

Chapter 9

What You'll Learn

- What landscape features on Earth are formed and changed by surface water.
- How surface water moves materials and impacts humans.

Why It's Important

Landscape features formed by surface water are among the most numerous and visible features on Earth. Running water has the greatest impact on humans because we depend on streams for drinking-water supplies and irrigation. Humans also experience the negative effects of floods.



To find out more about surface water, visit the Earth Science Web Site at earthgeu.com

Surface Water





Discovery Lab


Modeling Water Movement

When water seeps into the ground, it moves at various rates through the different materials that make up Earth's surface. These Earth materials are comprised of different particle sizes. In this activity, you will investigate the movement of water as it seeps through two different kinds of Earth materials.

1. Place a small window screen on each of two clear plastic shoe boxes.
2. Place an 8 cm × 16 cm clump of grass or sod on one screen.
3. Place an 8 cm × 16 cm clump of

barren soil on the other screen.

4. Lightly sprinkle 500 mL of water on each clump.

 **CAUTION:** Always wear an apron in the lab.

Observe In your science journal, describe what happens to the water after five minutes. Measure how much water passes through each clump and collects in the plastic shoe box. Explain any differences in the amount of water collected in each plastic shoe box.



SECTION

9.1

Surface Water Movement

OBJECTIVES

- **Explain** how surface water can move weathered materials.
- **Explain** how a stream carries its load.
- **Describe** how a floodplain develops.

VOCABULARY

runoff	bed load
watershed	discharge
divide	flood
solution	floodplain
suspension	

Earth's water supply is recycled in a continuous process called the water cycle. Water molecules move continuously through the water cycle following many pathways: they evaporate from a body of water or the surface of Earth, condense into cloud droplets, fall as precipitation back to Earth's surface, and soak into the ground. As part of a continuous cycle, the water eventually evaporates back into the atmosphere, again forms clouds, again falls as precipitation, and so on. Understanding the mechanics of the water cycle helps to explain the reasons for variations in the amount of water that is available throughout the world.

Often, a water molecule's pathway involves time spent within a living organism or as part of a snowfield, glacier, lake, or ocean. Although water molecules may follow a number of different pathways, the overall process is one of repeated evaporation and condensation powered by the Sun's energy. What happens once water reaches Earth's surface? Does all the water sink into the ground or evaporate?

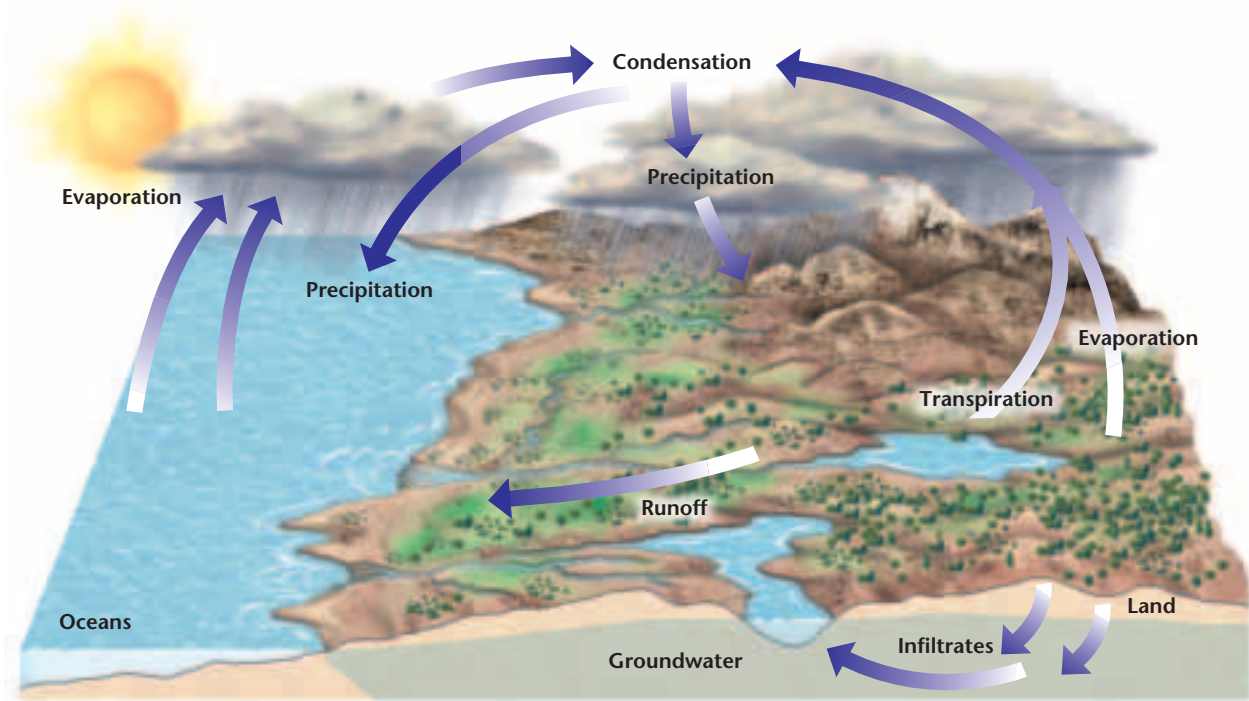


Figure 9-1 The water cycle, also referred to as the hydrologic cycle, is a never-ending, natural circulation of water through Earth’s systems. The Sun provides the energy for the water cycle. Radiation from the Sun causes water to change to a gas called water vapor. The process of water vapor changing to a fluid is called condensation.

RUNOFF

As shown in *Figure 9-1*, precipitation falls to Earth’s surface in the form of rain, snow, sleet, or hail. In most instances, solid forms of precipitation, such as snow, sleet, and hail, may eventually melt. Or they can also be incorporated into the mass of a glacier. Once water reaches Earth’s surface, it can evaporate into the atmosphere, soak into the ground, or flow down slopes on Earth’s surface. Water flowing downslope along Earth’s surface is called **runoff**. Runoff may reach a stream, river, or lake, may evaporate, or it may accumulate as puddles in low-lying small depressions and eventually seep into the ground. During and after heavy rains, you can observe these processes occurring in your own yard or local park. Water that seeps into Earth’s surface becomes groundwater.

A number of conditions determine whether water on Earth’s surface will seep into the ground or become runoff. For water to enter the ground, there must be large enough pores or spaces in the ground’s surface materials to accommodate the water’s volume, as in the loose soil illustrated in *Figure 9-2A*. If the pores already contain water, the newly fallen precipitation will either remain standing on top of the ground or, if the area has a slope, run downhill. Water standing on the surface of Earth eventually evaporates or flows away.

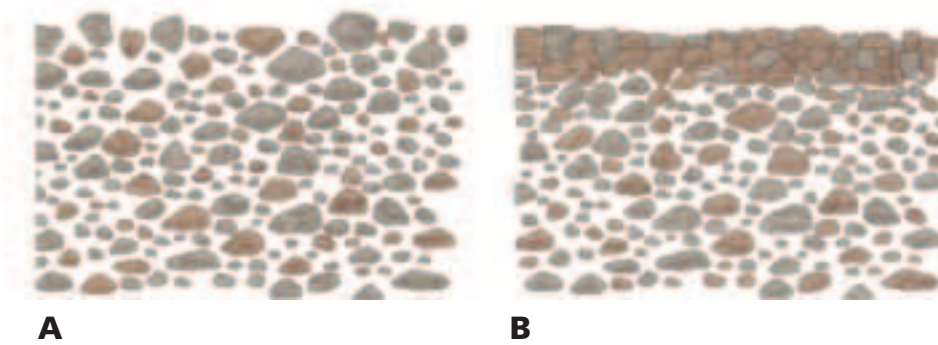


Figure 9-2 Soil that has open surface pores or spaces between particles allows water to infiltrate **(A)**. Soil that has few or no pores or spaces can restrict water's ability to seep in **(B)**.

