Water on Earth

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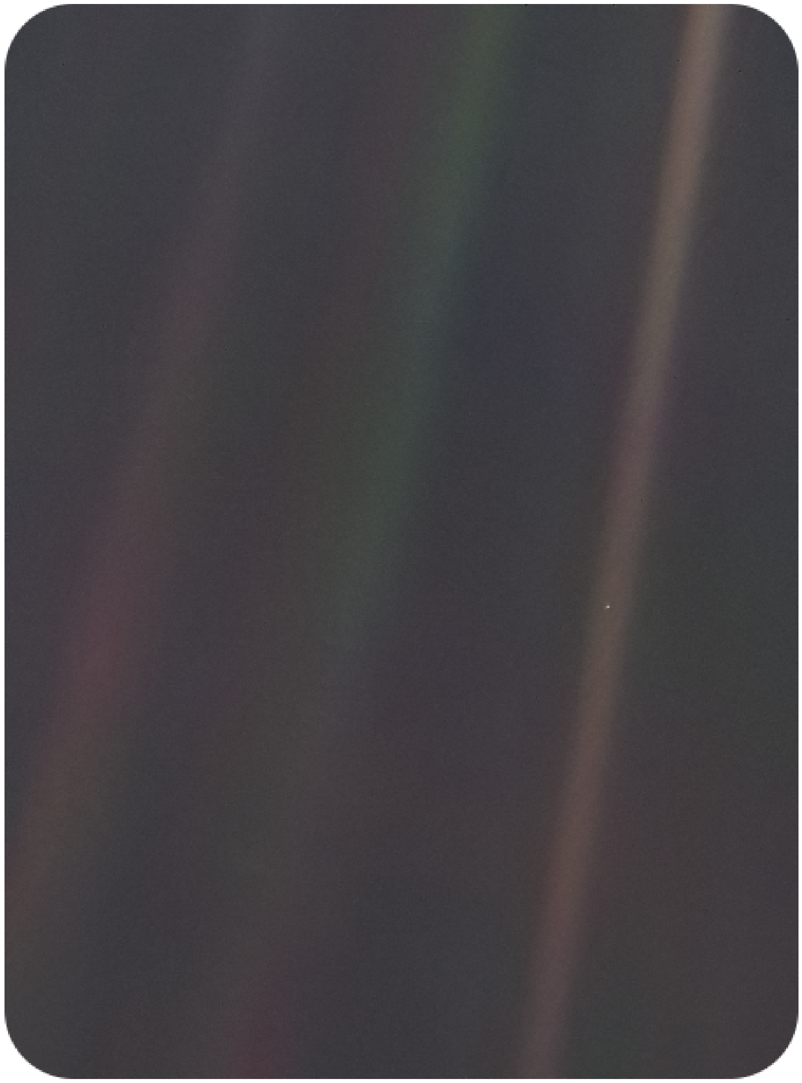
CHAPTER 1 Water on Earth

CHAPTER OUTLINE

Introduction



Pale Blue Dot.

"From this distant vantage point, the Earth might not seem of any particular interest. But for us, it's different. Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every 'superstar,' every 'supreme leader,' every saint and sinner in the history of our species lived there –on a mote of dust suspended in a sunbeam." —Carl Sagan, *Pale Blue Dot: A Vision of the Human Future in Space*, p. 6

1.1 Distribution of Water on Earth

- Describe the distribution of Earth's water.
- Explain why fresh water is a scarce resource.

Water, water everywhere. But how much of it is useful?

Earth is the water planet. From space, Earth is a blue ball, unlike any of the other planets in our solar system. Life, also unique to Earth of the planets in our solar system, depends on this water. While there's a lot of salt water, a surprisingly small amount of it is fresh water.

Distribution of Water

Earth's oceans contain 97% of the planet's water. That leaves just 3% as fresh water, water with low concentrations of salts (**Figure** 1.1). Most fresh water is trapped as ice in the vast glaciers and ice sheets of Greenland and Antarctica.

How is the 3% of fresh water divided into different reservoirs? How much of that water is useful for living creatures? How much for people?

A storage location for water such as an ocean, glacier, pond, or even the atmosphere is known as a **reservoir**. A water molecule may pass through a reservoir very quickly or may remain for much longer. The amount of time a molecule stays in a reservoir is known as its **residence time**.

Summary

- Of Earth's water, 97% is in the oceans.
- Of the remaining 3%, much is trapped in ice and glaciers.
- A substance is stored in a reservoir and the amount of time it stays in that reservoir is its residence time.

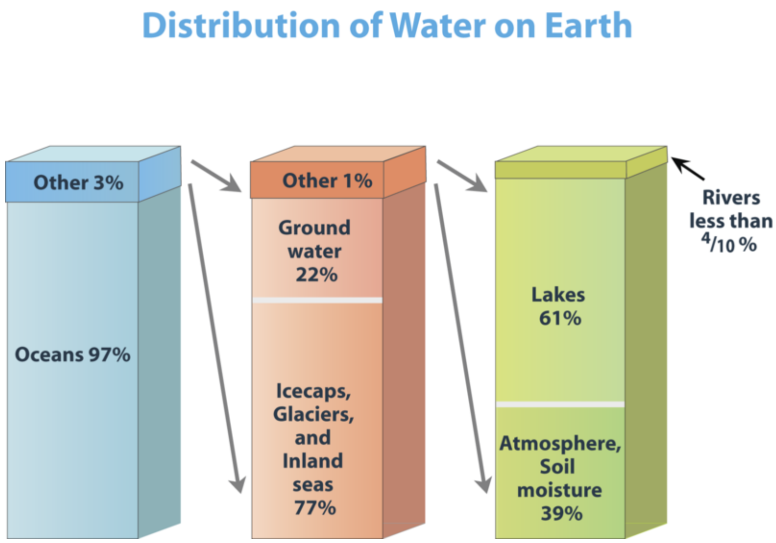


FIGURE 1.1
The distribution of Earth's water.

Explore More

Use the resource below to answer the questions that follow.

- **Where is the Fresh Water?** at http://ga.water.usgs.gov/edu/earthwherewater.html

1. How much of the Earth's water is ocean water?
2. How much freshwater is in glaciers?
3. How much freshwater is groundwater?
4. How much freshwater is in surface water and how much surface water is in lakes?
5. What is that tiny 3rd ball over Georgia?

Explore More Answers

1. 96.5%
2. 68.7%
3. 30.1%
4. 1.5% in surface water and 20.9% of that is in lakes
5. That is the amount of water in all freshwater lakes and rivers.

Review

1. If Earth is the water planet, why is water sometimes a scarce resource?
2. What are the reservoirs for water?
3. In which reservoirs does water have the longest residence times? The shortest?

Review Answers

1. Much of Earth's water is saline and much that is fresh water is frozen into ice. Since this water is not usable, the amount that is usable isn't always enough or it isn't always in the right places.
2. The ocean, glaciers, the atmosphere, lakes - everywhere water stays a while.

3. The oceans have a long residence time but glaciers may be longer.

1.2 States of Water

- Define polar molecule.
- Describe the water molecule.
- Identify the three states of water.

H - two - O. Why is something so simple so important?

Water is the most important substance on Earth. Think about all the things you use water for? If your water access were restricted what would you miss about it?

The Water Molecule

Water is simply two atoms of hydrogen and one atom of oxygen bonded together (**Figure** 1.2). The hydrogen ions are on one side of the oxygen ion, making water a **polar molecule**. This means that one side, the side with the hydrogen ions, has a slightly positive electrical charge. The other side, the side without the hydrogen ions, has a slightly negative charge.

Despite its simplicity, water has remarkable properties. Water expands when it freezes, has high surface tension (because of the polar nature of the molecules, they tend to stick together), and others. Without water, life might not be able to exist on Earth and it certainly would not have the tremendous complexity and diversity that we see.

Three States of Matter

Water is the only substance on Earth that is present in all three states of matter –as a solid, liquid or gas. (And Earth is the only planet where water is present in all three states.) Because of the ranges in temperature in specific locations around the planet, all three phases may be present in a single location or in a region. The three phases are solid (ice or snow), liquid (water), and gas (**water vapor**). See ice, water, and clouds (**Figure** 1.3).

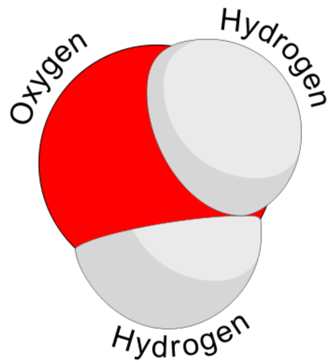


FIGURE 1.2
A water molecule. The hydrogen atoms have a slightly positive charge, and the oxygen atom has a slightly negative charge.

FIGURE 1.3
(a) Ice floating in the sea. Can you find all three phases of water in this image? (b) Liquid water. (c) Water vapor is invisible, but clouds that form when water vapor condenses are not.

Summary

- Water is a polar molecule with a more positive charge on one side and a more negative charge on the other side.
- Water is the only substance on Earth that is stable in all three states.
- Earth is the only planet in the Solar System that has water in all three states.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=HVT3Y3_gHGg Watch to 5:50.

1. What is the only substance that occurs naturally on Earth in all three states of matter?
2. Why do scientists look for water in other places in the solar system?
3. Describe the bond that keeps the water molecule together.
4. What does it mean to say that the water molecule is polar?
5. What are hydrogen bonds?
6. Why does water form a droplet if it is placed on waxed paper or teflon?
7. Why does water experience adhesion rather than cohesion with glass?

8. What causes water in a straw to rise higher than the surface level of the water in the beaker the tube is in?
9. Why is water such a great solvent?
10. Why doesn't oil mix with water?

Explore More Answers

1. water
2. Water is thought to be needed for life.
3. This is a covalent bond with each of the hydrogen ions sharing an electron with the oxygen ion.
4. The side with the oxygen has a slight negative charge and the side with the two hydrogen ions has a slight positive charge.
5. The positive pole of one water molecule is attracted to the negative pole of another and so on.
6. High cohesion causes each water molecule to be attracted to other water molecules more than they are attracted to the surface so the water forms a ball (or half a ball), which has the lowest surface area to volume.
7. Water attracts to the glass molecules more than it does to the other water molecules.
8. Capillary action: By adhesion water molecules are attracted to the molecules in the straw and by cohesion the water molecules in the beaker are attracted to the water molecules ones in the straw so the water climbs up the straw until gravity stops in.
9. When a polar substance gets into water the water molecule bonds to the substance rather than to itself.
10. Oil is not polar and can't overcome the strong cohesive properties of water. They are hydrophobic.

Review

1. What is a polar molecule?
2. What makes water a polar molecule?
3. What are the three states that a substance can have?
4. Where in the solar system is water found in all three states?

Review Answers

1. A polar molecule has a slight positive charge on one side and a slight negative charge on the other.
2. Water is polar because the hydrogen ions are on one side so that one side is positive and the oxygen is on the other side so it is negative.
3. Solid, liquid and gas
4. Just on Earth

1.3 Processes of the Water Cycle

- Describe the water cycle and describe the processes that carry water between reservoirs.
- Define the processes by which water changes state and explain the role each plays in the water cycle.

Where have these water molecules been?

Because of the unique properties of water, water molecules can cycle through almost anywhere on Earth. The water molecule found in your glass of water today could have erupted from a volcano early in Earth's history. In the intervening billions of years, the molecule probably spent time in a glacier or far below the ground. The molecule surely was high up in the atmosphere and maybe deep in the belly of a dinosaur. Where will that water molecule go next?

The Water Cycle

The movement of water around Earth's surface is the **hydrological (water) cycle** (**Figure** 1.4). Water inhabits reservoirs within the cycle, such as ponds, oceans, or the atmosphere. The molecules move between these reservoirs by certain processes, including condensation and precipitation. There are only so many water molecules and these molecules cycle around. If climate cools and glaciers and ice caps grow, there is less water for the oceans and sea level will fall. The reverse can also happen.

The following section looks at the reservoirs and the processes that move water between them.

Solar Energy

The Sun, many millions of kilometers away, provides the energy that drives the water cycle. Our nearest star directly impacts the water cycle by supplying the energy needed for evaporation.

Oceans

Most of Earth's water is stored in the oceans, where it can remain for hundreds or thousands of years.

