient between 600 and 400 metres.
3. Estimate the gradient between 400 metres on Priest Creek and the point where Mission Creek enters Okanagan Lake.

See Appendix 3 for [Exercise 13.4 answers](#).

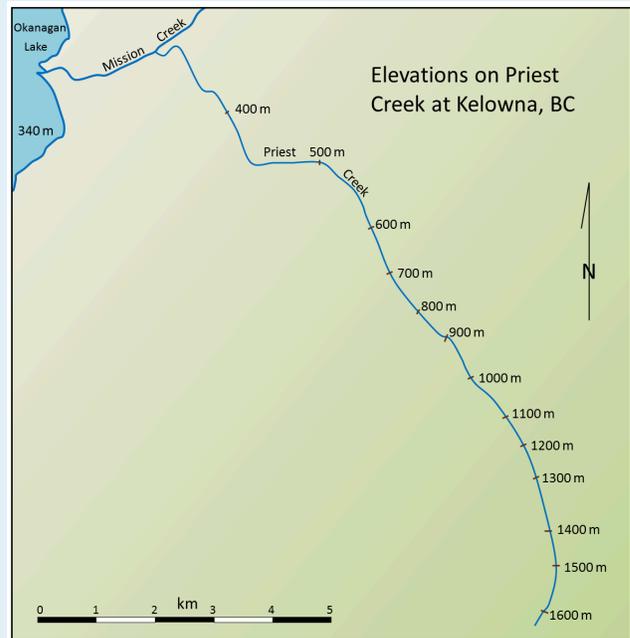


Figure 13.4.6 Elevations on Priest Creek at Kelowna, BC.

At the point where a stream enters a still body of water—a lake or the ocean—sediment is deposited and a delta forms. The Fraser River has created a large delta, which extends out into the Strait of Georgia (Figure 13.4.7). Much of the Fraser delta is very young in geological terms. Shortly after the end of the last glaciation (10,000 years ago), the delta did not extend past New Westminster. Since that time, all of the land that makes up Richmond, Delta, and parts of New Westminster and south Surrey has formed from sediment from the Fraser River. (You can see this in more detail at [Geoscape Vancouver](#).)



Figure 13.4.7 The delta of the Fraser River and the plume of sediment that extends across the Strait of Georgia. The land outlined in red has formed over the past 10,000 years.

Image Descriptions

Figure 13.4.5 image description: A part of the Nowitna River has curved around so sharply that it almost forms a circle before curving the other way again. Eventually, as the barrier between these two parts of the channel erodes, they will be joined and form an oxbow lake. [\[Return to Figure 13.4.5\]](#)

Media Attributions

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- Figure 13.4.3: “Meager Creek” © Isaac Earle. CC BY.
- Figure 13.4.5: “[Nowitna river](#)” by Oliver Kumis. CC BY-SA.
- Figure 13.4.7: [Delta of the Fraser River](#) by NASA. Taken September 2011. Adapted by Steven Earle. Public domain.

13.5 Flooding

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. In Canada, most streams show discharge variability similar to that of the Stikine River in northwestern B.C., as illustrated in Figure 13.5.1. The Stikine River has its lowest discharge levels in the depths of winter when freezing conditions persist throughout most of its drainage basin. Discharge starts to rise slowly in May, and then rises dramatically through the late spring and early summer as a winter's worth of snow melts. For the year shown, the minimum discharge on the Stikine River was 56 cubic metres per second (m^3/s) in March, and the maximum was 37 times higher, $2,470 \text{ m}^3/\text{s}$, in May.