Vegetation Soils that contain grasses or other vegetation allow more water to enter the ground than do soils with no vegetation. Precipitation falling on vegetation slowly flows down leaves and branches, and it eventually drops gently to the ground. In contrast, precipitation falls with far more force onto barren land. In such areas, soil particles clump together and form dense aggregates with few pores or spaces between them. The force of falling rain may then push the soil clumps together, thereby closing pores and allowing less water to enter, as illustrated in *Figure 9-2B*. This is why gardeners do not pack the soil around their plants. Compacting the soil reduces the spaces between the particles that are available for water to seep in, thus reducing the amount of water that is available to the plants' roots.

Rate of Precipitation Light, gentle precipitation infiltrates the dry ground. However, the rate of precipitation may temporarily exceed the rate of infiltration. For example, during heavy precipitation, water falls too quickly to soak into the ground and becomes runoff. Thus, a gentle, long-lasting rainfall is more beneficial to plants and causes less erosion by runoff than a torrential downpour. If you have a garden, remember that more water will enter the ground if you water your plants slowly and gently.

Soil Composition The physical and chemical composition of soil also affects its water-holding capacity. Soil consists of decayed organic matter, called humus, and minerals. Humus creates pores in the soil, thereby increasing a soil's ability to retain water. The minerals in soil have different particle sizes, which are classified as sand, silt, or clay. As you learned in Chapter 7, the percentages of particles of each size vary from soil to soil. Soil with a high percentage of coarse particles, such as sand, has relatively large pores between its particles that allow water to enter and pass through the soil quickly. In contrast, soil with a high percentage of fine particles, such as clay, clumps together and has few or no spaces between the particles.

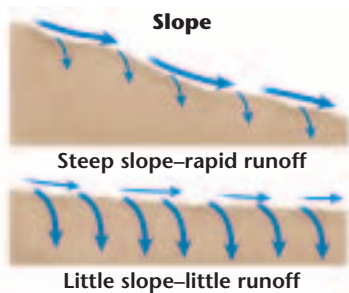


Figure 9-3 The angle of a slope is one variable that influences the movement of surface water on a slope.

Such small pores restrict both the amount of water that can enter the ground and the ease of movement of water through the soil.

Slope As you have learned, the slope of a land area plays a large role in determining the ability of water to enter the ground, as shown in *Figure 9-3*. Water from precipitation falling on slopes flows to areas of lower elevation. The steeper the slope, the faster the water flows. There is also greater potential for erosion on steep slopes. In areas with steep slopes, little water seeps into the ground before it runs off.

STREAM SYSTEMS

Precipitation that does not enter the ground usually runs off the surface quickly. Some surface water flows in thin sheets and eventually collects in small channels. As the amount of runoff increases, the channels widen, deepen, and become longer. Although it is common for these small channels to dry up shortly after precipitation stops, the channels again fill with water each time it rains and become larger and longer. If a sufficient supply of water develops, the water begins to flow more permanently in a channel and can become a stream.

All streams flow downslope in a watery path to lower elevations. However, the path of a stream can vary considerably, depending on the slope of the land and the type of material through which the stream flows. Some streams flow into lakes, while others flow directly into the ocean. Still others, called tributaries, flow into other streams, as shown in *Figure 9-4*. Each tributary increases the size of the stream it is joining and adds water to it. A large stream is called a river, and all its tributaries make up a stream, or river system. Small streams are called brooks and creeks. If there are any brooks or streams near your home, can you locate where they feed into other streams or lakes?

NATIONAL GEOGRAPHIC

To learn more about rivers, go to the [National Geographic Expedition](#) on page 870.

Figure 9-4 Numerous tributaries flow into several stream systems that drain into the Salton Sea in California.



WATERSHEDS AND DIVIDES

All of the land area whose water drains into a stream system is called the system's **watershed**, or drainage basin. Watersheds can be relatively small or extremely large in area. A **divide** is a high land area that separates one watershed from another. Each tributary in a stream system has its own watershed and divides, but they are all part of the larger stream system to which the tributary belongs. The watershed of the Mississippi River, shown in *Figure 9-5*, is the largest in North America.

STREAM LOAD

All the materials that the water in a stream carries is known as the stream's load. The living components of water include microscopic life-forms as well as larger plants and animals. The nonliving components of surface water include sediments, dissolved solids, and dissolved atmospheric gases, such as oxygen. There are three ways in which a stream carries its load.

Solution Material is carried in **solution** after it becomes dissolved in a stream's water. How much of a stream's load is carried in solution depends on the material through which the stream's water has passed. When water runs through or over rocks containing soluble



Figure 9-5 The watershed of the Mississippi River includes a large stream system. *How many major rivers are part of the Mississippi watershed?*

minerals, it dissolves small amounts of the minerals and carries them away in solution. Water may readily dissolve calcium carbonate from limestone and marble, for example. Streams also commonly carry soluble magnesium compounds. Groundwater adds most of the dissolved load to stream water, while runoff adds only a very small amount.

The amount of dissolved material that water carries is often expressed in parts per million, or ppm, as shown in **Table 9-1**. For example, a measurement of 10 ppm means that there are 10 parts of dissolved material for every 1 million parts of water. The total concentration of materials in solution in streams averages 115–120 ppm, although some streams carry as little dissolved materials as 10 ppm. Values greater than 10 000 ppm have been observed for streams draining desert basins. Measuring the amount of material in solution helps scientists monitor water quality.

Suspension All particles small enough to be held up by the turbulence of a stream’s moving water are carried in **suspension**. Particles, such as silt, clay, and sand, that are carried in suspension are part of a stream’s suspended load. The amount of material in suspension varies with the volume and velocity of the stream water. Rapidly moving water can carry larger particles in suspension than slowly moving water can. As the velocity of water decreases, the heavier particles settle to the bottom, as you can see by doing the *Problem-Solving Lab* on the next page.

Table 9-1 Concentrations of Some Materials Dissolved in River Water and Seawater

Materials	Concentration (ppm)			
	Amazon River	Mississippi River	World Average (est.)	Average Seawater
Silica (SiO ₂)	7.0	6.7	13.0	6.4
Calcium (Ca ²⁺)	4.3	42.0	15.0	400.0
Sodium (Na ⁺)	1.8	25.0	6.3	10 500.0
Potassium (K ⁺)	—	2.9	2.3	380.0
Magnesium (Mg ²⁺)	1.1	12.0	4.1	1350.0
Chloride (Cl ⁻)	1.9	30.0	7.8	19 000.0
Fluoride (F ⁻)	0.2	0.2	—	1.3
Sulfate (SO ₄ ²⁻)	3.0	56.0	11.0	2700.0
Bicarbonate (HCO ₃ ⁻)	19.0	132.0	58.0	142.0
Nitrate (NO ₃ ⁻)	0.1	2.4	1.0	0.5

Source: J. D. Hem, *Study and Interpretation of the Chemical Characteristics of Natural Water*, U.S. Geological Survey Water-Supply Paper 1473, 1970, pp. 11, 12, and 50.



Bed Load Sediments that are too large or heavy to be held up by turbulent water are transported by streams in another manner. A stream's **bed load** consists of sand, pebbles, and cobbles that the stream's water can roll or push along the bed of the stream. The faster the water moves, the larger the particles it can carry both in suspension and as part of its bed load. As the particles move, they rub, scrape, and grind against one another or against the solid rock of the streambed in a process called abrasion, the wearing away of solid Earth material. This action contributes to the physical weathering of the stream's bottom and sides, and it provides an additional source of material to be eroded by the stream, either in solution or as part of the suspended load.