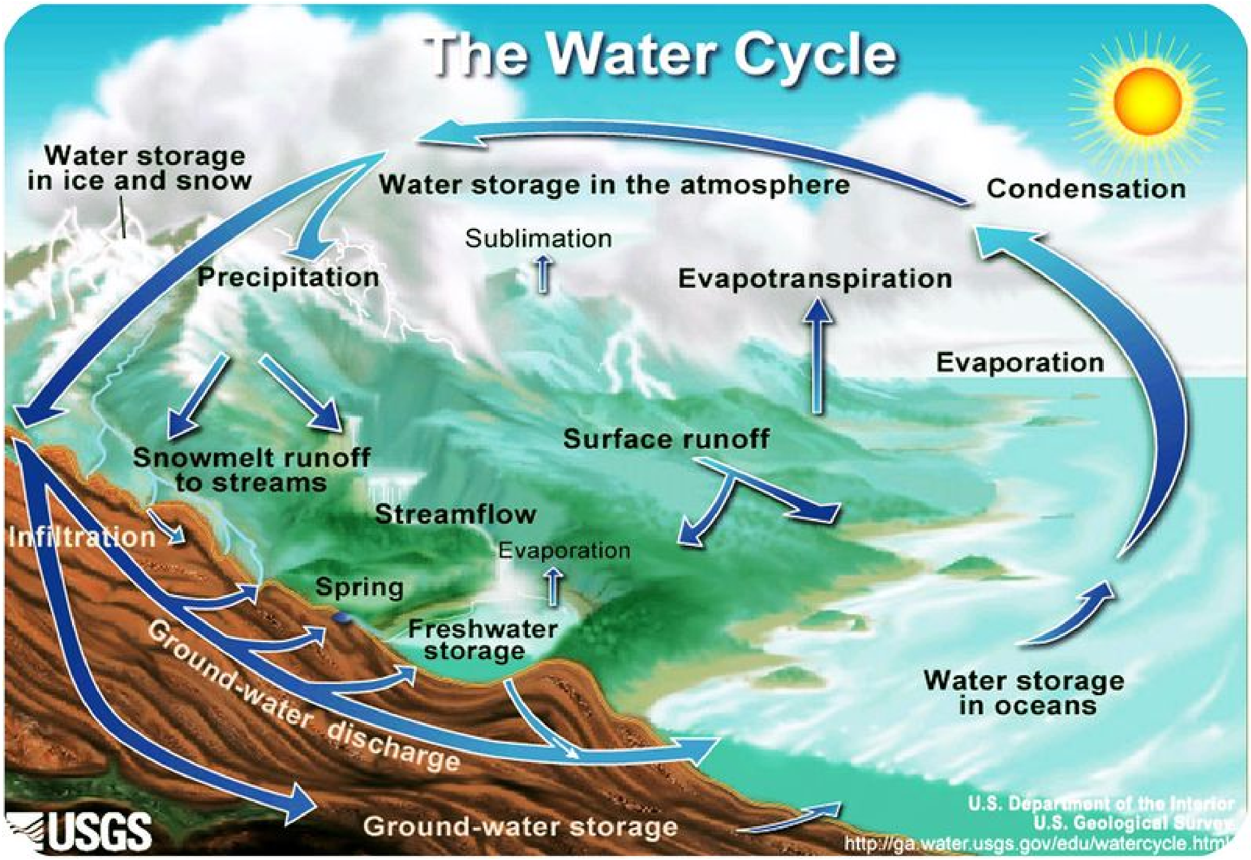


FIGURE 1.4

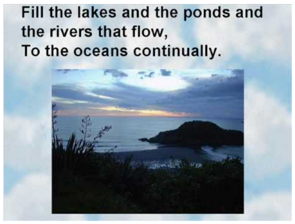
Because it is a cycle, the water cycle has no beginning and no end.

Atmosphere

Water changes from a liquid to a gas by **evaporation** to become water vapor. The Sun's energy can evaporate water from the ocean surface or from lakes, streams, or puddles on land. Only the water molecules evaporate; the salts remain in the ocean or a fresh water reservoir.

The water vapor remains in the atmosphere until it undergoes **condensation** to become tiny droplets of liquid. The droplets gather in clouds, which are blown about the globe by wind. As the water droplets in the clouds collide and grow, they fall from the sky as precipitation. **Precipitation** can be rain, sleet, hail, or snow. Sometimes precipitation falls back into the ocean and sometimes it falls onto the land surface.

For a little fun, watch this video. This water cycle song focuses on the role of the Sun in moving H_2O from one reservoir to another. The movement of all sorts of matter between reservoirs depends on Earth's internal or external sources of energy: http://www.youtube.com/watch?v=Zx_1g5pGFLI (2:38).



MEDIA

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URL: http://gamma.ck12.org/flx/render/embeddedobject/1623

This animation shows the annual cycle of monthly mean precipitation around the world: http://en.wikipedia.org/wiki/File:MeanMonthlyP.gif .

Streams and Lakes

When water falls from the sky as rain it may enter streams and rivers that flow downward to oceans and lakes. Water that falls as snow may sit on a mountain for several months. Snow may become part of the ice in a glacier, where it may remain for hundreds or thousands of years. Snow and ice may go directly back into the air by sublimation, the process in which a solid changes directly into a gas without first becoming a liquid. Although you probably have not seen water vapor undergoing **sublimation** from a glacier, you may have seen dry ice sublimate in air.

Snow and ice slowly melt over time to become liquid water, which provides a steady flow of fresh water to streams, rivers, and lakes below. A water droplet falling as rain could also become part of a stream or a lake. At the surface, the water may eventually evaporate and reenter the atmosphere.

Soil

A significant amount of water infiltrates into the ground. Soil moisture is an important reservoir for water (**Figure** 1.5). Water trapped in soil is important for plants to grow.

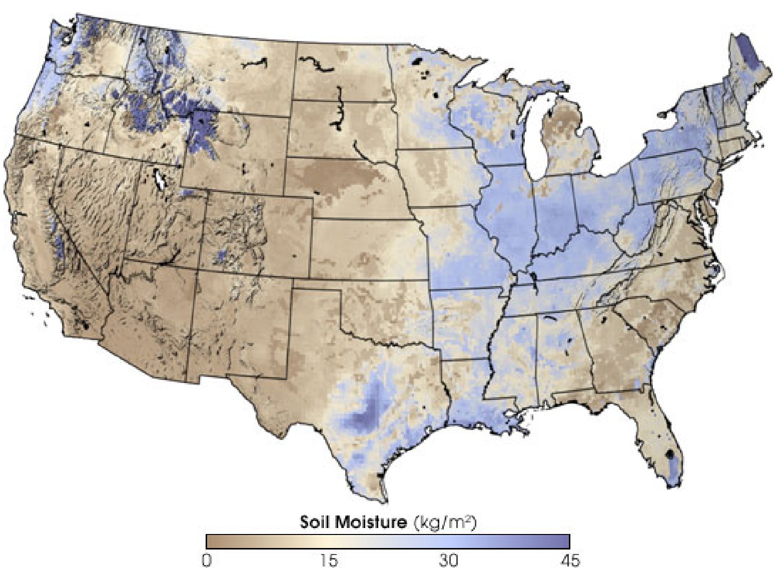

FIGURE 1.5

The moisture content of soil in the United States varies greatly.

Groundwater

Water may seep through dirt and rock below the soil and then through pores infiltrating the ground to go into Earth's groundwater system. Groundwater enters aquifers that may store fresh water for centuries. Alternatively, the water may come to the surface through springs or find its way back to the oceans.

Biosphere

Plants and animals depend on water to live. They also play a role in the water cycle. Plants take up water from the soil and release large amounts of water vapor into the air through their leaves (**Figure** 1.6), a process known as **transpiration**.

An online guide to the hydrologic cycle from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/hyd/home.rxml .

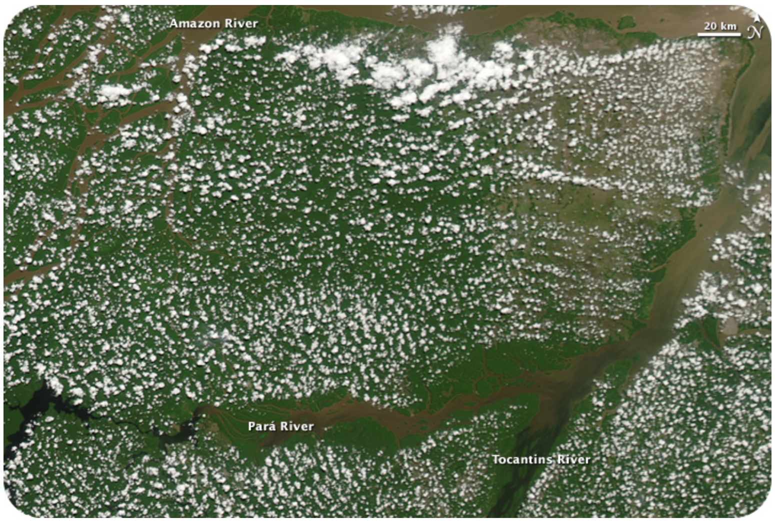

FIGURE 1.6
Clouds form above the Amazon Rainforest even in the dry season because of moisture from plant transpiration.

How the water cycle works and how rising global temperatures will affect the water cycle, especially in California, are the topics of this Quest video.

Watch it at http://www.kqed.org/quest/television/tracking-raindrops/.

MEDIA
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Human Uses

People also depend on water as a natural resource. Not content to get water directly from streams or ponds, humans create canals, aqueducts, dams, and wells to collect water and direct it to where they want it (**Figure** 1.7).

Summary

- The water cycle describes all of the reservoirs of water and the processes that carry it between them.
- Water changes state by evaporation, condensation, and sublimation.
- Plants release water through their leaves by transpiration.

FIGURE 1.7
Pont du Gard in France is an ancient aqueduct and bridge that was part of of a well-developed system that supplied water around the Roman empire.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=8NwS86wtmlM

1. How often is water added to the Earth system?
2. How can the two parts of the water cycle be summarized?
3. What are the major reservoirs for water?
4. What is precipitation?
5. Where does snow melt go?
6. As rain falls onto land, what can happen to it?
7. How long does water stay in groundwater?
8. How does water get back into the atmosphere?
9. How do plants engage in transpiration?

Explore More Answers

1. Never; the water that we have is the water we have always had.
2. flows and stores or storages
3. the atmosphere, oceans, ice sheets glaciers, snow packs, lakes, rivers steams, reservoirs and watersheds, wetlands, soil, plants and trees, groundwater
4. It is the process of water falling onto the Earth: rain, snow, hail.
5. Snow melt enters surface runoff, like streams and rivers.
6. It might enter surface runoff, might be intercepted by vegetation, it might enter the ground by infiltration.
7. Some stays a very long time, thousands to millions of years.
8. It evaporates into the atmosphere.
9. Water is taken up by plant roots; it travels up the stems and leaves and then transpires through the leaves.

Review

1. What is transpiration?
2. Describe when and how sublimation occurs.

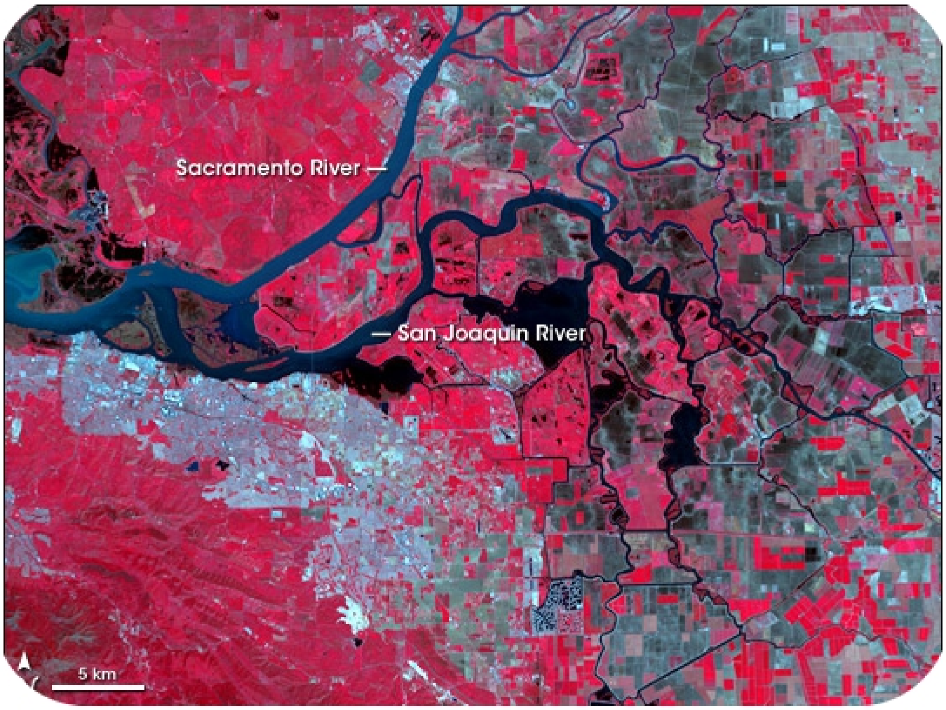
3. What is the role of the major reservoirs in the water cycle?

Review Answers

1. Transpiration is when plants release water vapor through their leaves.
2. Sublimation is when water goes from snow and ice, the solid form, into the atmosphere, the gas form, without going through the liquid form first.
3. The major reservoirs are ponds lakes, glaciers, oceans, atmosphere

1.4 Streams and Rivers

- Define stream and describe its parts and stages.