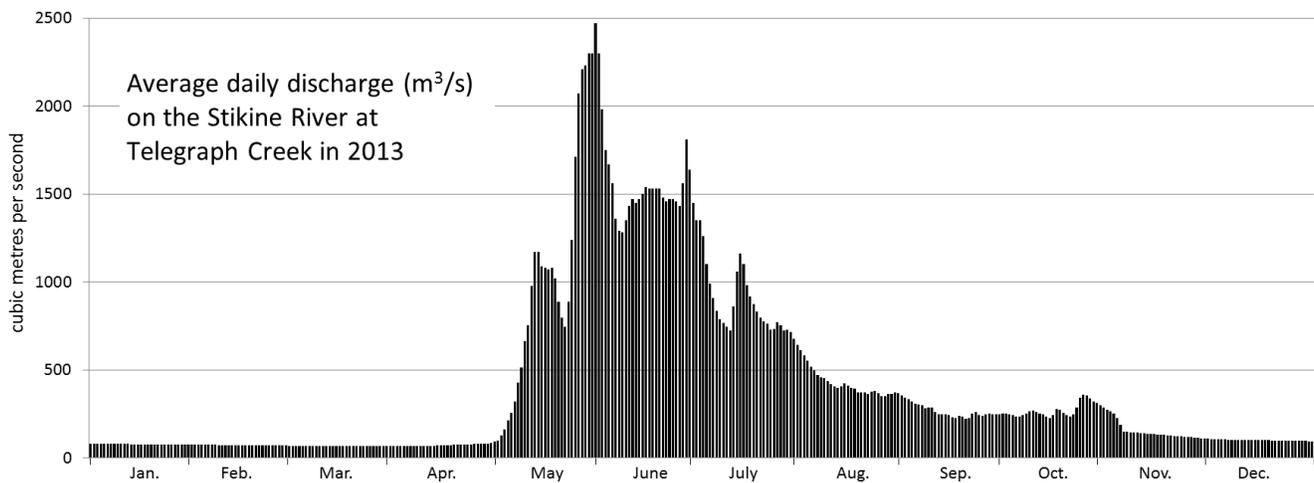


Figure 13.5.1 Variations in discharge of the Stikine River during 2013. [\[Image Description\]](#)

Streams in coastal areas of southern British Columbia show a very different pattern from those in most of the rest of the country because their drainage basins do not remain entirely frozen and because they receive a lot of rain (rather than snow) during the winter. The Qualicum River on Vancouver Island typically has its highest discharge levels in January or February and its lowest levels in late summer (Figure 13.5.2). In 2013, the minimum discharge was $1.6 \text{ m}^3/\text{s}$, in August, and the maximum was 34 times higher, $53 \text{ m}^3/\text{s}$, in March.

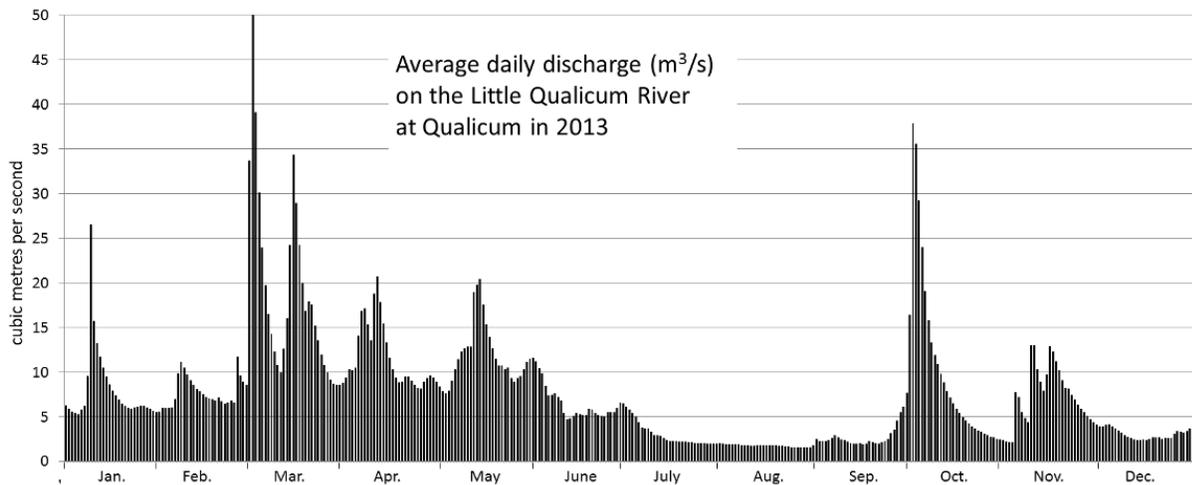


Figure 13.5.2 Variations in discharge of the Qualicum River during 2013. [\[Image Description\]](#)