As gravity pulls stream water to lower elevations, the stream's load moves along with the water. The moving water continuously tosses and tumbles the weathered material, whose pieces become smooth and rounded over time, as shown in *Figure 9-6*. Most pebbles along the bottoms and sides of streams are round and polished as a result of this process.

Bed load sediments not only wear away one another, but they also abrade the surface of the streambed. Potholes may form on the bottoms of streams where pebbles have continued to swirl around in



Figure 9-6 The rounded shapes and smooth pebbles were caused by the stream erosion of the Snake River in Grand Teton National Park, Wyoming.

Problem-Solving Lab

Using Graphs

Predict how sediments move in a stream The velocity of water affects the transport of different-sized particles.

Analysis

1. Study the graph at right.
2. At what velocity would flowing water pick up a pebble?
3. Over what range of velocities would flowing water carry a pebble?

Thinking Critically

4. Infer which of the following objects would not fall into the same size range as a pebble: a large chicken egg, a baseball, a golf ball, a table-tennis ball, a volleyball, and a pea. How would you test your conclusions?

Stream Velocity and Particle Size	
Boulders	25.6 cm
Cobbles	6.4 cm
Pebbles	0.2 cm
Sand	0.006 cm
Silt	0.0004 cm
Clay	0.00001 cm





Figure 9-7 The potholes in this Wisconsin River streambed were scoured out by the abrasive action of the stream's bed load. The river is located at Grandfather Falls, Wisconsin.

one area and have slowly worn holes into solid rock. For example, potholes more than 3 m deep have formed near Little Falls, New York, in the Mohawk River Valley. Potholes can be found even in streambeds composed of very hard, exposed bedrock. The huge depressions in the streambed of the Wisconsin River, shown in *Figure 9-7*, were scoured out of granite. Large streambed potholes dramatically illustrate the powerful abrasive action caused by a stream's bed load.

STREAM VELOCITY AND CARRYING CAPACITY

The ability of a stream to transport material, referred to as its carrying capacity, depends on both the velocity and the amount of water moving in the stream. Study *Figure 9-8* as you read. The channel's slope, depth, and width all affect the speed and direction in which water moves within it. A stream's water moves more quickly where there is less friction; consequently, smooth-sided channels with great slope and depth allow water to move most rapidly. The total volume of moving water also affects a stream's carrying capacity. **Discharge** is the measure of the volume of stream water that flows over a particular location within a given period of time. Discharge is commonly expressed in cubic meters per second (m^3/s). The following formula is used to calculate the discharge of a stream:

$$\begin{array}{ccccccc} \text{discharge} & = & \text{width} & \times & \text{depth} & \times & \text{velocity} \\ (\text{m}^3/\text{s}) & & (\text{m}) & & (\text{m}) & & (\text{m}/\text{s}) \end{array}$$

The largest river in North America, the Mississippi, has a huge average discharge of $173\,600\text{ m}^3/\text{s}$. However, the Amazon River, the largest in the world, has an incredible discharge ten times that amount. The discharge from the Amazon River over a 24-hour period would supply New York City's water needs for nine years!

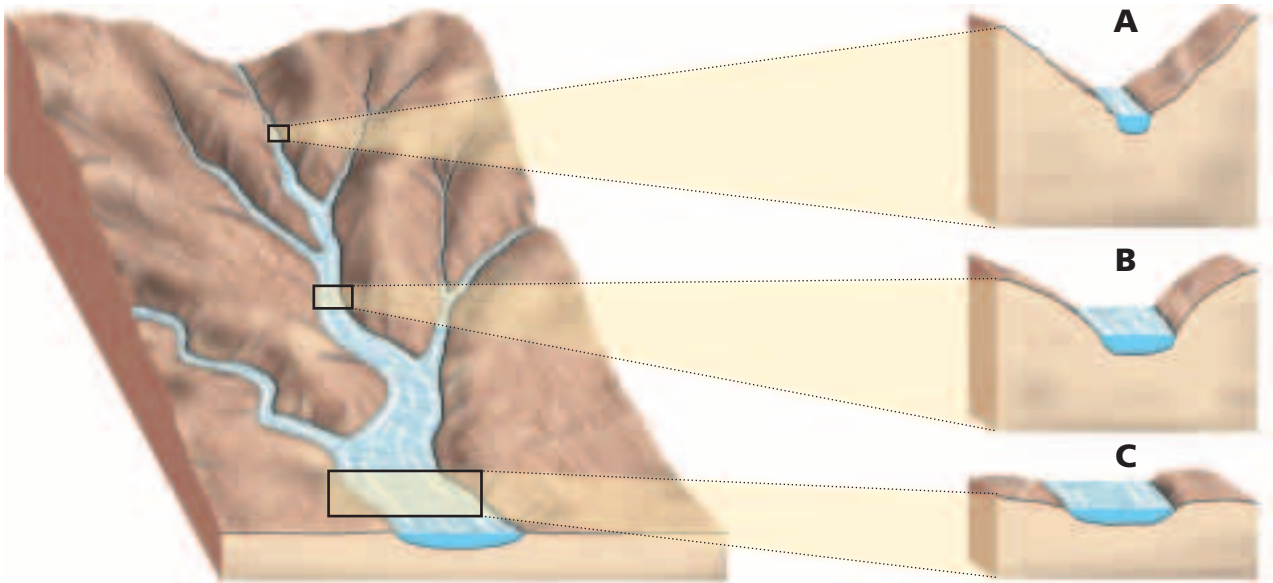


Figure 9-8 Describe the changes in the downstream direction of the stream's channel as the water flows from section A to section C.

As a stream's discharge increases, the stream's carrying capacity increases as well. The increased discharge results in a stream with greater carrying capacity as modeled in the *GeoLab* at the end of the chapter. Both water velocity and volume increase during times of heavy precipitation, rapid melting of snow, and flooding. In addition to increasing a stream's carrying capacity, these conditions heighten a stream's ability to erode the land over which it passes. As a result of an increase in erosional power, a streambed can widen and deepen, thereby increasing the stream slope and further adding to the stream's carrying capacity. As shown in *Figure 9-9*, the extraordinary power of water during such times can be especially hazardous for people who do not anticipate the dangers associated with flooding.

Figure 9-9 Several days of heavy rains in Buenos Aires, Argentina caused flood waters to strand traffic in the city.

FLOODPLAINS

The amount of water being transported in a particular stream at any given time varies with weather conditions. Sometimes, more water pours into a stream than the banks of the stream channel can hold. A **flood** occurs when water spills over the sides of a stream's banks onto the adjacent land. The broad, flat area that extends out from a stream's bank and is covered by excess water during times of flooding is known as the stream's **floodplain**. Floodwater carries along with it a great amount of sediment eroded from Earth's surface and the sides of the stream channel. As floodwater recedes and its volume and speed decrease, the water drops its sediment load onto the stream's floodplain.



Figure 9-10 Floodplain deposits contain fertile soils.

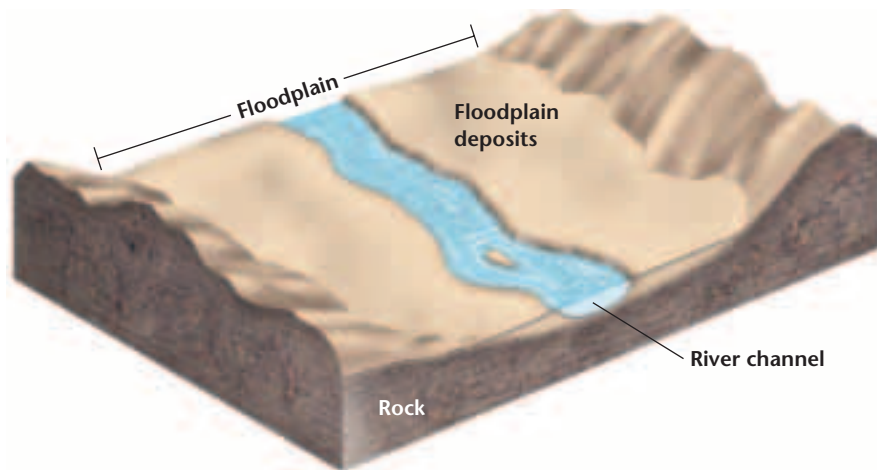


Figure 9-10 illustrates a floodplain after a river overflows its channel. Floodplains develop highly fertile soils as more sediment is deposited with each subsequent flood. These fertile soils have historically enticed farmers to use the land for crop production, even at the risk of losing homes and crops to subsequent flooding.