Do you see the Sacramento and San Joaquin Rivers?

The farmland in the Central Valley of California is among the most productive in the world. Besides good soil and a mild climate, the region has a lot of water. Streams drain off of the Sierra Nevada mountains to the east and join the mighty Sacramento and San Joaquin Rivers in the Central Valley. How many of the features that are discussed below can you find in this image?

Streams

Streams are bodies of water that have a current; they are in constant motion. Geologists recognize many categories of streams depending on their size, depth, speed, and location. Creeks, brooks, tributaries, bayous, and rivers are all streams. In streams, water always flows downhill, but the form that downhill movement takes varies with rock type, topography, and many other factors. Stream erosion and deposition are extremely important creators and destroyers of landforms.

Rivers are the largest streams. People have used rivers since the beginning of civilization as a source of water, food, transportation, defense, power, recreation, and waste disposal.

With its high mountains, valleys and Pacific coastline, the western United States exhibits nearly all of the features common to rivers and streams. The photos below are from the western states of Montana, California and Colorado.

Parts of a Stream

A stream originates at its source. A source is likely to be in the high mountains where snows collect in winter and melt in summer, or a source might be a spring. A stream may have more than one source.

Two streams come together at a **confluence**. The smaller of the two streams is a **tributary** of the larger stream (**Figure** 1.8).

FIGURE 1.8
The confluence between the Yellowstone River and one of its tributaries, the Gardiner River, in Montana.

The point at which a stream comes into a large body of water, like an ocean or a lake, is called the **mouth**. Where the stream meets the ocean or lake is an **estuary** (**Figure** 1.9).

FIGURE 1.9
The mouth of the Klamath River creates an estuary where it flows into the Pacific Ocean in California.

The mix of fresh and salt water where a river runs into the ocean creates a diversity of environments where many different types of organisms create unique ecosystems.

Stages of Streams

As a stream flows from higher elevations, like in the mountains, towards lower elevations, like the ocean, the work of the stream changes. At a stream's **headwaters**, often high in the mountains, gradients are steep (**Figure** 1.10). The stream moves fast and does lots of work eroding the stream bed.

FIGURE 1.10
Headwaters of the Roaring Fork River in Colorado.

As a stream moves into lower areas, the gradient is not as steep. Now the stream does more work eroding the edges of its banks. Many streams develop curves in their channels called **meanders** (**Figure** 1.11).

FIGURE 1.11
The East River meanders through Crested Butte, Colorado.

As the river moves onto flatter ground, the stream erodes the outer edges of its banks to carve a **floodplain**, which is a flat, level area surrounding the stream channel (**Figure** 1.12).

Base level is where a stream meets a large body of standing water, usually the ocean, but sometimes a lake or pond. Streams work to down cut in their stream beds until they reach base level. The higher the elevation, the farther the stream is from where it will reach base level and the more cutting it has to do. The ultimate base level is sea level.

Divides

A **divide** is a topographically high area that separates a landscape into different water basins (**Figure** 1.13). Rain that falls on the north side of a ridge flows into the northern drainage basin and rain that falls on the south side flows into the southern drainage basin. On a much grander scale, entire continents have divides, known as **continental divides**.

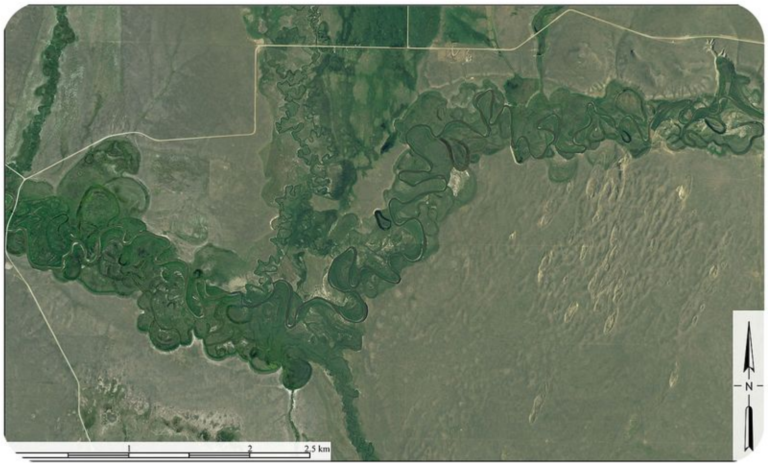


FIGURE 1.12
A green floodplain surrounds the Red Rock River as it flows through Montana.

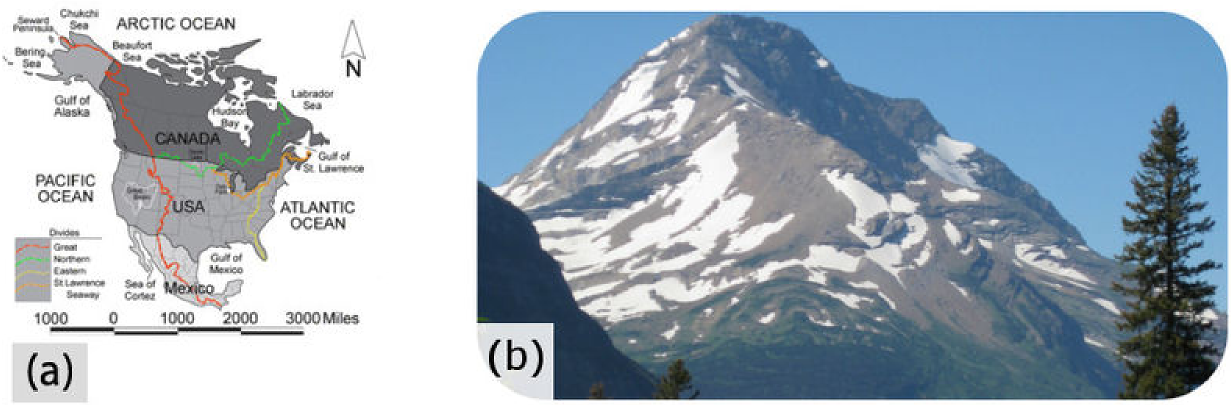


FIGURE 1.13
(a) The divides of North America. In the Rocky Mountains in Colorado, where does a raindrop falling on the western slope end up? How about on the eastern slope? (b) At Triple Divide Peak in Montana water may flow to the Pacific, the Atlantic, or Hudson Bay depending on where it falls. Can you locate where in the map of North America this peak sits?

Summary

- A moving body of water of any size is a stream.
- A tributary begins at its headwaters on one side of a divide, comes together with another tributary at a confluence, and empties out at an estuary.
- Base level is where a large body of water is located; sea level is the ultimate base level.

Explore More

Use the resources below to answer the questions that follow.

- **Streams and Rivers** at http://www.youtube.com/watch?v=TxI9gTvNY0M (3:45)

MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/1633

1. Does the geology shape the river's path or does the river's path shape the geology? Explain.
2. Where is water speed and weight the greatest? What happens there?
3. Where is the water speed the slowest? What happens there?
4. What shape is created by this fast moving water?

- **Minnesota River Sediment** at http://www.youtube.com/watch?v=FvZcDTFXguY (2:59)

MEDIA
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URL: http://gamma.ck12.org/flx/render/embeddedobject/4770

4. What has destabilized the Minnesota River area? What was the result of that?
5. Why are there waterfalls in some places and ravines in others?
6. Where does most of the sediment end up?
7. Why are some sources of sediment considered to be augmented by human activity?

Explore More Answers

1. Both. The river has to go where the geology makes it possible but the river erodes and deposits to alter the geology.
2. The water is fastest on the outer banks. The speed of the water causes the outer bank to erode.
3. The water is slowest on the inner parts of meanders. Beach sediments are deposited as the water slows there.
4. looped meanders
5. A sudden down cutting event make made the valley 150-feet down from the rest of the region.
6. Where bedrock is exposed the water falls down. Where there are glacial sediments, the water forms ravines.
7. Most of the sediment ends up in Lake Pepin.
8. Where humans disturb the soil, the sedimentation rate is higher.

Review

1. Very little land is below sea level and all of it does not drain to the sea. Why not?
2. What happens to two drops of water that fall on opposite sides of a divide?
3. What happens to a river's floodplain if the river is dammed?

Review Answers

1. Water can't flow uphill. If the water is below sea level it can't flow uphill to sea level.
2. They go to different watersheds and ultimately to different oceans.
3. There is less sediment because the sediment is trapped by the dam. There is also less flooding because the dam keeps the river enclosed. So the floodplain will not get a renewal of sediments along with their nutrients regularly.

1.5 Ponds and Lakes

- Describe the characteristics and zones of ponds and lakes.

Why is Lake Tahoe so large and clear?

Block faulting in the eastern Sierra Nevada Mountains created a basin that filled with water. This created beautiful Lake Tahoe, which straddles the California-Nevada border. The lake has been exceedingly clear though its history, although now development around the lake has resulted in some loss of clarity.

Ponds

Ponds are small bodies of fresh water that usually have no outlet; ponds are often are fed by underground springs. Like lakes, ponds are bordered by hills or low rises so the water is blocked from flowing directly downhill.

Lakes

Lakes are larger bodies of water. Lakes are usually fresh water, although the Great Salt Lake in Utah is just one exception. Water usually drains out of a lake through a river or a stream and all lakes lose water to evaporation.

Lakes form in a variety of different ways: in depressions carved by glaciers, in calderas (**Figure** 1.14), and along tectonic faults, to name a few. Subglacial lakes are even found below a frozen ice cap.

As a result of geologic history and the arrangement of land masses, most lakes are in the Northern Hemisphere. In fact, more than 60% of all the world's lakes are in Canada —most of these lakes were formed by the glaciers that covered most of Canada in the last Ice Age (**Figure** 1.15).

Lakes are not permanent features of a landscape. Some come and go with the seasons, as water levels rise and fall. Over a longer time, lakes disappear when they fill with sediments, if the springs or streams that fill them diminish,

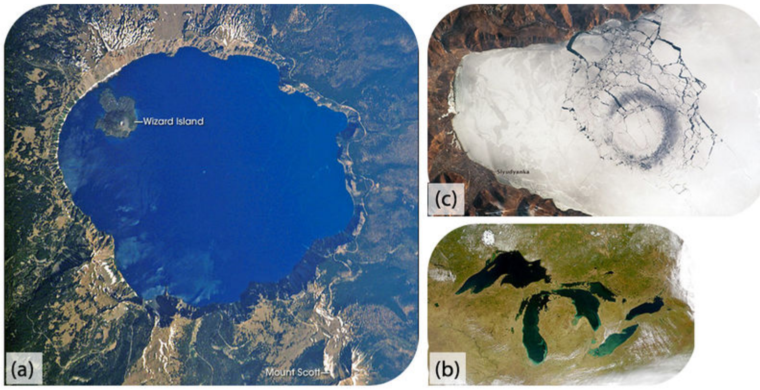


FIGURE 1.14
(a) Crater Lake in Oregon is in a volcanic caldera. Lakes can also form in volcanic craters and impact craters. (b) The Great Lakes fill depressions eroded as glaciers scraped rock out from the landscape. (c) Lake Baikal, ice coated in winter in this image, formed as water filled up a tectonic faults.

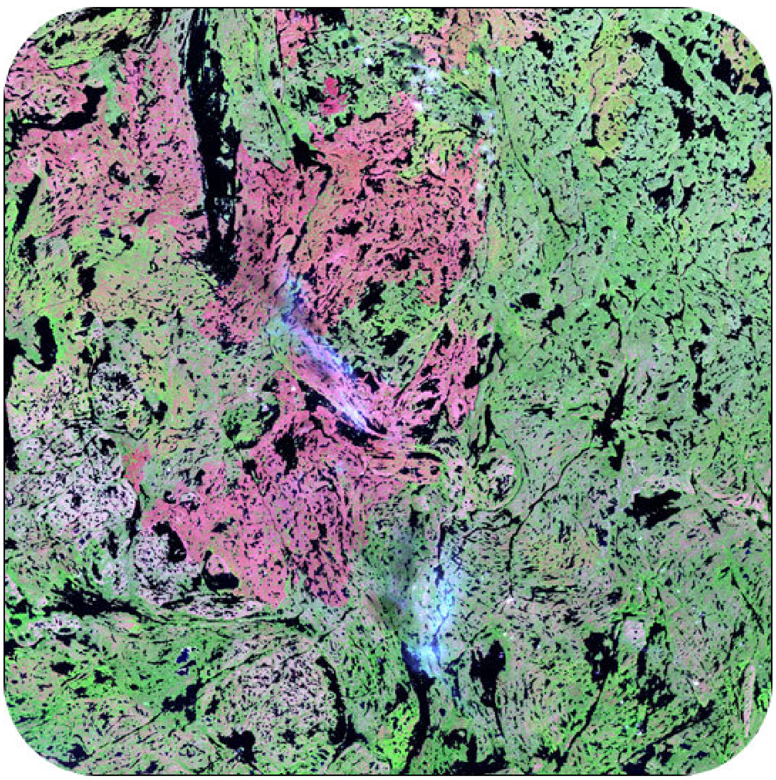


FIGURE 1.15
Lakes near Yellowknife were carved by glaciers during the last Ice Age.

or if their outlets grow because of erosion. When the climate of an area changes, lakes can either expand or shrink (**Figure** 1.16). Lakes may disappear if precipitation significantly diminishes.