When a stream's discharge increases, both the water level (**stage**) and the velocity increase as well. Rapidly flowing streams become muddy and large volumes of sediment are transported both in suspension and along the stream bed. In extreme situations, the water level reaches the top of the stream's banks (the **bank-full stage**, see Figure 13.3.4), and if it rises any more, it floods the surrounding terrain. In the case of mature or old-age streams, this could include a vast area of relatively flat ground known as a flood plain, which is the area that is typically covered with water during a major flood. Because fine river sediments are deposited on flood plains, they are ideally suited for agriculture, and thus are typically occupied by farms and residences, and in many cases, by towns or cities. Such infrastructure is highly vulnerable to damage from flooding, and the people that live and work there are at risk.

Most streams in Canada have the greatest risk of flooding in the late spring and early summer when stream discharges rise in response to melting snow. In some cases, this is exacerbated by spring storms. In years when melting is especially fast and/or spring storms are particularly intense, flooding can be very severe.

One of the worst floods in Canadian history took place in the Fraser Valley in late May and early June of 1948. The early spring of that year had been cold, and a large snow pack in the interior was slow to melt. In mid-May, temperatures rose quickly and melting was accelerated by rainfall. Fraser River discharge levels rose rapidly over several days during late May, and the dykes built to protect the valley were breached in a dozen places. Approximately one-third of the flood plain was inundated and many homes and other buildings were destroyed, but there were no deaths. The Fraser River flood of 1948, which was the highest in the past century, was followed by very high river levels in 1950 and 1972 and by relatively high levels several times since then, the most recent being 2007 (Table 13.1). In the years following 1948, millions of dollars were spent repairing and raising the existing dykes and building new ones; since then damage from flooding in the Fraser Valley has been relatively limited.

Table 13.1 Ranking of the maximum stage and discharge values for the Fraser River at Hope between 1948 and 2008. Typical discharge levels are around 1,000 m³/s.¹

Rank	Year	Month	Date	Stage (metres)	Discharge (cubic metres per second)
1	1948	May	31	11.0	15,200
2	1972	June	16	10.1	12,900
3	1950	June	20	9.9	12,500
4	1964	June	21	9.6	11,600
5	1997	June	5	9.5	11,300
6	1955	June	29	9.4	11,300
7	1999	June	22	9.4	11,000
8	2007	June	10	9.3	10,850
9	1974	June	22	9.3	10,800
10	2002	June	21	9.2	10,600

Serious flooding happened in July in 1996 in the Saguenay-Lac St. Jean region of Quebec. In this case, the floods were caused by two weeks of heavy rainfall followed by one day of exceptional rainfall. July 19 saw 270 millimetres of rain, equivalent to the region's normal rainfall for the entire month of July. Ten deaths were attributed to the Saguenay floods, and the economic toll was estimated at \$1.5 billion.

Just a year after the Saguenay floods, the Red River in Minnesota, North Dakota, and Manitoba reached its highest level since 1826. As is typical for the Red River, the 1997 flooding was due to rapid snowmelt. Because of the south to north flow of the river, the flooding starts in Minnesota and North Dakota, where melting starts earlier, and builds toward the north. The residents of Manitoba had plenty of warning that the 1997 flood was coming because there was severe flooding at several locations on the U.S. side of the border.

After the 1950 Red River flood, the Manitoba government built a channel around the city of Winnipeg to reduce the potential of flooding in the city (Figure 13.5.3). Known as the Red River Floodway, the channel was completed in 1964 at a cost of \$63 million. Since then it has been used many times to alleviate flooding in Winnipeg, and is estimated to have saved many billions of dollars in flood damage. The massive 1997 flood was almost too much for the floodway; in fact the amount of water diverted was greater than the designed capacity. The floodway has recently been expanded so that it can be used to divert more of the Red River's flow away from Winnipeg.