Topic: Floods

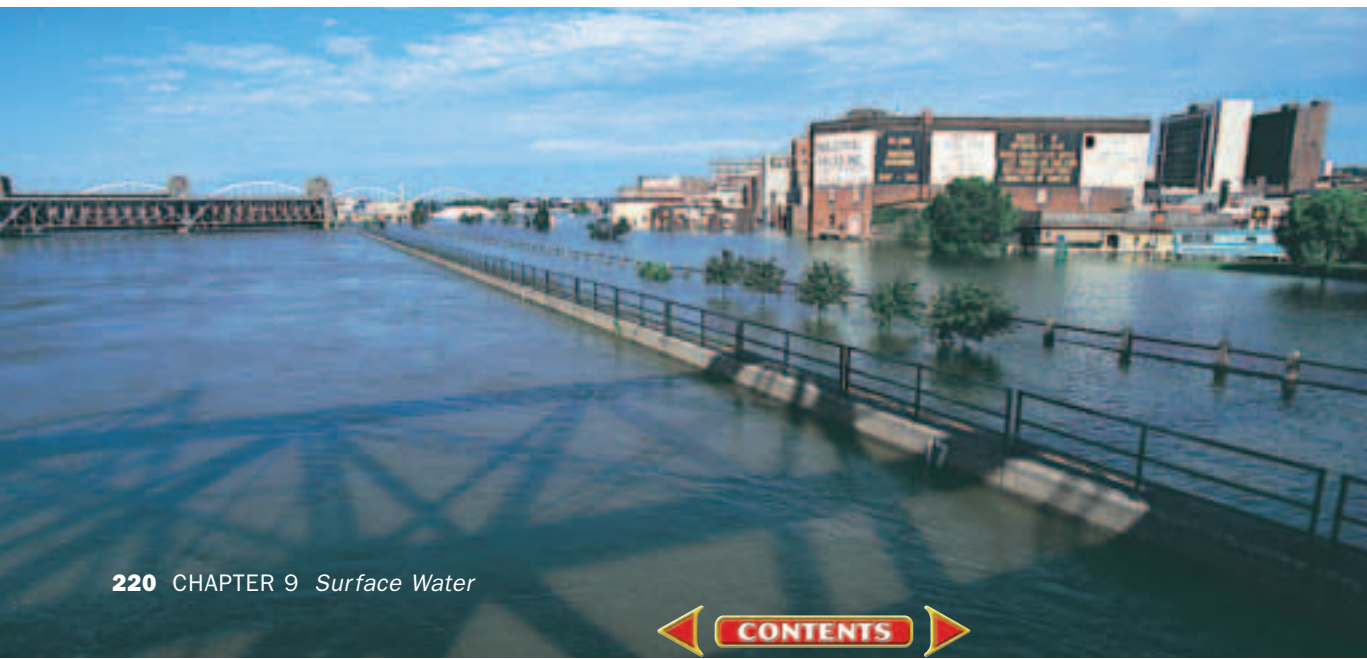
To find out more about floods and flood prevention, visit the Earth Science Web Site at earthgeu.com

Activity: Write a brief report to compare and contrast the flooding of the Yellow River in China, the Nile River in Egypt, and the Mississippi River in the United States.

FLOODS

Floods are a natural occurrence. When a stream reaches its flood stage, a flood can occur, as shown in *Figure 9-11*. Flood stage is the level at which a stream overflows its banks and the crest of the stream is the maximum height. Because it takes time for runoff to collect in streams, the water continues to rise and may reach its crest days after precipitation ends. The resulting flooding may occur over localized, small areas or across large regions. The flooding of a small area is known as an upstream flood. Sudden rainstorms that drop large amounts of rain within a short period of time cause upstream floods,


Figure 9-11 Davenport, Iowa was just one of many areas that was flooded by the Mississippi River in 1993.



as do dam failures. Although they are localized, upstream floods can do a great deal of damage within a very short period of time.

Heavy accumulations of excess water from large regional drainage systems result in downstream floods. Such floods occur during or after long-lasting, intense storms or spring thaws of large snowpacks. The tremendous volumes of water involved in a downstream flood can result in extensive damage. For example, the devastating floods in 1993 along the Mississippi River, which frequently causes downstream flooding, left landscape scars that are still visible today.

FLOOD MONITORING AND WARNING SYSTEMS

 In an attempt to provide warnings for people at risk, government agencies monitor potential flood conditions. The National Weather Service monitors changing weather conditions. Earth-orbiting weather satellites photograph Earth and collect and transmit information about weather conditions, storms, and streams. In addition, the U.S. Geological Survey (USGS) has established gauging stations, as shown in *Figure 9-12*, on approximately 4400 streams in the United States. The gauging stations provide a continuous record of the water level in each stream. Technological advances have made it possible for anyone with Internet access to obtain real-time data on streams through government-sponsored Web sites.


In areas that are prone to severe flooding, warning systems are the first step in implementing emergency management plans. Flood warnings and emergency plans often allow people to safely evacuate an area in advance of a flood. 



Figure 9-12 This USGS stream gauging station is located in the northwest section of Washington State.



**ENVIRONMENTAL
CONNECTION**

SECTION ASSESSMENT

1. Describe ways in which moving water can carve a landscape.
2. Explain the three ways in which a stream carries its load.
3. What is the relationship between the carrying capacity of a stream and its discharge and velocity?
4. Explain why little water from runoff seeps into the ground in areas of steep slopes.
5. Discuss how a floodplain forms and why people live on floodplains.
6. **Thinking Critically** Under what conditions might a stream's volume increase, and under what conditions might it decrease? How would the size of the sediment particles in the stream's load differ in the two situations?

SKILL REVIEW

7. **Making Tables** Design a data table that compares how silt, clay, sand, and large pebbles settle to the bottom of a stream as the velocity of water decreases. For more help, refer to the *Skill Handbook*.





SECTION **9.2**

Stream Development

OBJECTIVES

- **Describe** some of the physical features of stream development.
- **Explain** the process of rejuvenation in stream development.

VOCABULARY

- stream channel
- stream bank
- meander
- delta
- rejuvenation

As a stream develops, it changes in shape, width, and size, as well as the landscapes over which it flows. Stream flow is part of a dynamic system that is greatly influenced by the varying environmental conditions of the stream’s surroundings.

MOVING WATER CARVES A PATH

The first and foremost condition necessary for stream formation is an adequate supply of water. Precipitation provides the water for the beginnings of stream formation. In areas where precipitation falls infrequently, stream development and flow are also infrequent. For example, in some desert areas, where years pass between rainfalls, the streams that form are short-lived. However, most parts of the temperate and tropical regions on Earth experience precipitation on a regular basis.

The region where water first accumulates to supply a stream is called the headwaters. It is common for a stream’s headwaters to be high in the mountains. Falling precipitation accumulates in small gullies at these higher elevations and forms briskly moving streams. As surface water first begins its flow, its path may not be well defined. In time, however, the moving water carves a narrow pathway into the sediment or rock called a **stream channel**. The channel widens and deepens as more and more water accumulates and cuts into Earth’s surface. As shown in *Figure 9-13*, the moving water is held within the confines of the stream channel by the **stream banks**, the ground bordering the stream on each side. If you have ever fished in a stream, you might have sat on a stream bank to do so.