Large lakes have tidal systems and currents, and can even affect weather patterns. The Great Lakes in the United States contain 22% of the world's fresh surface water (**Figure** 1.14). The largest them, Lake Superior, has a tide that rises and falls several centimeters each day. The Great Lakes are large enough to alter the weather system in Northeastern United States by the "lake effect," which is an increase in snow downwind of the relatively warm lakes. The Great Lakes are home to countless species of fish and wildlife.

Many lakes are not natural, but are human-made. People dam a stream in a suitable spot and then let the water back up behind it, creating a lake. These lakes are called "reservoirs."

FIGURE 1.16
The Badwater Basin in Death Valley contains water in wet years. The lake basin is a remnant from when the region was much wetter just after the Ice Ages.

Summary

- Ponds are small water bodies often fed by springs.
- A lake may form in many locations, including a volcanic crater, where a glacier has carved out a depression, or a fault zone.
- Lakes have surface, open-water, and deep-water zones.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=X26ocQkhNH4

1. What are the names for the zones: nearshore; open water; deep water; bottom surface
2. Why does a large lake harbor a lot of life?
3. What is a typical temperate zone lake like in the summer? What is the temperature structure?
4. What is a typical temperate zone lake like in the autumn? What is the temperature structure?
5. What is a typical temperate zone lake like in the winter? What is the temperature structure?
6. What is different about a lake in a tropical region?
7. Why doesn't a lake live forever?

Explore More Answers

1. litoral; limnetic; profundal; benthic
2. Large lakes are well mixed.
3. In the summer the sun heats the surface; wind mixes the surface, but a thermocline keeps the cold water deep.
4. In the autumn, the surface water cools so there is mixing through the lake and there is little to no temperature difference at different depths.
5. In the winter, ice forms at the surface, the warmer water stays below the ice.
6. In the spring, the cold water at the surface sinks and so the water overturns and the temperature is the same throughout.
7. The lake doesn't freeze in the winter so it doesn't cycle. The surface doesn't mix with the deep water and the deep water doesn't get any oxygen.

8. Sediments fill the lake until it becomes marshy and then disappears.

Review

1. What is the reason that Earth has many more lakes than is normal during Earth's history? What will happen as climate warms?
2. What are some of the ways lakes can form?
3. What is the difference between ponds and lakes? How are they similar?

Review Answers

1. The lakes are the result of ice age glaciers that carved the ground and melted so that water filled the basins.
2. Lakes can form in ground carved by glaciers, in the collapsed tops of volcanoes (calderas), along earthquake faults, and below glaciers.
3. A pond is smaller and has no outlet. Ponds are often fed by underground springs. Lakes are larger and have an outlet. Both are almost always fresh water.

1.6 Flooding

- Explain the causes and effects of floods.
- Describe types of flood protection.

Why are there so many floods?

Floods are a natural part of the water cycle, but that doesn't make them any less terrifying. Put most simply, a flood is an overflow of water in one place. How can you prepare for a flood? What do you do if you're caught in one?

Causes of Floods

Floods usually occur when precipitation falls more quickly than water can be absorbed into the ground or carried away by rivers or streams. Waters may build up gradually over a period of weeks, when a long period of rainfall or snowmelt fills the ground with water and raises stream levels.

Extremely heavy rains across the Midwestern U.S. in April 2011 led to flooding of the rivers in the Mississippi River basin in May 2011 (**Figures** 1.17 and 1.18).

Flash Floods

Flash floods are sudden and unexpected, taking place when very intense rains fall over a very brief period (**Figure** 1.19). A flash flood may do its damage miles from where the rain actually falls if the water travels far down a dry streambed.

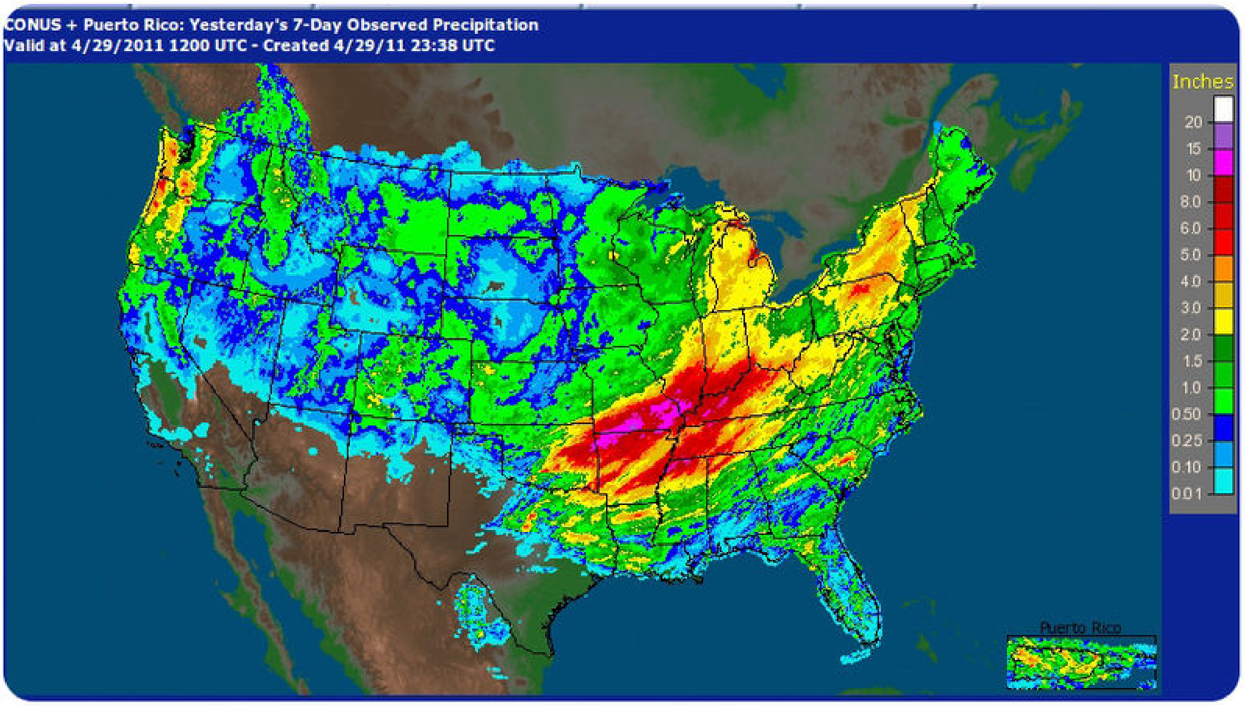


FIGURE 1.17
This map shows the accumulated rainfall across the U.S. in the days from April 22 to April 29, 2011.

FIGURE 1.18
Record flow in the Ohio and Mississippi Rivers has to go somewhere. Normal spring river levels are shown in 2010. The flooded region in the image from May 3, 2011 is the New Madrid Floodway, where overflow water is meant to go. 2011 is the first time since 1927 that this floodway was used.

FIGURE 1.19
A 2004 flash flood in England devastated two villages when 3-1/2 inches of rain fell in 60 minutes. Pictured here is some of the damage from the flash flood.

Buffers to Flooding

Heavily vegetated lands are less likely to experience flooding. Plants slow down water as it runs over the land, giving it time to enter the ground. Even if the ground is too wet to absorb more water, plants still slow the water's passage and increase the time between rainfall and the water's arrival in a stream; this could keep all the water falling over a region from hitting the stream at once. Wetlands act as a buffer between land and high water levels and play a key role in minimizing the impacts of floods. Flooding is often more severe in areas that have been recently logged.

Flood Protection

People try to protect areas that might flood with dams, and dams are usually very effective. But high water levels sometimes cause a dam to break and then flooding can be catastrophic. People may also line a river bank with **levees**, high walls that keep the stream within its banks during floods. A levee in one location may just force the high water up or downstream and cause flooding there. The New Madrid Overflow in the **Figure** 1.18 was created with the recognition that the Mississippi River sometimes simply cannot be contained by levees and must be allowed to flood.

Effects of Floods

Not all the consequences of flooding are negative. Rivers deposit new nutrient-rich sediments when they flood, so floodplains have traditionally been good for farming. Flooding as a source of nutrients was important to Egyptians along the Nile River until the Aswan Dam was built in the 1960s. Although the dam protects crops and settlements from the annual floods, farmers must now use fertilizers to feed their cops.

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

"Floods 101" is a National Geographic video found in Environment Video, Natural Disasters, Landslides, and more: http://video.nationalgeographic.com/video/player/environment/ .

FIGURE 1.20
Within the floodplain of the Nile, soils are fertile enough for productive agriculture. Beyond this, infertile desert soils prevent viable farming.

Summary

- When the amount of water in a drainage exceeds the capacity of the drainage, there is a flood.
- Floods are made worse when vegetation is cleared, when the land is already soaked, or when hillsides have been logged.
- People build dams and levees to protect from flooding.
- Floods are a source of nutrients on a floodplain.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=HagFJXBMofo

1. What is a flash flood?
2. What don't thunderstorms cause flash floods?
3. How might a mountainous region experience flash floods?
4. Where do flash floods occur?
5. Why might a flash flood occur not where the rain falls?
6. Why are urban areas prone to flash floods?
7. What is the difference between a flash flood and a flood?
8. If you are in a mountainous area and a flash flood is predicted what should you not do?
9. What are the safety tips for floods?

Explore More Answers

1. A sudden rise in the water level of a stream in response to heavy rains.
2. They are usually relatively small and over quickly.
3. If humid air rises up over the mountains and forms thunderstorms over and over.
4. In the drainage basin: the land area from which rainfall collects to reach a given point along a particular river.
5. If the rain is uphill.
6. Asphalt and concrete do not absorb water and so there is lots of water runoff.

7. A flash flood occurs in mountainous areas, the water flows very fast downstream and creates fast moving dangerous water. Floods occur in low-lying areas where water flows over the banks.
8. You should not drive on a road out of the region
9. Watch for rising water levels; get to high ground; don't pitch a tent in a dry stream bed; don't attempt to cross water that is more than knee deep; If the car stalls get out and get up to higher ground; listen to the news.

Review

1. How does a flash flood differ from another type of flood?
2. What was the role of flooding on the Nile River and what was the consequence of damming the river?
3. Why do floods still occur, even though people build dams and levees?

Review Answers

1. Flash floods are sudden and occur in regions where there is a lot of topography. The flood may take place in a region that is a long distance from where the rain fell. A flood is when a stream overflows it's banks. It can usually be predicted.
2. Each year the river would flood and bring sediments and nutrients onto the farms of the floodplain. The dam caused the soil to become infertile so the farmers must buy fertilizers.
3. The protections aren't always big enough or in the right place.Protections build up the water in the stream so that when there isn't a protection the subsequent flood s even bigger.

1.7 Glaciers

- Describe the formation, movement, and characteristics of glaciers.

Can solid ice really move?

Yes! Ice that moves downslope is called a "glacier." Glaciers move extremely slowly along the land surface. They may survive for thousands of years.

Where are the Glaciers?

Nearly all glacial ice, 99%, is contained in ice sheets in the polar regions, particularly Antarctica and Greenland.

Glaciers often form in the mountains because higher altitudes are colder and more likely to have snow that falls and collects. Every continent, except Australia, hosts at least some glaciers in the high mountains.

Types of Glaciers

The types of glaciers are:

- **Continental glaciers** are large ice sheets that cover relatively flat ground. These glaciers flow outward from where the greatest amounts of snow and ice accumulate.
- **Alpine (valley) glaciers** flow downhill from where the snow and ice accumulates through mountains along existing valleys.
- **Ice caps** are large glaciers that cover a larger area than just a valley, possibly an entire mountain range or region. Glaciers come off of ice caps into valleys.

FIGURE 1.21
The Greenland ice cap covers the entire landmass.

Glacial Growth

Formation

Glaciers grow when more snow falls near the top of the glacier, in the **zone of accumulation**, than is melted from lower down in the glacier, in the **zone of ablation**. These two zones are separated by the equilibrium line.

Snow falls and over time converts to granular ice known as firn. Eventually, as more snow and ice collect, the firn becomes denser and converts to glacial ice.

Water is too warm for a glacier to form, so they form only on land. A glacier may run out from land into water, but it usually breaks up into icebergs that eventually melt into the water.

Movement

Whether an ice field moves or not depends on the amount of ice in the field, the steepness of the slope and the roughness of the ground surface. Ice moves where the pressure is so great that it undergoes plastic flow. Ice also slides at the bottom, often lubricated by water that has melted and travels between the ground and the ice.