1. Mannerström, M, 2008, Comprehensive Review of Fraser River at Hope Flood Hydrology and Flows Scoping Study, Report prepared for the B.C. Ministry of the Environment [PDF]. Available at: http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/review_fraser_flood_flows_hope.pdf

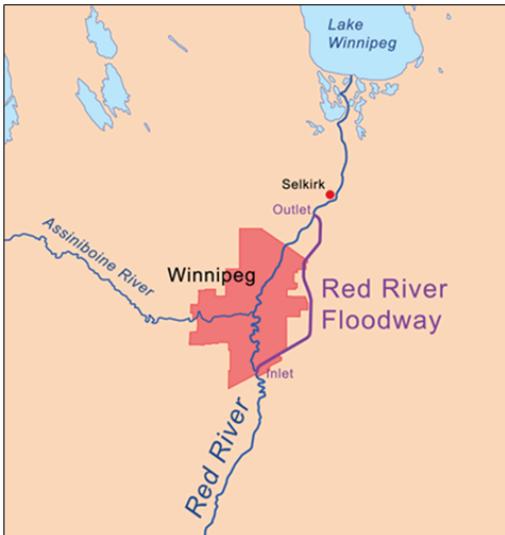


Figure 13.5.3 Map of the Red River floodway around Winnipeg, MB (left), and aerial view of the southern (inlet) end of the floodway (right).

Canada's most costly flood ever was the June 2013 flood in southern Alberta. The flooding was initiated by snowmelt and worsened by heavy rains in the Rockies due to an anomalous flow of moist air from the Pacific and the Caribbean. At Canmore, rainfall amounts exceeded 200 millimetres in 36 hours, and at High River, 325 millimetres of rain fell in 48 hours.

In late June and early July, the discharges of several rivers in the area, including the Bow River in Banff, Canmore, and Exshaw, the Bow and Elbow Rivers in Calgary, the Sheep River in Okotoks, and the Highwood River in High River, reached levels that were 5 to 10 times higher than normal for the time of year (see Exercise 13.5). Large areas of Calgary, Okotoks, and High River were flooded and five people died (see Figures 13.5.2 and 13.5.3). The cost of the 2013 flood is estimated to be approximately \$5 billion. Learn more about [Alberta's flood of the century](#).

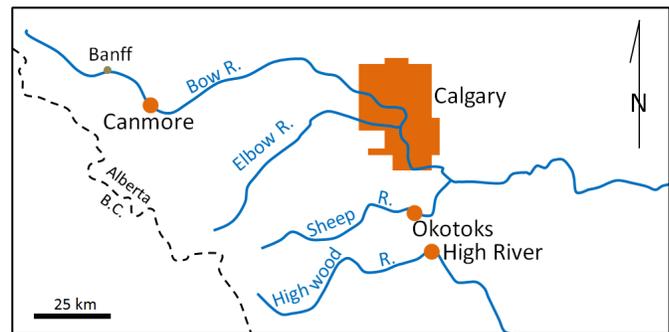


Figure 13.5.4 Map of the communities most affected by the 2013 Alberta floods (in orange).



Figure 13.5.5 Flooding in Calgary (June 21, left) and Okotoks (June 20, right) during the 2013 southern Alberta flood.

Exercise 13.5 Flood probability on the Bow River

Figure 13.5.6 shows the highest discharges per year between 1915 and 2014 on the Bow River at Calgary. Using this data set, we can calculate the recurrence interval (R_i) for any particular flood magnitude using the equation: $R_i = (n+1)/r$ (where n is the number of floods in the record being considered, and r is the rank of the particular flood). There are a few years missing in this record, and the actual number of data points is 95.