Figure 9-13 The river banks confine the water of the San Pedro River in the San Pedro Riparian National Conservation Area in Arizona.



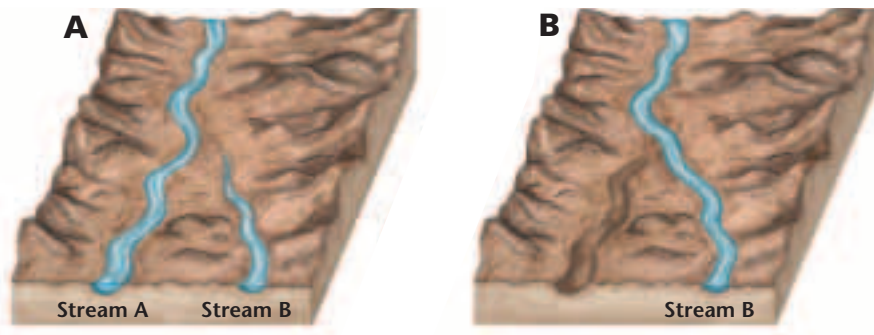


Figure 9-14 The headward erosion of stream B cuts into stream A and draws away its waters into one stream.

The process by which small streams erode away the rock or soil at the head of a stream is known as headward erosion. Headward erosion involves lengthening the stream. Streams at this point in their development are relatively small and narrow. These streams move swiftly over the rough terrain, and they often form waterfalls and rapids as they flow over steep inclines.

Sometimes, a stream erodes its way through the high area separating two drainage basins, joins another stream, and then draws away its water. This process is called stream capture, or stream piracy. As shown in **Figure 9-14**, the lower portion of the captured stream loses its water source, while the invading stream gains an additional source of water.

FORMATION OF STREAM VALLEYS

As a stream actively erodes its path through the sediment or rock, a V-shaped channel develops. V-shaped channels have steep sides and sometimes form canyons or gorges. The Grand Canyon is perhaps the best-known example of a V-shaped valley carved by a stream, the Colorado River. Ausable Chasm, in New York State, is another impressive, but very narrow, deep gorge carved by a stream. **Figure 9-15** shows the classic V-shaped valley created by the Yellowstone River.

A stream continues to erode until it reaches its base level, the elevation at which it enters another stream or body of water. The lowest base level possible for any stream is sea level, the point at which the stream enters the ocean. As a stream continues to erode its channel toward its base level, erosion will continue along the sides of the



Figure 9-15 A V-shaped valley was formed on the Lower Falls of the Yellowstone River in Wyoming.



Figure 9-16 The Delaware Water Gap in Pennsylvania has been eroded into a wider, broader valley.

V-shaped channel. As shown in *Figure 9-16*, in time, a V-shaped valley will be eroded into a broader valley that has gentle slopes.

MEANDERING STREAMS

As stream channels develop into broader valleys, the volume of water and sediment that they are able to carry increases. In addition, a stream's slope, or gradient, decreases as it nears its base level, and as a result the channel gets wider. The decrease in gradient causes water to build up within the stream channel. Sometimes, the water begins to erode the sides of the channel in such a way that the overall path of the stream starts to bend or wind. As shown in *Figure 9-17*, a bend or curve in a stream channel caused by moving water is called a **meander**.

Water in the straight parts of a stream flows at different velocities, depending on the location of the water in the channel. In a straight length of a stream, water in the center of the channel is flowing at the maximum velocity. Water along the bottom and sides of the channel flows more slowly because it experiences friction as it moves against the land. In contrast, the water moving along the outside of a meander curve experiences the greatest rate of flow within the meander. The water that flows along this outside part of the curve continues to erode away the sides of the streambed, thus making the meander larger. Along the inside of the meander, the water moves more slowly and deposition is dominant. These differences in the rate of water flow within meanders cause the meanders to become more accentuated over time. *Figure 9-18* illustrates the processes of erosion and



Figure 9-17 Several meanders are formed in the Tundra River in Yukon, Canada.

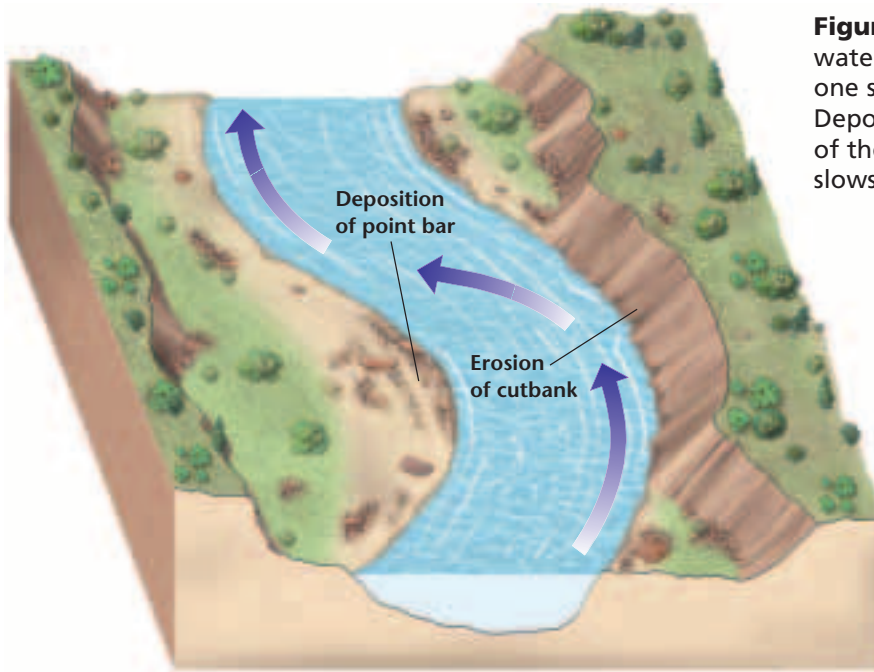


Figure 9-18 The high velocity of water in a meandering stream erodes one side of the stream's bank. Deposition occurs when the velocity of the water in a meandering stream slows down.

deposition along a meander, and **Figure 9-19** shows the points of maximum water velocity within a meander and within a straight part of a stream. Stream meanders continue to develop and become larger and wider over time. After some degree of winding, however, it is common for a stream to cut off a meander and once again flow along a straighter path. The stream then deposits material along the adjoining meander and eventually blocks off its water supply, as shown in **Figure 9-20**. The blocked-off meander becomes an oxbow lake, which eventually dries up.

As a stream approaches a larger body of water or its ultimate end point, the ocean, the streambed's gradient flattens out and its channel becomes very wide. The area of the stream that leads into the ocean or another large body of water is called the mouth. The mouth of the Mississippi River is extremely wide.

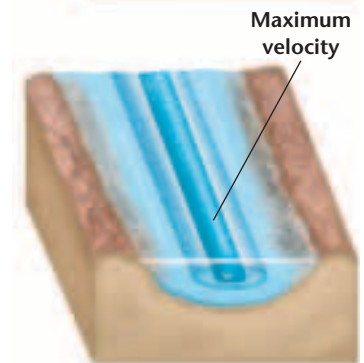
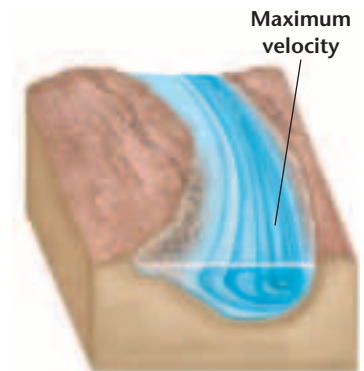


Figure 9-19 The maximum velocity of water in a stream will change its direction as the stream meanders.