The speed of a glacier ranges from extremely fast, where conditions are favorable, to nearly zero.

Because the ice is moving, glaciers have **crevasses**, where cracks form in the ice as a result of movement. The large crevasse at the top of an alpine glacier where ice that is moving is separated from ice that is stuck to the mountain above is called a **bergshrund**.

FIGURE 1.22
Crevasses in a glacier are the result of movement.

Shrinking

Glaciers are melting back in many locations around the world. When a glacier no longer moves, it is called an ice sheet. This usually happens when it is less than 0.1 km2 in area and 50 m thick.

Glacier National Park

Many of the glaciers in Glacier National Park have shrunk and are no longer active. Summer temperatures have risen rapidly in this part of the country and so the rate of melting has picked up. Whereas Glacier National Park had 150 glaciers in 1850, there are only about 25 today. Recent estimates are that the park will have no active glaciers as early as 2020.

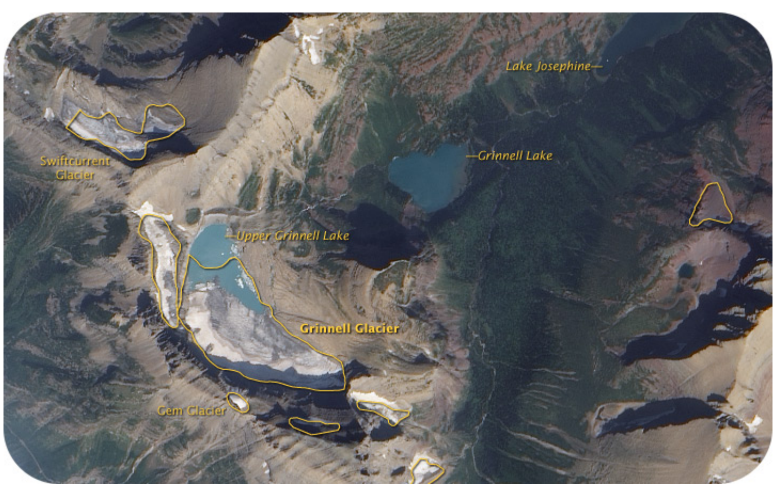


FIGURE 1.23
This satellite image shows Grinnell Glacier, Swiftcurrent Glacier, and Gem Glacier in 2003 with an outline of the extent of the glaciers as they were in 1950. Although it continues to be classified as a glacier, Gem Glacier is only 0.020 km^2 (5 acres) in area, only one-fifth the size of the smallest active glaciers.

Glaciers as a Resource

In regions where summers are long and dry, melting glaciers in mountain regions provide an important source of water for organisms and often for nearby human populations.

Summary

- Glaciers are ice that moves because the amount of snow and ice that collects in the zone of accumulation exceeds the amount that melts off in the zone of ablation.
- Continental glaciers form in a central location with ice moving outward in all directions. Alpine glaciers form in high mountains and travel through valleys.
- Because glaciers move, they have characteristic features like crevasses and bergshrunds.

Explore More

Use the resource below to answer the questions that follow.

- **Yosemite Nature Notes: Glaciers** at http://youtu.be/mgnzSTY5zRg (8:35)

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1625

1. Where are glaciers found in Yosemite National Park?
2. What is the largest glacier in Yosemite National Park?
3. What is the environment on and around a glacier like?
4. What are the dangers on glaciers?
5. What is a crevasse? What creates it?
6. What is a glacier?
7. Describe the bergshrund.
8. What is the challenge with protecting glaciers in Yosemite National Park?

Explore More Answers

1. Glaciers are found in the highest mountains in cirques.
2. Lyell Glacier is the largest
3. It's very open, no trees, few if any plants, and little soil. The ultraviolet radiation is intense.
4. Ice and rocks are moving, the glacier is steep and slippery.
5. A crevasse is an open gap or fissure that forms as the glacier moves downhill.
6. A glacier is a mass of moving ice.
7. The bergshrund is a big crevasse between the rocky cliff and the glacier at the head of the glacier. There is a space between the rock and the ice where the glacier is pulling away.
8. The changes in climate that are causing the glaciers to melt are caused by actions from outside the park. Park personnel have no control over what happens outside the park.

Review

1. Compare and contrast alpine glaciers, continental glaciers, and ice caps.
2. With a glacier that is melting back, what is happening in the zone of accumulation and the zone of ablation? What is happening to the equilibrium line?
3. How do glaciers serve as a water resource for people and organisms in the summertime?

Review Answers

1. Alpine glaciers occur in mountains and flow downhill. Continental glaciers cover relatively flat ground and flow outward from the locations where large amounts of snow accumulate. Ice caps are large glaciers that cover a mountain range or region.
2. The amount of snow falling on the zone of accumulation is less than the amount of melting that is taking place in the zone of ablation. The equilibrium line is moving uphill.
3. Glaciers melt in the summer and feed streams that can be used by people and organisms.

1.8 Introduction to Groundwater

- Define aquifer and explain how aquifers form and recharge.

Is there always water flowing beneath the land surface?

Although this may seem surprising, water beneath the ground is commonplace, moving slowly and silently through an aquifer and then bubbling to the surface at a spring. Groundwater is an extremely important source of water in many parts of the world where development and agriculture outmatch the amount of water available from rainfall and streams.

Aquifer

Groundwater resides in **aquifers**, porous rock and sediment with water in between. Water is attracted to the soil particles, and **capillary action**, which describes how water moves through porous media, moves water from wet soil to dry areas.

Aquifers are found at different depths. Some are just below the surface and some are found much deeper below the land surface. A region may have more than one aquifer beneath it and even most deserts are above aquifers. The source region for an aquifer beneath a desert is likely to be far away, perhaps in a mountainous area.

Recharge

The amount of water that is available to enter groundwater in a region, called **recharge**, is influenced by the local climate, the slope of the land, the type of rock found at the surface, the vegetation cover, land use in the area, and water retention, which is the amount of water that remains in the ground. More water goes into the ground where there is a lot of rain, flat land, porous rock, exposed soil, and where water is not already filling the soil and rock.

Fossil Water

The residence time of water in a groundwater aquifer can be from minutes to thousands of years. Groundwater is often called "fossil water" because it has remained in the ground for so long, often since the end of the ice ages.

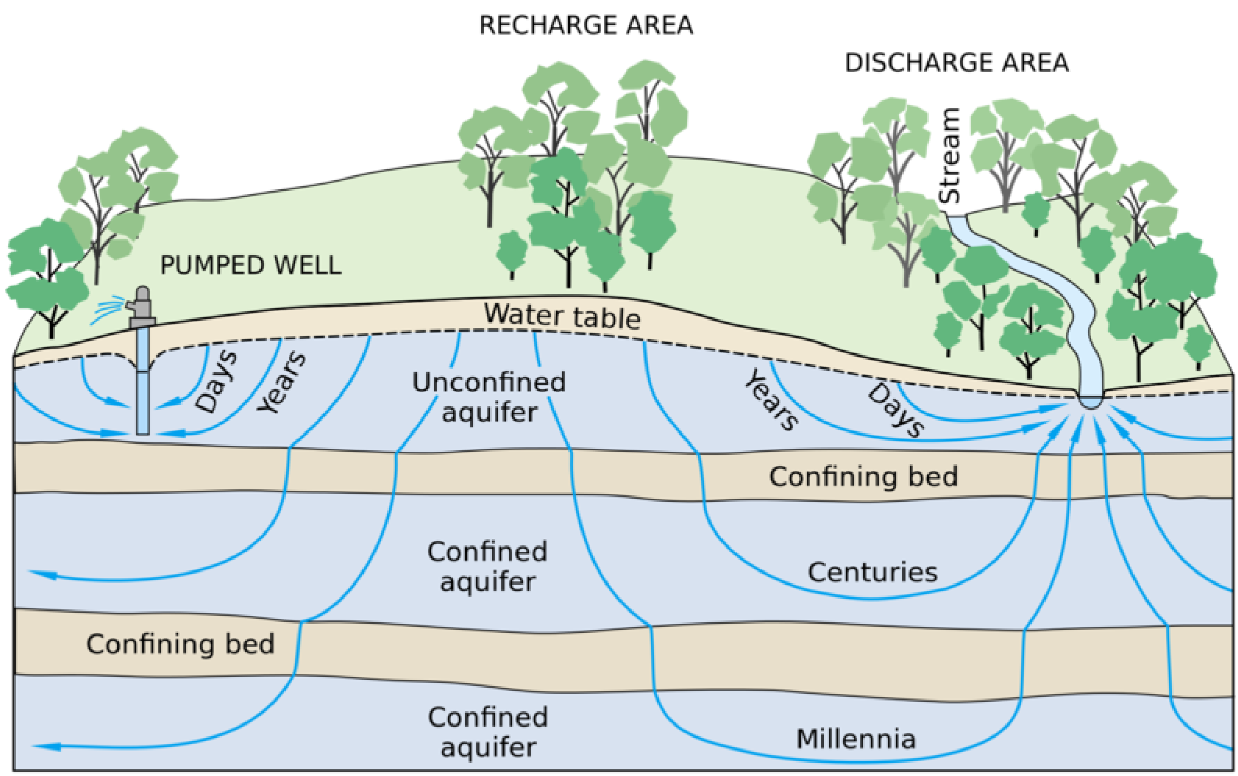


FIGURE 1.24

A diagram of groundwater flow through aquifers showing residence times. Deeper aquifers typically contain older "fossil water."

Summary

- Groundwater is in aquifers, a porous and permeable rock layer.
- Groundwater recharges in wet regions.
- Much groundwater is from the end of the ice ages, so it is called fossil water.

Explore More

Use this resource to answer the questions that follow.

1. What is surface water?
2. What is groundwater?
3. What is groundwater stored in?
4. What is the largest aquifer in the United States?

5. What is the top of the aquifer called?
6. What is the area above and the area below the water table called?
7. How does water end up in groundwater?
8. How long can water stay in the aquifer?
9. How does groundwater reach the surface naturally? ’
10. How does surface water become groundwater?
11. What do humans do with groundwater?
12. Under what conditions could humans drain aquifers?

Explore More Answers

1. Every lake, pond, stream and ocean on Earth.
2. Water that is crammed between rock and sediment underground.
3. aquifers
4. the High Plains Aquifer
5. the water table
6. the unsaturated zone; the saturated zone
7. Some water infiltrates down through the surface into the water table.
8. Some can stay for thousands of years.
9. If the land surface goes below the water table the water will appear as a stream or pond. It can flow onto the ground as a spring.
10. It infiltrates into the ground from surface water.
11. Everything we do with surface water: bathe, drink, grow food, industrial purposes.
12. Taking out more water than is replenished by natural processes.

Review

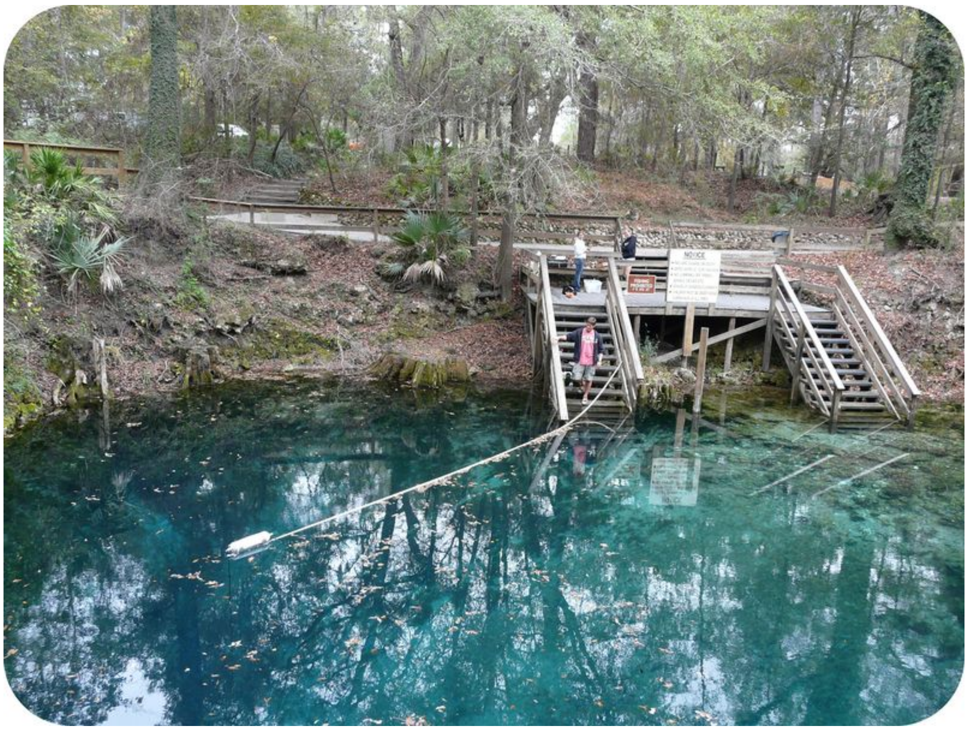
1. How does water move through an aquifer?
2. Where does groundwater come from in a region that has very little rainfall?
3. If groundwater is used, how will there be more? Is there always the same amount of water in an aquifer.