The largest flood recorded on the Bow River over that period was the one in 2013, 1,840 cubic metres per second (m^3/s) on June 21. R_i for that flood is $(95+1)/1 = 96$ years. The probability of such a flood in any future year is $1/R_i$, which is 1%. The fifth largest flood was just a few years earlier in 2005, at $791 m^3/s$. R_i for that flood is $(95+1)/5 = 19.2$ years. The recurrence probability is 5%.

1. Calculate the recurrence interval for the second largest flood (1932, $1,520 m^3/s$).
2. What is the probability that a flood of $1,520 m^3/s$ will happen next year?
3. Examine the 100-year trend for floods on the Bow River. If you ignore the major floods (the labelled ones), what is the general trend of peak discharges over that time?

See Appendix 3 for [Exercise 13.5 answers](#).

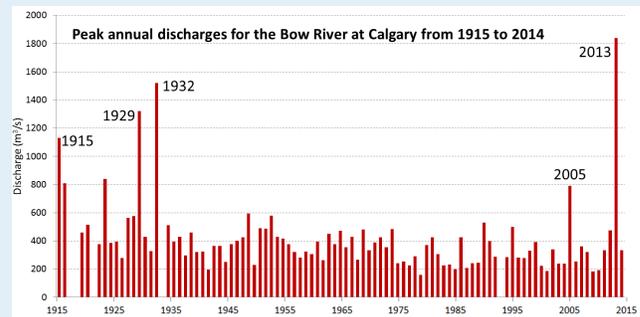


Figure 13.5.6 Graph of the highest discharge from the Bow River each year from 1915 to 2014. [\[Image Description\]](#)

One of the things that the 2013 flood on the Bow River teaches us is that we can't predict when a flood will occur or how big it will be, so in order to minimize damage and casualties we need to be prepared. Some of the ways of doing that are as follows:

- Mapping flood plains and not building within them

- Building dykes or dams where necessary
- Monitoring the winter snowpack, the weather, and stream discharges
- Creating emergency plans
- Educating the public

Image Descriptions

Figure 13.5.1 image description: The highest and lowest daily average discharge from the Stikine River by month in 2013 in cubic metres per second (m³/s).

Month	Lowest daily average discharge (m³/s)	Highest daily average discharge (m³/s)
January	100	100
February	100	100
March	100	100
April	100	100
May	150	2,450
June	1,250	1,800
July	700	1,450
August	300	700
September	250	300
October	250	750
November	150	600
December	100	100

[\[Return to Figure 13.5.1\]](#)

Figure 13.5.2 image description: The highest and lowest daily average discharge from the Qualicum River by month in 2013 in cubic metres per second (m^3/s).

Month	Lowest daily average discharge (m^3/s)	Highest daily average discharge (m^3/s)
January	5	24
February	6	14
March	8	50
April	7	21
May	7	20
June	5	12
July	3	7
August	2	3
September	3	8
October	3	37
November	3	13
December	3	4

[\[Return to Figure 13.5.2\]](#)

Figure 13.5.6 image description: Peak annual discharge from the Bow River from 1915 to 2014 in cubic metres per second (m³/s)

Year	Peak Annual Discharge (m³/s)
1915	1,125 (major)
1916	800
1919	475
1920	525
1922	375
1923	850
1924	400
1925	400
1926	275
1927	575
1928	580
1929	1,325 (major)
1930	425
1931	325
1932	1,520 (major)
1934	525
1935	400
1936	425
1937	300
1938	475
1939	325
1940	325
1941	200
1942	375
1943	375
1944	250
1945	375
1946	400

Year	Peak Annual Discharge (m³/s)
1947	425
1948	600
1949	225
1950	500
1951	500
1952	575
1953	425
1954	400
1955	375
1956	325
1957	275
1958	325
1959	300
1960	400
1961	250
1962	450
1963	375
1964	475
1965	350
1966	425
1967	275
1968	475
1969	325
1970	400
1971	425
1972	350
1973	350
1974	250
1975	250