Figure 9-20 The Devil's Elbow is an oxbow lake along the Congaree River in Congaree Swamp National Monument in South Carolina.






Figure 9-21 An alluvial fan was formed at Mormon Point beneath Black Mountain in Death Valley National Park in California.

DEPOSITION OF SEDIMENT

Streams that lose velocity also lose their ability to carry sediment. A stream's velocity lessens and its sediment load drops when its gradient abruptly decreases. In dry regions, where mountain streams commonly flow down narrow valleys onto broad, flat, valley floors, a stream's gradient may suddenly decrease causing the stream to drop its sediment as a fan-shaped deposit called an *alluvial fan*. Alluvial fans

are sloping depositional features formed at the bases of slopes and composed mostly of sand and gravel. They are found worldwide but are most common in dry, mountainous regions such as Death Valley, California, shown in *Figure 9-21*.

Streams also lose velocity and the ability to carry sediment when they join larger bodies of quiet water. The triangular deposit that forms where a stream enters a large body of water is called a **delta**, named for the triangle-shaped Greek letter *delta* (Δ). Delta deposits usually consist of silt and clay particles. As a delta develops, sediments build up and slow the stream water, sometimes even blocking its movement. Smaller distributary streams then form to carry the stream water through the developing delta. The Mississippi River Delta, shown in *Figure 9-22*, began forming millions of years ago. Today, the city of New Orleans, Louisiana is located on that delta, an area that was under seawater only 5000 years ago.



Using Math

Using Numbers If a stream's average velocity is 5 m/s, its width is 30 m, and its average depth is 10 m, what is the amount of the stream's discharge?

Figure 9-22 This photo shows a portion of the Mississippi River Delta. The delta consists of silt, sand, and clay deposits.





Figure 9-23 A steep-sided canyon occurs along a meander on the Escalante River in Glen Canyon National Recreation Area in Utah.

REJUVENATION

During the process of stream formation, downcutting, or the wearing away of the streambed, is a major erosional process until the stream reaches its base level, when downcutting stops. However, if the land over which the stream is flowing uplifts or if the base level lowers, the stream undergoes rejuvenation. *Rejuvenation* means “to make young again.” During **rejuvenation**, the stream actively resumes the process of downcutting toward its base level. This causes an increase in the stream’s rate of flow, and the stream’s channel once again becomes V-shaped. If rejuvenation occurs in an area where there are meanders, deep sided canyons are formed. This effect is evident in Utah’s Escalante River, shown in *Figure 9-23*.

SECTION ASSESSMENT

1. Describe the formation of an oxbow lake.
2. Compare the rate of water flow on the inside of a meander curve with that on the outside of the curve.
3. Describe four changes that a stream undergoes as it works its way toward the ocean.
4. What are the differences between an alluvial fan and a delta?
5. **Thinking Critically** How does the type of bedrock over which a stream flows affect

the time it takes for the stream to reach its base level?

SKILL REVIEW

6. **Making Graphs** Make a line graph that plots the direction of change in a hypothetical stream’s rate of flow at the stream’s headwaters, at midstream, and at its mouth. For more help, refer to the *Skill Handbook*.



Lakes and Freshwater Wetlands

OBJECTIVES

- **Explain** the formation of freshwater lakes and wetlands.
- **Describe** the process of eutrophication.
- **Recognize** the effects of human activity on lake development.

VOCABULARY

lake
eutrophication
wetland

You have probably swum in, fished in, or gazed at the beauty of a lake. But, did you ever think about how lakes form? A **lake** is a depression in the surface materials of a landscape that collects and holds water. As shown in the *MiniLab* on the following page, surface materials determine where a lake can form. Lakes sometimes accumulate water from streams and runoff that flow into them. Lakes also receive water from local precipitation, springs, and other sources. Most lakes have outlets from which water flows to rivers and to the ocean. People sometimes build small lakes called ponds to serve as sources of water for livestock, to maintain fish supplies, to attract wildlife, or for their natural beauty. Reservoirs are lakes made for the primary purpose of storing water for a community's use.

ORIGINS OF LAKES

Natural lakes form in different ways in surface depressions and in low areas. As you have learned, oxbow lakes form when streams cut off meanders and leave isolated channels of water. Lakes can also form when stream flow becomes blocked by sediment from landslides. Other lakes, such as Utah's Great Salt Lake, shown in **Figure 9-24**, are remnants of prehistoric lakes that have receded to lower-lying areas.

Still other lakes have glacial origins, as you learned in Chapter 8. The basins of these lakes formed as glaciers gouged out the land during the ice ages. Most of the lakes in Europe and North America are in recently glaciated areas. Glacial moraines originally dammed some of these depressions and restricted the outward flow of water. The lakes that formed as a result are known as moraine-dammed lakes, shown in **Figure 9-25**. In another process, cirques carved high in the mountains by valley glaciers filled with water to form cirque lakes. Other lakes

Figure 9-24 The Great Salt Lake in northern Utah has a much greater salinity than the oceans.



formed as blocks of ice left on the outwash plain ahead of melting glaciers eventually melted and left depressions called kettles. When these depressions filled with water, they formed kettle lakes.

Many lakes are found in areas where limestone is the dominant bedrock. As groundwater percolating through limestone bedrock slowly dissolves calcium carbonate, it leaves holes in the limestone and forms caverns. In some places, the ceilings of these caverns become so thin and weak that they collapse, which leaves depressions that may fill with water in time.

LAKES UNDERGO CHANGE

Water from precipitation, runoff, and underground sources can maintain a lake's water supply. Some lakes contain water only during times of heavy rain or excessive runoff from spring thaws. A depression that receives more water than it loses to evaporation or use by humans will exist as a lake for a long period of time. However, lakes are temporary water-holding areas; over hundreds of thousands of years, lakes usually fill in with sediment and become part of a new landscape.



Eutrophication Through the process of photosynthesis, plants add oxygen and waste products to lake water. Animals that live in a lake use the water's oxygen and add waste products to the water as they conduct their life processes. The decay process that occurs after plants and animals die also uses up dissolved oxygen supplies. The amount of dissolved oxygen helps determine the quality of lake water and its ability to support life.

Figure 9-25 The moraine-dammed lakes in Banff National Park in Alberta, Canada were formed from glacial activity.

MiniLab

Surface materials determine where a lake can form.

Model how different Earth materials may allow lakes to form. Lakes form when depressions or low areas fill with water.

Procedure   **CAUTION:** Always wear safety goggles and an apron in the lab.

1. Use three clear, plastic shoe boxes. Half fill each one with Earth materials: clay, sand, and gravel.
2. Slightly compress the material in each shoe box. Then make a shallow depression in each surface.
3. Slowly pour 500 mL of water into each of the depressions.

Analyze and Conclude

1. Describe what happened to the 500 mL of water that was added to each shoe box.
2. How is this activity similar to what actually happens on Earth's surface when a lake forms?
3. What can you infer about the Earth materials in which lakes most commonly form?

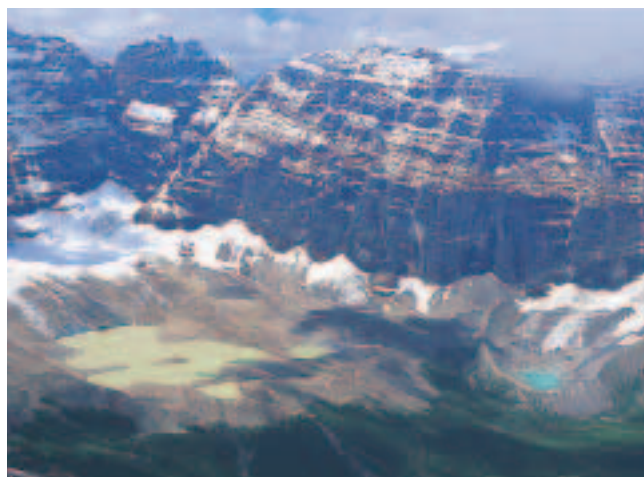




Figure 9-26 The aquatic species of this pond will change over the years because of the effects of eutrophication.