Review Answers

1. Water must move through a porous layer by capillary action.
2. Groundwater has been stored for thousands of years so it is just there and has been since the end of the ice ages.
3. Groundwater is recharged by rain and other water sources. It may be used beyond what is being recharged though so the amount of water in the aquifer goes down.

1.9 Groundwater Aquifers

- Describe the features of an aquifer.
- Define water table and explain how changes in the water table occur.
- Explain how springs are created.



Does groundwater move as an underground river?

People often think of groundwater as an underground river, but that is rarely true. In Florida, though, water has so thoroughly dissolved the limestone that streams travel underground and above ground. This photo shows where a large spring brings groundwater to the surface as if from nowhere.

Features of an Aquifer

To be a good aquifer, the rock in the aquifer must have good:

- **porosity**: small spaces between grains
- **permeability**: connections between pores

This animation shows porosity and permeability. The water droplets are found in the pores between the sediment grains, which is porosity. When the water can travel between ores, that's permeability. http://www.nature.nps.gov/GEOLOGY/usgsnps/animate/POROS_3.MPG

To reach an aquifer, surface water infiltrates downward into the ground through tiny spaces or pores in the rock. The water travels down through the permeable rock until it reaches a layer that does not have pores; this rock is **impermeable** (**Figure** 1.25). This impermeable rock layer forms the base of the aquifer. The upper surface where the groundwater reaches is the **water table**.

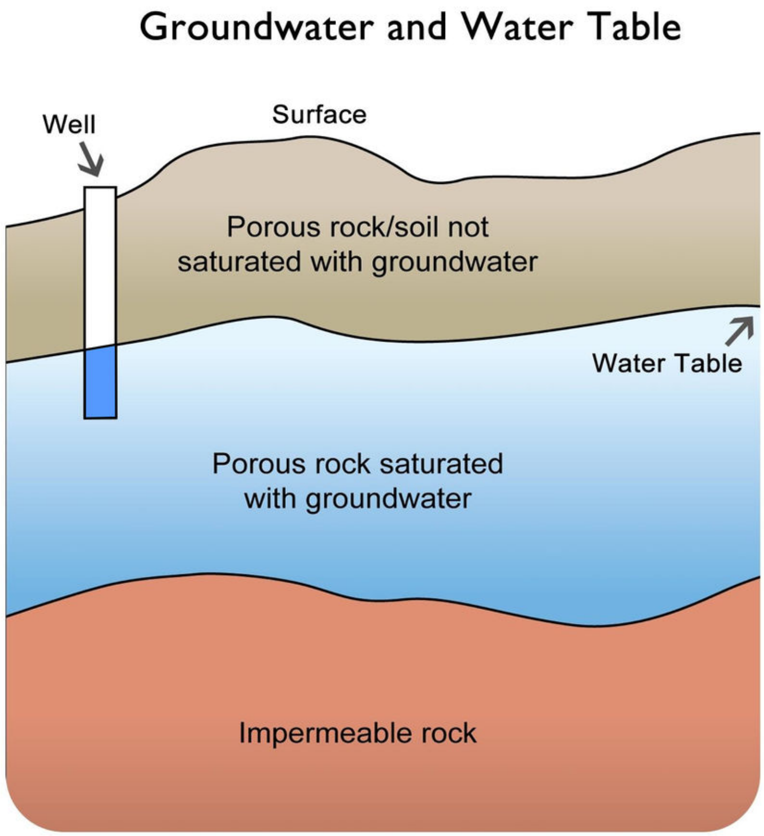


FIGURE 1.25
Groundwater is found beneath the solid surface. Notice that the water table roughly mirrors the slope of the land's surface. A well penetrates the water table.

The Water Table

For a groundwater aquifer to contain the same amount of water, the amount of recharge must equal the amount of discharge. What are the likely sources of recharge? What are the likely sources of discharge?

What happens to the water table when there is a lot of rainfall? What happens when there is a drought? Although groundwater levels do not rise and fall as rapidly as at the surface, over time the water table will rise during wet periods and fall during droughts.

In wet regions, streams are fed by groundwater; the surface of the stream is the top of the water table (**Figure** 1.26). In dry regions, water seeps down from the stream into the aquifer. These streams are often dry much of the year. Water leaves a groundwater reservoir in streams or springs. People take water from aquifers, too.

Springs

Groundwater meets the surface in a stream (**Figure** 1.26) or a **spring** (**Figure** 1.27). A spring may be constant, or may only flow at certain times of year. Towns in many locations depend on water from springs. Springs can be an extremely important source of water in locations where surface water is scarce.

Wells

A **well** is created by digging or drilling to reach groundwater. It is important for anyone who intends to dig a well to know how deep beneath the surface the water table is. When the water table is close to the surface, wells are a convenient method for extracting water. When the water table is far below the surface, specialized equipment must

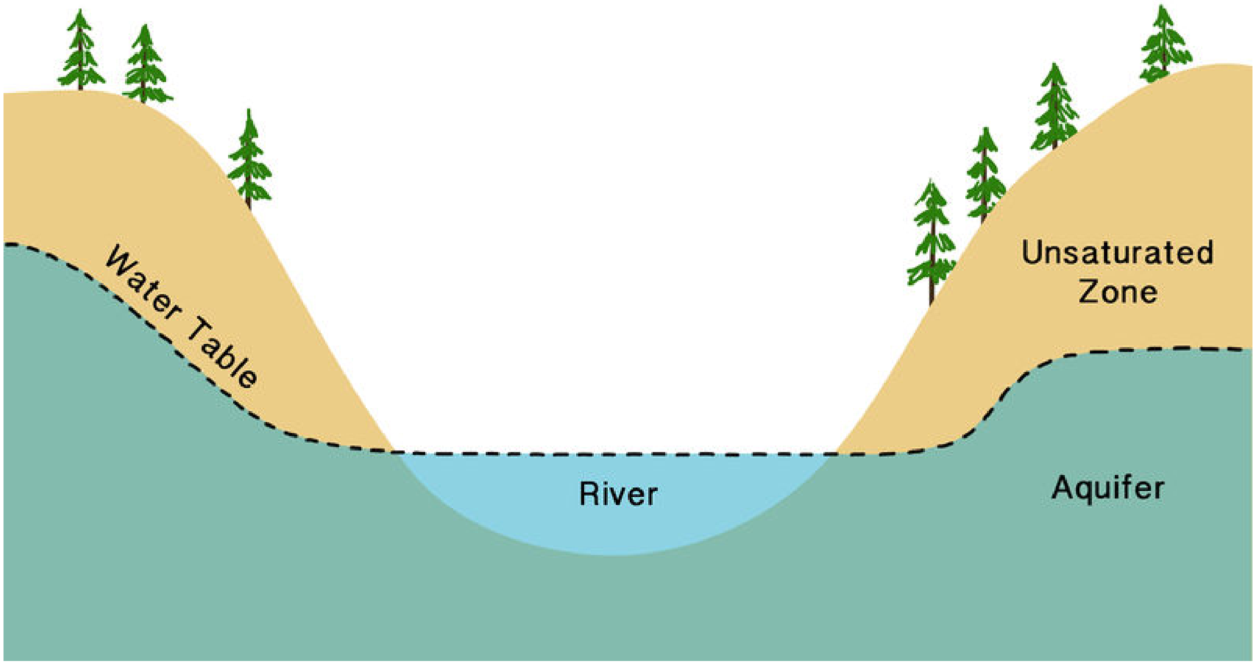


FIGURE 1.26
The top of the stream is the top of the water table. The stream feeds the aquifer.

FIGURE 1.27
A spring in Croatia bubbles to the surface and feeds the river Cetina.

be used to dig a well. Most wells use motorized pumps to bring water to the surface, but some still require people to use a bucket to draw water up (**Figure** 1.28).

FIGURE 1.28
An old-fashioned well that uses a bucket drawn up by hand.

Summary

- A rock layer must be porous and permeable to be a good aquifer. An impermeable layer makes up the bottom of an aquifer.
- The water table rises and falls with additions or subtractions to the groundwater system.
- Although people get groundwater from springs, which bring water to the surface, most groundwater is accessed using wells.

Explore More

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=guqinVOHTqc

MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/1628

1. How and where does water get into the aquifer?
2. What happens in the recharge zone?
3. What is the artesian zone?
4. What does hydrologic pressure do?
5. Where are the wells located and why?
6. What is a confined aquifer?
7. What is the saline water zone?
8. What happens when pollution leaks from a single area?
9. Explain the two types of pollutants.

10. What can cause each type of pollution?
11. How can the pollution of aquifers be prevented?

Explore More Answers

1. It enters in the drainage area,which is in the Texas Hill Country and catchment area. It rains and the water goes into the ground.
2. In the recharge zone the water enters the limestone and filter into the aquifer.
3. The artesian zone is where the water is under hydrological pressure.
4. It allows the water to come up at springs and into wells.
5. In the artesian zone because the water comes up more easily there.
6. The rocks above the aquifer are impermeable to water. The water is trapped in the aquifer from the top and bottom.
7. Bad water, it moves slower and the water is more mineralized.
8. The pollutants enter the aquifer and into other wells, eventually coming out of the spring.
9. point source and non=point source
10. Point source can be pinpointed to one event, like a tank. Non-point source can be an accumulation of events, like rain picking up oil and taking it over the ground.
11. Don't dump things onto he recharge zone; close abandoned wells properly; maintain current wells to standards.

Review

1. What happens to the water table in an extremely wet year? In an extremely dry one?
2. What characteristics are needed for rock in and around an aquifer?
3. What causes a spring?

Review Answers

1. In a wet year the water table will rise; in a dry year it will lower.
2. The rock in the aquifer must be porous and permeable. the rock around the aquifer must be impermeable.
3. Springs are where groundwater meets the surface on a hillside where it may create a stream.

1.10 Importance of the Oceans

- Describe the important roles of oceans as related to climate, the water cycle, and biodiversity.

Just what is down there?

Mostly the oceans are cold, dark and have extremely high pressure. Except at the very top, they are completely inhospitable to humans. Even this humpback whale can only dive to about 700 feet, so there's a lot about the ocean it doesn't know. Earth would not be the same planet without its oceans.

Oceans Moderate Climate

The oceans, along with the atmosphere, keep temperatures fairly constant worldwide. While some places on Earth get as cold as -70^{o}C and others as hot as 55^{o}C, the range is only 125^{o}C. On Mercury temperatures go from -180^{o}C to 430^{o}C, a range of 610^{o}C.

The oceans, along with the atmosphere, distribute heat around the planet. The oceans absorb heat near the Equator and then move that solar energy to more polar regions. The oceans also moderate climate within a region. At the same latitude, the temperature range is smaller in lands nearer the oceans than away from the oceans. Summer temperatures are not as hot, and winter temperatures are not as cold, because water takes a long time to heat up or cool down.

Water Cycle

The oceans are an essential part of Earth's water cycle. Since they cover so much of the planet, most evaporation comes from oceans and most precipitation falls on oceans.

Biologically Rich

The oceans are home to an enormous amount of life. That is, they have tremendous biodiversity (**Figure** 1.29). Tiny ocean plants, called phytoplankton, create the base of a food web that supports all sorts of life forms. Marine life makes up the majority of all biomass on Earth. (**Biomass** is the total mass of living organisms in a given area.) These organisms supply us with food and even the oxygen created by marine plants.

FIGURE 1.29
Polar bears are well adapted to frigid Arctic waters.

Summary

- Oceans moderate Earth's temperature by not changing temperature rapidly and by distributing heat around the planet.
- Oceans are an enormous reservoir for water in the water cycle.
- Oceans have tremendous biodiversity and the majority of all biomass on Earth.

Making Connections

MEDIA
Click image to the left for use the URL below.
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Explore More

Use this resource to answer the questions that follow.

http://cmore.soest.hawaii.edu/oceanacidification/documents/PML_TechnicalSheet_high_CO2_world.pdf Use pages 1 2.

1. How much of Earth's surface do the ocean's cover? How much of global primary productivity comes from the oceans?
2. How do the oceans regulate the Earth system?
3. What are the ocean's living and non-living resources?
4. What social and economic goods and services does the ocean provide?
5. What do ocean currents transport as they travel around the globe?
6. What does carbon dioxide do in the oceans?
7. If a lot of the carbon dioxide that has been released in the past 150 years has entered the deep ocean, when might it cause temperatures to rise and why?
8. How are marine organisms used for food and biotechnology?
9. What other resources are found in the ocean?
10. How does the ocean provide defense from storms?