Year	Peak Annual Discharge (m³/s)
1976	225
1977	300
1978	150
1979	375
1980	425
1981	300
1982	225
1983	225
1984	200
1985	425
1986	200
1987	250
1988	250
1989	550
1990	400
1991	300
1994	300
1995	500
1996	300
1997	300
1998	350
1999	400
2000	225
2001	175
2002	350
2003	250
2004	250
2005	791 (major)
2006	250

Year	Peak Annual Discharge (m ³ /s)
2007	375
2008	325
2009	175
2010	200
2011	350
2012	475
2013	1,840 (major)
2014	350

[\[Return to Figure 13.5.6\]](#)

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Summary

The topics covered in this chapter can be summarized as follows:

Section	Summary
13.1 The Hydrological Cycle	Water is stored in the oceans, glacial ice, the ground, lakes, rivers, and the atmosphere. Its movement is powered by the sun and gravity.
13.2 Drainage Basins	All of the precipitation that falls within a drainage basin flows into the stream that drains that area. Stream drainage patterns are determined by the type of rock within the basin. Over geological time, streams change the landscape that they flow within, and eventually they become graded, meaning their profile is a smooth curve. A stream can lose that gradation if there is renewed uplift or if their base level changes for some reason.
13.3 Stream Erosion and Deposition	Erosion and deposition of particles within streams is primarily determined by the velocity of the water. Erosion and deposition of different-sized particles can happen at the same time. Some particles are moved along the bottom of a river while some are suspended in the water. It takes a greater velocity of water to erode a particle from a stream bed than it does to keep it in suspension. Ions are also transported in solution. When a stream rises and then occupies its flood plain, the velocity slows and natural levées form along the edges of the channel.
13.4 Stream Types	Youthful streams in steep areas erode rapidly, and they tend to have steep, rocky, and relatively straight channels. Where sediment-rich streams empty into areas with lower gradients, braided streams can form. In areas with even lower gradients, and where silt and sand are the dominant sediments, meanders are common. Deltas form where streams flow into standing water.
13.5 Flooding	Most streams in Canada have their highest discharge rates in spring and early summer, although many of B.C.'s coastal streams are highest in the winter. Floods happen when a stream rises high enough to spill over its banks and spread across its flood plain. Some of the more significant floods in Canada include the Fraser River flood of 1948, the Saguenay River flood of 1996, the Red River flood of 1997, and the Alberta floods of 2013. We can estimate the probability of a specific flood level based on the record of past floods, and we can take steps to minimize the impacts of flooding.

Questions for Review

1. What is the proportion of liquid (not frozen) **freshwater** on Earth expressed as a percentage of all water on Earth?
2. What percentage of that fresh water is groundwater?
3. What type of rock, and what processes, can lead to the formation of a trellis drainage pattern?
4. Why do many of the streams in the southwestern part of Vancouver Island flow to the ocean as

waterfalls?

5. Where would you expect to find the fastest water flow on a straight stretch of a stream?
6. Sand grains can be moved by traction and saltation. What minimum stream velocities might be required to move 1 millimetre sand grains?
7. If the flow velocity of a stream is 1 cm per second, what sizes of particles can be eroded, what sizes can be transported if they are already in suspension, and what sizes of particles cannot be moved at all?
8. Under what circumstances might a braided stream develop?
9. How would the gradient of a stream be affected if a meander is cut off?
10. The elevation of the Fraser River at Hope is 41 metres. From there it flows approximately 147 kilometres to the sea. What is the average gradient of the river (metres per kilometre) over that distance?
11. How do B.C.'s coastal streams differ from most of the rest of the streams in Canada in terms of their annual flow patterns? Why?
12. Why do most serious floods in Canada happen in late May, June, or early July?
13. There is a 65-year record of peak annual discharges on the Ashnola River near Princeton, B.C. During this time, the second highest discharge was $175 \text{ m}^3/\text{s}$. Based on this information, what is the recurrence interval (Ri) for that discharge level, and what is the probability that there will be a similar peak discharge next year?

Answers to Review Questions can be found in [Appendix 2](#).