The process by which lakes become rich in nutrients from the surrounding watershed, thereby resulting in a change in the kinds of organisms in the lake, is called **eutrophication**. **Figure 9-26** shows a pond undergoing eutrophication. Although eutrophication is a natural process, it can be sped up with the addition of nutrients, such as fertilizers, that contain nitrogen and phosphorus. When this happens, the animal and plant communities in the lake can change rapidly. Algae growing in the water may suddenly multiply very quickly. The excessive algae growth in a lake or pond appears as green scum. Other organisms that eat the algae can multiply in numbers as well. The resulting overpopulation and decay of a large number of plants and animals depletes the water's oxygen supply. Fish and other sensitive organisms may die as a result of the lack of oxygen in the water.

Other major sources of nutrients that concentrate in lakes are animal wastes and phosphate detergents. Lakes can also suffer from the release of toxins from nearby industries and untreated sewage, as shown in the *Science & the Environment* feature at the end of the chapter.

Freshwater Wetlands A **wetland** is a land area that is covered with water for a large part of the year. Wetlands include environments commonly known as bogs, marshes, and swamps. They have certain soil types and support specific plant species.

A bog, shown in **Figure 9-27**, is an interesting wetland that deserves a closer look. Bogs are not stream-fed, but instead receive their water from precipitation. The waterlogged soil tends to be rich in *Sphagnum*, also called peat moss. The breakdown of peat moss produces acids, thereby contributing to the soil's acidity. The waterlogged, acidic soil supports unusual plant species, including insect-eating pitcher plants, sundew, and Venus' flytrap.



Figure 9-27 This bog in Norway has acid-rich soil that supports a variety of organisms.



Freshwater marshes frequently form along the mouths of streams and in areas with extensive deltas. The constant supply of water allows for the lush growth of marsh grasses. The shallow roots of the grasses anchor deposits of silt and mud on the delta, thereby slowing the water and expanding the marsh area. Grasses, reeds, sedges, and rushes, along with abundant wildlife, are common in marsh areas.

Swamps are low-lying areas often located near streams. Swamps may develop from marshes that have filled in sufficiently to support the growth of shrubs and trees. As these larger plants grow and begin to shade the marsh plants, the marsh plants die. Swamps that existed 250 million years ago developed into present-day coal reserves that are common in Pennsylvania and many other locations in the United States and around the world.

Wetlands play a valuable role in improving water quality. They serve as a filtering system that traps pollutants, sediments, and pathogenic bacteria contained in water sources. Wetlands also provide vital habitats for migratory waterbirds and homes for an abundance of other wildlife, as shown in **Figure 9-28**. Unfortunately, people's desire for land often conflicts with the need to preserve wetlands. In the past, it was common for wetland areas to be filled in to create more land on which to build. Government data reveal that from the late 1700s to the mid-1980s, the continental United States lost 50 percent of its wetlands. By 1985, it was estimated that 50 percent of the wetlands in Europe were drained. Now, however, the preservation of wetland areas has become a global concern.



Figure 9-28 The wetlands in Bosque del Apache National Wildlife Refuge in New Mexico are home to migrating snow geese.

SECTION ASSESSMENT

1. Describe the process of eutrophication.
2. What human activities affect the process of eutrophication?
3. What conditions are necessary for the formation of a natural lake?
4. **Thinking Critically** Describe a situation in which protection of wetlands may conflict with human plans for land use.

SKILL REVIEW

5. **Making Tables** Design a data table that compares the various types of lakes, their origins, and their characteristics. For more help, refer to the *Skill Handbook*.

Modeling Stream Velocity and Slope

Water in streams flows from areas of higher elevation to areas of lower elevation. The rate of stream flow varies from one stream to another and also in different areas of the same stream.

Preparation

Problem

Determine how slope may affect stream-flow velocity.

Materials

1-m length of vinyl gutter pipe
ring stand and clamp
water source with long hose
protractor with plumb bob
sink or container to catch water
stopwatch
grease pencil
meterstick
paper
hole punch

Objectives

In this GeoLab, you will:

- **Measure** the time it takes for water to flow down a channel at different slopes and depths.
- **Organize** your data in a table.
- **Plot** the data on a graph to show how stream velocity is directly proportional to the stream channel's slope and depth.
- **Describe** the relationship between slope and rate of stream flow.

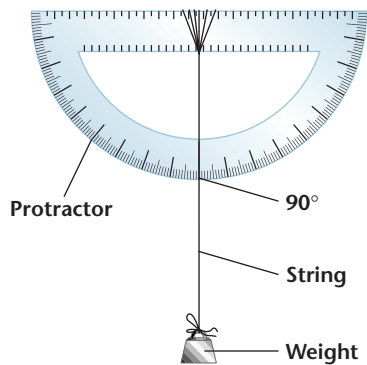
Safety Precautions

Always wear safety goggles in the lab.



Procedure

1. Use the hole punch to make 10 to 15 paper circles to be used as floating markers.
2. Use the illustration below as a guide to set up the protractor with the plumb bob.



3. Use the grease pencil to mark two lines across the inside of the gutter pipe at a distance of 40 cm apart.
4. Use the ring stand and clamp to hold the gutter pipe at an angle of 10° . Place the end of the pipe in a sink or basin to collect the discharged flow of water.
5. Attach a long hose to a water faucet in the sink.
6. Keep the hose in the sink until you are ready to use it. Then turn on the water and adjust the flow until the water is moving quickly enough to provide a steady flow.
7. Bend the hose temporarily to block the water flow until the hose is positioned at least 5 cm above the top line marked on the pipe.
8. Keep the water moving at the same rate of flow for all slope angles being investigated.
9. Drop a floating marker approximately 4 cm above the top line on the pipe and into the flowing water. Measure the time it takes for the floating marker to move from the top line to the bottom line. Record the time in your science journal.
10. Repeat step 9 two more times.
11. Repeat steps 9 and 10 but change the slope to 20° , then 30° , and then 40° .
12. Make a line graph of the average stream-flow velocity.

Analyze

1. Why is it important to keep the water flow constant in this activity?
2. Which variables had to be controlled to avoid errors in your data?
3. Using your graph, predict the velocity of water flow for a 35° slope.

Conclude & Apply

1. What is the relationship between the rate of water flow and the angle of the slope?
2. Describe one reason why a stream's slope might change.
3. Where would you expect to find streams with the highest water-flow velocity?

Science & the Environment



The Jewel of Siberia

Pollution is threatening the ecosystems of Lake Baikal, the oldest, largest, and deepest freshwater lake on Earth. What is causing the problems? Are there any solutions for saving the lake?

A Natural Paradise

Known as the “Jewel of Siberia,” Lake Baikal is the oldest and largest freshwater lake on Earth. Estimated to be 25 million years old, Lake Baikal contains 20% of Earth’s unfrozen freshwater, that is, one-fifth of the world’s fresh surface water. The lake contains approximately 80% of the former Soviet Union’s freshwater supply and covers approximately 31 500 km². It reaches a maximum depth of approximately 1637 m making it the deepest lake in the world.

Fed by 330 tributaries, and surrounded by forests and mountain ranges, it is home to a wide variety of plant and animal species. The area is home to everything from microscopic organisms to large mammals including elk, moose, deer, and the brown bear.

One animal found only in this area is the Nerpa or Baikal seal. The Nerpa is the only known species of freshwater seal. It is believed that the seal may have migrated to the area in search of food while the lake was being formed thousands of years ago.