Explore More Answers

1. over 70%; about 50%
2. They transfer heat around the world; drive climate and weather systems; play a key role in the global carbon cycle.
3. They are many from fisheries to marine biotechnology, from minerals to renewable energy.
4. It provides tourism and recreation, marine transport and security, protection.
5. heat, gas and matter
6. Carbon dioxide dissolves in seawater, forming carbonic acid. The carbon is removed from the ocean when it becomes part of calcium carbonate shells and limestone.
7. It could take hundreds of years for it to leave the deep sea and enter the atmosphere.
8. About 1 billion people rely on fish as their main source of protein. Marine biotechnology creates products and services for health, beauty and medicine.
9. oil, gas, minerals, renewable energy such as wind farms or tidal and wave energy plants
10. Coral reefs, salt marshes, and coastlines are defenses from storms.

Review

1. What organisms form the base of the ocean food web?
2. How do the oceans moderate Earth's temperature?
3. What role do oceans play in the water cycle?

Review Answers

1. phytoplankton
2. Ocean currents bring the heat from warm areas into colder regions and cold water into warmer regions so that temperatures become more moderate.
3. The oceans are the largest reservoir. they receive the most precipitation and experience the most evaporation.

1.11 Seawater Chemistry

- Describe the composition of seawater.
- Explain the relationship between the composition of seawater and its properties.

What is salt?

Besides making food taste better, salt is important for the human diet. Before refrigeration, salt was essential for curing and preserving food. Even in antiquity people built access roads they called "salt roads" so that they could obtain this essential mineral. What is salt? It's what you get when you evaporate seawater!

Composition of Ocean Water

Remember that H_2O is a polar molecule, so it can dissolve many substances (**Figure** 1.30). Salts, sugars, acids, bases, and organic molecules can all dissolve in water.

Salinity

Where does the salt in seawater come from? As water moves through rock and soil on land it picks up ions. This is the flip side of weathering. Salts comprise about 3.5% of the mass of ocean water, but the salt content, or **salinity**, is different in different locations.

What would the salinity be like in an estuary? Where seawater mixes with fresh water, salinity is lower than average.

What would the salinity be like where there is lots of evaporation? Where there is lots of evaporation but little circulation of water, salinity can be much higher. The Dead Sea has 30% salinity —nearly nine times the average salinity of ocean water (**Figure** 1.31). Why do you think this water body is called the Dead Sea?

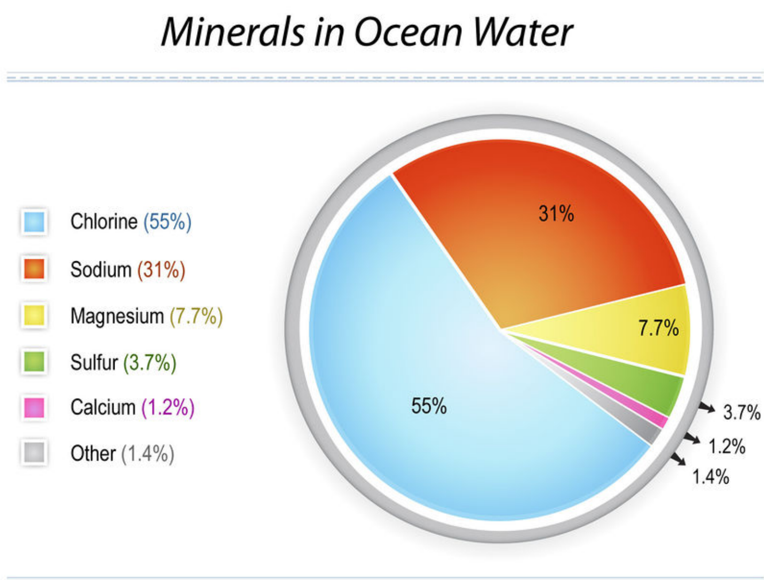
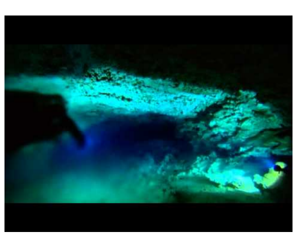


FIGURE 1.30
Ocean water is composed of many substances, many of them salts such as sodium, magnesium, and calcium chloride.

FIGURE 1.31
Because of the increased salinity, the water in the Dead Sea is very dense, it has such high salinity that people can easily float in it!

In some areas, dense saltwater and less dense freshwater mix, and they form an immiscible layer, just like oil and water. One such place is a "cenote", or underground cave, very common in certain parts of Central America. Check out the video below:

http://www.youtube.com/watch?v=dHn80f3lAUs



MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/4775

Interactive ocean maps can show salinity, temperature, nutrients, and other characteristics: http://earthguide.ucsd.edu/earthguide/diagrams/levitus/index.html .

Density

With so many dissolved substances mixed in seawater, what is the **density** (mass per volume) of seawater relative to fresh water?

Water density increases as:

- salinity increases
- temperature decreases
- pressure increases

Differences in water density are responsible for deep ocean currents, as will be discussed in the "Deep Ocean Currents" concept.

Summary

- Water moving through rock and soil picks up ions that end up as salts in large water bodies.
- Ocean water contains salts, sugars, acids, bases, and organic molecules.
- Water density increases as salinity and pressure increase, or as temperature decreases.

Making Connections

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/58235

Explore More

Use the resource below to answer the questions that follow.

- **Ocean Chemistry** at http://www.youtube.com/watch?v=KUadxcKtH-g (4:58)

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/4776

1. What happens to water as it cools?
2. What plays a crucial role in ocean movement?
3. What does algae require?
4. What do diatoms require?
5. Why is calcium important to organisms in the oceans?
6. Why is phosphate required?
7. How does carbon enter the oceans?
8. What is a dead zone?
9. Where is nitrogen fixed in the ocean?
10. Where does the iron in oceans come from?
11. Why are there plans to seed areas of the ocean with iron?

Explore More Answers

1. It becomes denser and it sinks.
2. wind
3. Algae require carbon, nutrients and sunlight for photosynthesis.
4. silicate
5. skeletal materials
6. Phosphate is needed to sustain life; it is needed in biological molecules and chemical processes.
7. river runoff, waves, waves on the shore
8. A dead zone is where excess nutrients increase the population of phytoplankton so high that they exceed the available nutrients and the population collapses.
9. dead zones and beneath seafloor sediments
10. Iron in the oceans mostly comes from dust in the wind.
11. Since iron is a limiting nutrient in some areas, seeding the ocean with iron will increase phytoplankton populations, which will increase the amount of carbon that is taken down to the bottom of the ocean (sequestered).

Review

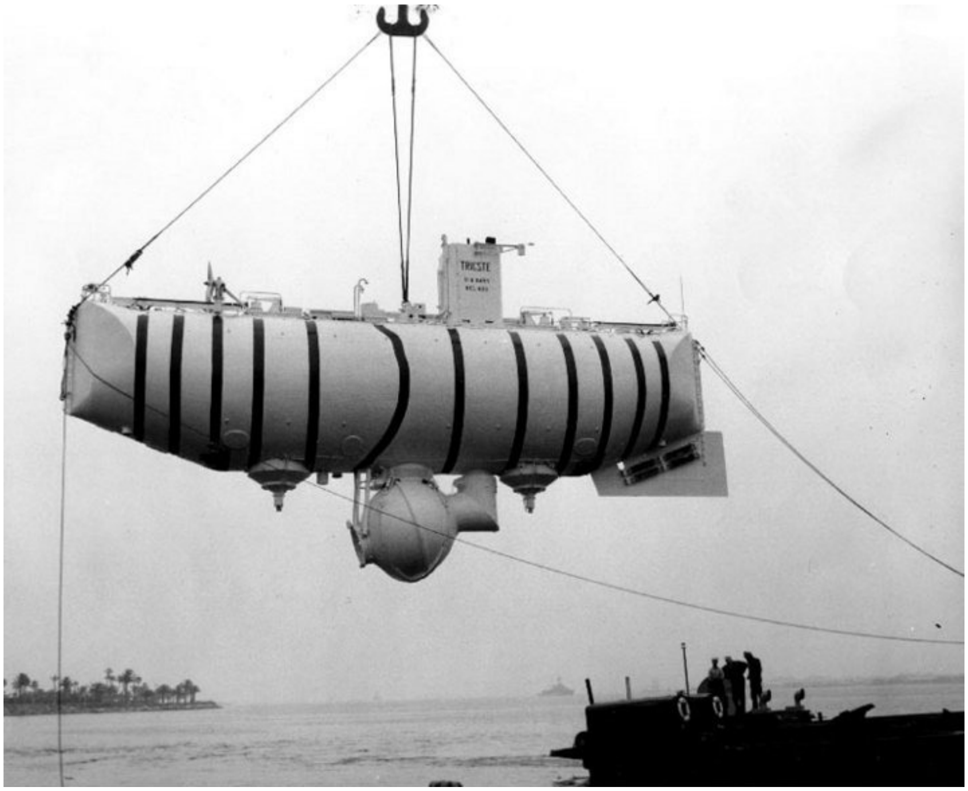
1. Streams aren't salty, so why is the ocean salty?
2. In a region of the ocean where evaporation is high, what happens to the density of the water and why? What does the water do?
3. What would need to happen for the all of the oceans to become more saline?

Review Answers

1. The tiny amount of salt in streams can't be detected but over time that amount of salt added plus the evaporation of water without salt has made the ocean salty.
2. Salinity increases so density increases. The water sinks.
3. There would need to be an increase in the evaporation rate or a decrease in the rate shells and limestone are made out of the salts.

1.12 Ocean Zones

- Identify and describe the vertical and horizontal ocean zones.



There's a trench in the bottom of the sea. Would you like to visit it?

In 1960, two men in a specially designed submarine called the Trieste descended into a submarine trench called the Challenger Deep (10,916 meters). This depth remains a record for a manned descent. The film director, James Cameron,, got to 10,898 meters in his one-man vessel, the Deepsea Challenger, in 2012. Would you like to go to the bottom of the ocean in that vessel?

Divisions of the Ocean

Oceanographers divide the ocean into zones both vertically and horizontally.

Vertical Divisions

To better understand regions of the ocean, scientists define the **water column** by depth. They divide the entire ocean into two zones vertically, based on light level. Large lakes are divided into similar regions.

- Sunlight only penetrates the sea surface to a depth of about 200 m, creating the **photic zone** ("photic" means light). Organisms that photosynthesize depend on sunlight for food and so are restricted to the photic zone. Since tiny photosynthetic organisms, known as phytoplankton, supply nearly all of the energy and nutrients to the rest of the marine food web, most other marine organisms live in or at least visit the photic zone.

- In the **aphotic zone** there is not enough light for photosynthesis. The aphotic zone makes up the majority of the ocean, but has a relatively small amount of its life, both in diversity of type and in numbers. The aphotic zone is subdivided based on depth (**Figure** 1.32).

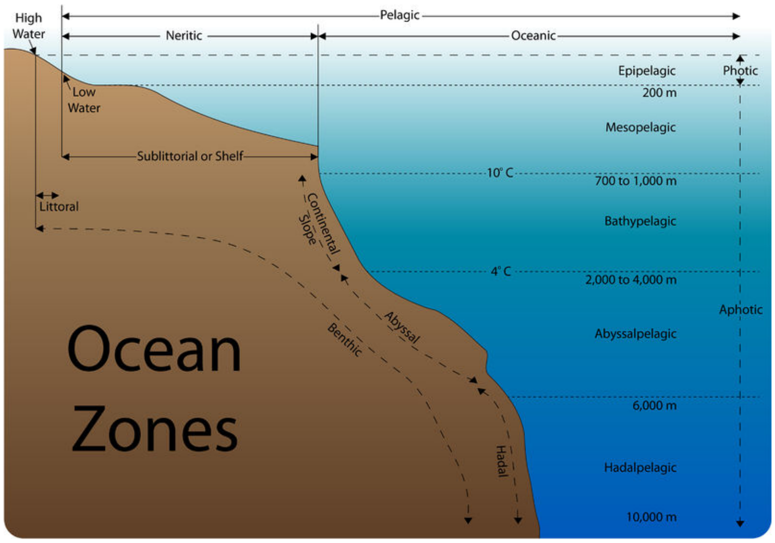


FIGURE 1.32
Vertical and horizontal ocean zones.

The average depth of the ocean is 3,790 m, a lot more shallow than the deep trenches but still an incredible depth for sea creatures to live in. What makes it so hard to live at the bottom of the ocean? The three major factors that make the deep ocean hard to inhabit are the absence of light, low temperature, and extremely high pressure.

Horizontal Divisions

The seabed is divided into the zones described above, but ocean itself is also divided horizontally by distance from the shore.

- Nearest to the shore lies the **intertidal zone** (also called the littoral zone), the region between the high and low tidal marks. The hallmark of the intertidal is change: water is in constant motion in the form of waves, tides, and currents. The land is sometimes under water and sometimes exposed.
- The **neritic zone** is from low tide mark and slopes gradually downward to the edge of the seaward side of the continental shelf. Some sunlight penetrates to the seabed here.
- The **oceanic zone** is the entire rest of the ocean from the bottom edge of the neritic zone, where sunlight does not reach the bottom. The sea bed and water column are subdivided further, as seen in the **Figure** 1.32.