Threatened

Pollution has begun to slowly take its toll on animal and plant species in the region. Studies have reported that the fish population is dying out and thousands of the Baikal seals have died. High toxin levels from a nearby pulp and paper factory may be the cause. According to other

studies, DDT and other pesticides have entered the waters via aerial spraying, and have been found in the lake’s sediment.

Attempts to restrict the release of toxins into the freshwater lake have failed due to concern over the loss of industry and jobs. For example, if a lakeside pulp and paper factory were forced to close, many people would be left unemployed.

Many organizations have banded together in Russia to attempt to preserve the Lake Baikal area. There is even cooperation between groups in the United States and Russia who have been working together to come up with solutions to the problems facing the industry and the environment. Their activities range from efforts to save the Baikal seal to promoting tourism as a more attractive form of economic stability in the area.

Activity

Form small groups to research and discuss possible solutions to the problems threatening the ecosystems of Lake Baikal. How can the lake and its inhabitants be preserved without having to totally remove industry from the area? Visit the Earth Science Web Site at earthgeu.com to learn more about the struggle to save Lake Baikal and its many inhabitants.



CHAPTER 9 Study Guide

Summary

SECTION 9.1

Surface Water Movement



Main Ideas

- Water on Earth may follow a variety of pathways as it is recycled through the processes of evaporation and condensation.
- Infiltration of water into the ground depends on the number of open pores or spaces in Earth materials and on the presence of unsaturated pores in the ground.
- All the land area that drains into a stream system is the system's watershed, or drainage basin. Elevated land areas called divides separate one watershed from another.
- A stream's load is all the material the stream carries, including material in solution, in suspension, and as bed load.
- A floodplain is a broad, flat area that extends out from a stream's bank during times of flooding.
- Flooding occurs in small, localized areas as upstream floods or in large, downstream floods. Damage from flooding can be devastating.

Vocabulary

bed load (p. 217)
discharge (p. 218)
divide (p. 215)
flood (p. 219)
floodplain (p. 219)
runoff (p. 212)
solution (p. 215)
suspension (p. 216)
watershed (p. 215)

SECTION 9.2

Stream Development



Main Ideas

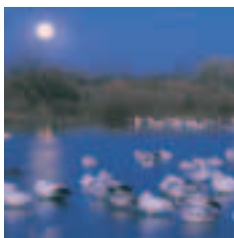
- Water from precipitation gathers in gullies at a stream's source area, or headwaters. The stream's water flows in channels confined by the stream's banks.
- Alluvial fans and deltas form when stream velocity decreases and sediment is deposited. Alluvial fans are fan shaped, and they form where water flows down steep slopes onto flat plains. Deltas are triangular, and they form when streams enter large, relatively quiet bodies of water.

Vocabulary

delta (p. 226)
meander (p. 224)
rejuvenation (p. 227)
stream bank (p. 222)
stream channel (p. 222)

SECTION 9.3

Lakes and Freshwater Wetlands



Main Ideas

- Lakes form in a variety of ways when depressions on land fill with water. Lakes may be natural or human-made.
- Eutrophication is a natural nutrient enrichment process that may be sped up when nutrients from fertilizers, detergents, or sewage are added.
- Wetlands are low-lying areas that are periodically saturated with water and support specific plant species. Wetlands include bogs, marshes, and swamps.

Vocabulary

eutrophication (p. 230)
lake (p. 228)
wetland (p. 230)



CHAPTER 9 Assessment

Understanding Main Ideas

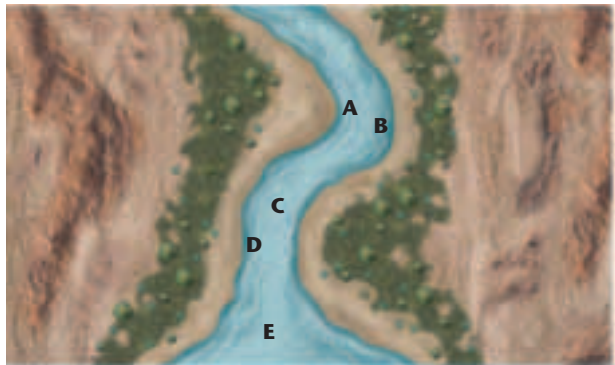
- Which factor least affects the rate of runoff?
 - slope
 - vegetation
 - volume of runoff
 - nearness to water
- What areas are most likely to contain fertile soils?
 - watersheds
 - dried-up streambeds
 - floodplains
 - mountainous areas
- Which substance is most likely to be carried by a stream in solution?
 - quartz
 - sand
 - calcite
 - silt
- What material plays a major role in the eutrophication of lakes?
 - iron
 - phosphate
 - ozone
 - salt
- During the process of eutrophication, what happens to the oxygen present in a lake?
 - It increases.
 - It decreases.
 - It stays the same.
 - It evaporates.
- What kind of streams form V-shaped valleys?
 - streams that are first forming
 - streams that carry much sediment
 - streams that move slowly
 - streams that have meanders
- Where does water move most rapidly in the straight length of a stream?
 - along the bottom
 - along the sides
 - near the surface
 - in the center
- If a stream is carrying sand, silt, clay, and small pebbles, which one is deposited last as the stream begins to slow down?
 - clay
 - silt
 - sand
 - small pebbles

- Where do alluvial fans form?
 - on the outside of meanders
 - where streams enter the ocean
 - near lakes
 - along the bases of mountains

Applying Main Ideas

- In what ways are a delta and an alluvial fan similar, and in what ways are they different?
- Why is it important to preserve wetlands?
- What means do governments use to try to prevent the loss of life and property in flood-prone areas?

Use the following aerial view of a stream to answer questions 13–15.



Test-Taking Tip

BEAT THE CLOCK—AND THEN GO BACK

As you take a practice test, pace yourself to finish each section just a few minutes early so you can go back and check over your work. You will sometimes find a mistake or two.

CHAPTER 9 Assessment

- At which location in the aerial view does the stream's water have the greatest velocity?
- At which location is deposition most actively occurring?
- At which location is erosion most actively occurring?
- What is the discharge of a stream that has a velocity of 300 m/s and is 25-m wide and 3-m deep?

Thinking Critically

- Why is a lake with a clay bottom able to hold more water than a lake with a sand bottom?
- One morning, there was a torrential thunderstorm. In the afternoon, the skies cleared and a gardener decided to plant a tree. After digging in the ground only a short distance down, the gardener found that the ground was very dry. How could the ground be dry despite the heavy rains earlier in the day?
- If floodplains are such hazardous areas to live in, why have so many people settled in these potential flood zones?
- Use the following terms to construct a concept map to organize the major ideas in Section 9.1. For more help, refer to the *Skill Handbook*.

solution

silt

parts per million

suspension

bed load

clay

cobbles

dissolved minerals

pebbles

Standardized Test Practice

- Which condition would create the most runoff?
 - land covered with vegetation
 - plants in densely packed soil
 - light precipitation
 - soil with a high percentage of sand
- In which part of a meander does the water travel the fastest?
 - the water that moves along the inside curve of the meander
 - the water that moves along the bottom of the meander
 - the water that moves along the outside curve of a meander
 - all water flows at the same rate
- Which of the following is NOT a value of wetlands?
 - feeding lakes and deltas with nutrient- and oxygen-rich water
 - filtering water by trapping pollutants, sediments, and pathogenic bacteria
 - providing habitats for migratory birds and other wildlife
 - preserving fossils due to the anaerobic and acidic conditions
- As the velocity of a stream decreases, which transported particle size would settle to the stream's bottom first?
 - clay
 - silt
 - pebble
 - sand
- Which condition helps determine the quality of lake water?
 - the amount of nitrogen
 - the amount of dissolved calcium carbonate
 - the amount of potassium
 - the amount of dissolved oxygen