Summary

- The most important vertical distinction in the oceans is between the small surface zone that has light, the photic zone, and the entire rest of the ocean without light, the aphotic zone.
- The ocean is divided into horizontal zones based on the depth of water beneath: the intertidal, neritic, and oceanic.
- Why does most of the life in the oceans live in or at least visit the surface?

Making Connections

MEDIA

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Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=sNPHuUvW2Nk

1. What is common to all of the benthic zones? What are the benthic subzones from shallow to deep?
2. What does pelagic mean? What are the pelagic zones from shallow to deep?
3. Why does the neritic zone have the highest density of productivity, density of life and nutrient levels?
4. Why does the epipelagic zone have the most productivity?
5. Why do organisms go between zones?
6. Where does the deep oceans get nutrients?
7. What is unique about the littoral zone?
8. How do conditions vary between the top and bottom of the littoral zone?

Explore More Answers

1. They are all on the bottom of the sea. They start with sublittoral, then bathyal, abyssal and hadal.
2. Pelagic is open water. The zones are epipelagic, mesopelagic, bathypelagic and abyssalpelagic.
3. Upwelling brings nutrients up from the deep and also runoff from land brings in nutrients. High nutrients will lead to high productivity and a high density of life.
4. It is in the photic zone and it tops most of the open oceans.
5. They may go to the highest productivity zones to eat and the zones farthest from predators to give birth or do other things.
6. The organisms that die on the surface sink to the deep ocean.
7. This is the intertidal; sometimes it's underwater and sometimes it's emerged.
8. At the top organisms are mostly emergent,but they may get sprayed. At the bottom the organisms are almost always covered with water. In between is a gradation between these two. Some organisms are underwater half the day and emerged half the day.

Review

1. Why is there so little life at the bottom of the ocean?
2. Compare and contrast the intertidal, neritic, and oceanic zones.
3. Do you think that the line between the photic and aphotic zones is solid and that life is either in one or the other, or do you think the divisions are more gradational? Why?

Review Answers

1. The bottom is a long way from sunlight. It is very dark and the pressure is very high. There are nutrients that fall down from the top.
2. In the intertidal zone the organisms are exposed to air at least some of the time. The region is exposed to a lot of water movement. In the neritic zone there is sunlight still, but it gets fainter toward the bottom. This zone

is over the continental shelf. In the oceanic zone sunlight does not reach the bottom, although it is at the top. This is the open ocean.

3. The light gets fainter with depth. There is a vanishing amount of light, but no distinct line. This is the same thing that happens when the sun sets in the absence of a moon. It just gets fainter and fainter until it is dark.

1.13 Wind Waves

- Describe the characteristics of ocean waves.
- Explain how wind forms ocean waves.

If ocean waves are caused by wind, how can there be strong waves on calm days?

Waves form where there are winds. Energy from the wind is transferred to the water and then that is transferred to nearby water molecules. The wave moves as a transfer of energy across the sea. Once the wave starts, it doesn't need more wind to keep it going.

Ocean Waves

Waves have been discussed in previous concepts in several contexts: seismic waves traveling through the planet, sound waves traveling through seawater, and ocean waves eroding beaches. Waves transfer energy, and the size of a wave and the distance it travels depends on the amount of energy that it carries. This concept studies the most familiar waves, those on the ocean's surface.

Building Big Waves

Ocean waves originate from wind blowing –steady winds or high storm winds –over the water. Sometimes these winds are far from where the ocean waves are seen. What factors create the largest ocean waves?

The largest wind waves form when the wind

- is very strong
- blows steadily for a long time
- blows over a long distance

The wind could be strong, but if it gusts for just a short time, large waves won't form.

Wind blowing across the water transfers energy to that water. The energy first creates tiny ripples, which make an uneven surface for the wind to catch so that it may create larger waves. These waves travel across the ocean out of the area where the wind is blowing.

Remember that a wave is a transfer of energy. Do you think the same molecules of water that start out in a wave in the middle of the ocean later arrive at the shore? The molecules are not the same, but the energy is transferred across the ocean.

Shape of a Wave

Water molecules in waves make circles or ellipses (**Figure** 1.33). Energy transfers between molecules, but the molecules themselves mostly bob up and down in place.

In this animation, a water bottle bobs in place like a water molecule: http://www.onr.navy.mil/Focus/ocean/motion/waves1.htm .

An animation of motion in wind waves from the Scripps Institution of Oceanography: http://earthguide.ucsd.edu/earthguide/diagrams/waves/swf/wave_wind.html .

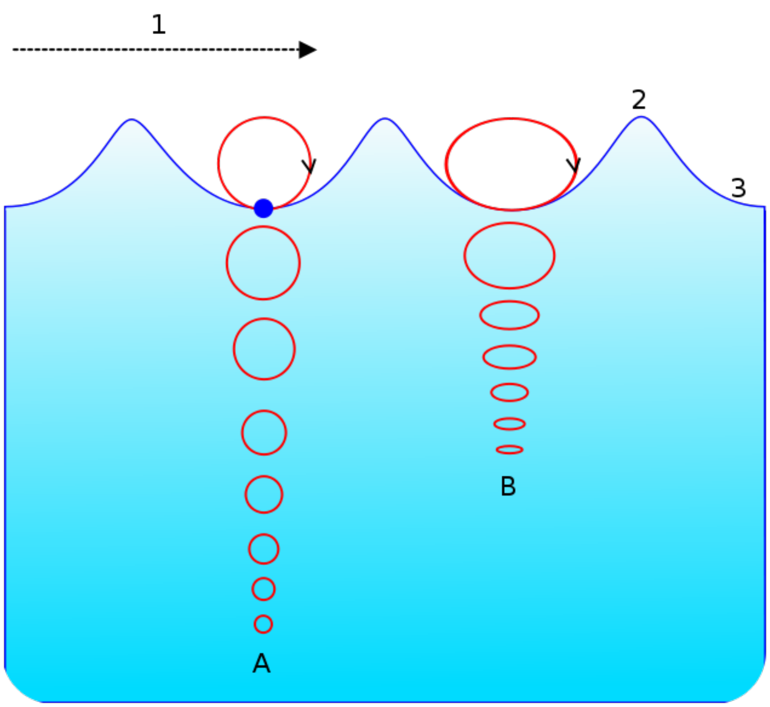

FIGURE 1.33
The circles show the motion of a water molecule in a wind wave. Wave energy is greatest at the surface and decreases with depth. "A" shows that a water molecule travels in a circular motion in deep water. "B" shows that molecules in shallow water travel in an elliptical path because of the ocean bottom.

An animation of a deep water wave is seen here: http://en.wikipedia.org/wiki/File:Deep_water_wave.gif .

An animation of a shallow water wave is seen here: http://commons.wikimedia.org/wiki/File:Shallow_water_wave.gif .

Waves Break

When does a wave break? Do waves only break when they reach shore? Waves break when they become too tall to be supported by their base. This can happen at sea but happens predictably as a wave moves up a shore. The energy at the bottom of the wave is lost by friction with the ground, so that the bottom of the wave slows down but the top of the wave continues at the same speed. The crest falls over and crashes down.

Storm Surge

Some of the damage done by storms is from **storm surge**. Water piles up at a shoreline as storm winds push waves into the coast. Storm surge may raise sea level as much as 7.5 m (25 ft), which can be devastating in a shallow land area when winds, waves, and rain are intense.

A wild video of "Storm Surge" can be seen on National Geographic Videos, Environment Video, Natural Disasters, Landslides, and more: http://video.nationalgeographic.com/video/player/environment/ .

Maverick waves are massive. Learning how they are generated can tell scientists a great deal about how the ocean creates waves and especially large waves.

Learn more by watching this video at http://www.kqed.org/quest/television/science-of-big-waves.

MEDIA

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URL: http://gamma.ck12.org/flx/render/embeddedobject/116517

Summary

- The largest wind waves are built when a strong wind blows for a long time over a large area.
- When a wave breaks onshore it is not the water but the energy that has traveled from where the wave formed.
- A wave breaks when it is too tall to be supported by its base, which is common as a wave moves up the shore.

Explore More

Use these resources to answer the questions that follow.

http://channel.nationalgeographic.com/channel/videos/development-of-ocean-waves/

1. What does an ocean wave transport?
2. Where does a wave begin? What condition is necessary?
3. What happens first and why is this necessary?
4. What happens after more wind energy is added?
5. What travels in a wave? What evidence is there that this is what's happening?
6. What happens when the wave arrives at the shore?
7. Where is the energy released? What can this energy do?

Explore More Answers

1. energy
2. Far out at sea where there is wind.
3. A few ripples form and capture the power of the wind.
4. Swells form.
5. Just energy. A surfer sitting on a board just moves up and down now forward.

6. The water gets shallow, so the bottom of the wave slows down. The top goes ahead, the peak topples over and creates a breaking wave.
7. On the shore. The energy can erode the shoreline.

Review

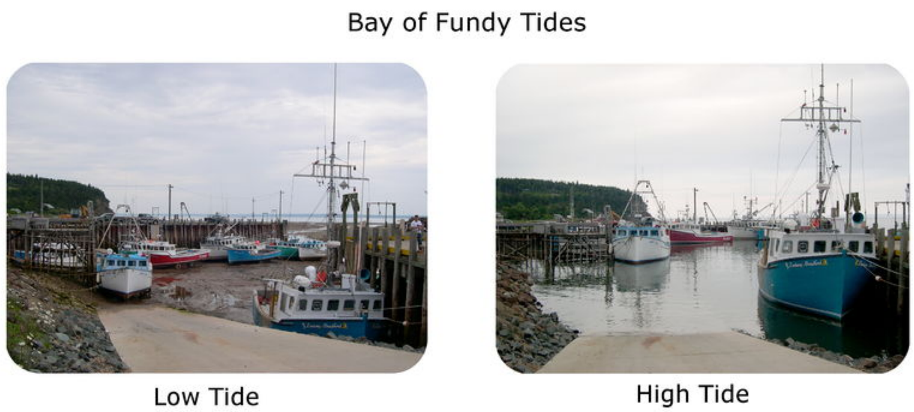
1. What causes a wave to break? Does this only happen along a shore?
2. When a hurricane reaches land, the damage done to coastal development often depends on how high the tide is. Why would this make a difference?
3. Describe how a wave that forms in the central Pacific travels to and breaks at the beach in San Diego, California.

Review Answers

1. Waves break when they become too tall for their base. This can happen at sea but it is most likely to happen along a shore where the bottom moves upward.
2. The wave is high and it is placed on top of the tide. So if the tide is high the total height of the water will be very damaging.
3. The wave begins in a region in the middle of the ocean where there is steady wind or high wind. The wind blows over the area and transfers energy; the first waves are tiny ripples. As more wind blows the additional energy creates larger waves. The waves are energy that travels across the ocean until one breaks in California.

1.14 Tides

- Define tides.
- Describe types of tides.
- Explain why tides occur.



How could a tide be so extreme?

These two photos show high tide (left) and low tide (right) at Bay of Fundy on the Gulf of Maine. The Bay of Fundy has the greatest tidal ranges on Earth at 38.4 feet. Why is this tidal range so extreme? Why aren't all tidal ranges so great? Tidal range depends on many factors, including the slope of the continental margin.

The Tides

Tides are the daily rise and fall of sea level at any given place. The pull of the Moon's gravity on Earth is the primary cause of tides and the pull of the Sun's gravity on Earth is the secondary cause (**Figure** 1.34). The Moon has a greater effect because, although it is much smaller than the Sun, it is much closer. The Moon's pull is about twice that of the Sun's.

To understand the tides it is easiest to start with the effect of the Moon on Earth. As the Moon revolves around our planet, its gravity pulls Earth toward it. The lithosphere is unable to move much, but the water is pulled by the gravity and a bulge is created. This bulge is the high tide beneath the Moon. On the other side of the Earth, a high tide is produced where the Moon's pull is weakest. These two water bulges on opposite sides of the Earth aligned with the Moon are the **high tides**. The places directly in between the high tides are **low tides**. As the Earth rotates beneath the Moon, a single spot will experience two high tides and two low tides approximately every day.

High tides occur about every 12 hours and 25 minutes. The reason is that the Moon takes 24 hours and 50 minutes to rotate once around the Earth, so the Moon is over the same location every 24 hours and 50 minutes. Since high tides occur twice a day, one arrives each 12 hours and 25 minutes. What is the time between a high tide and the next low tide?

The gravity of the Sun also pulls Earth's water towards it and causes its own tides. Because the Sun is so far away, its pull is smaller than the Moon's.

Some coastal areas do not follow this pattern at all. These coastal areas may have one high and one low tide per day or a different amount of time between two high tides. These differences are often because of local conditions, such as the shape of the coastline that the tide is entering.

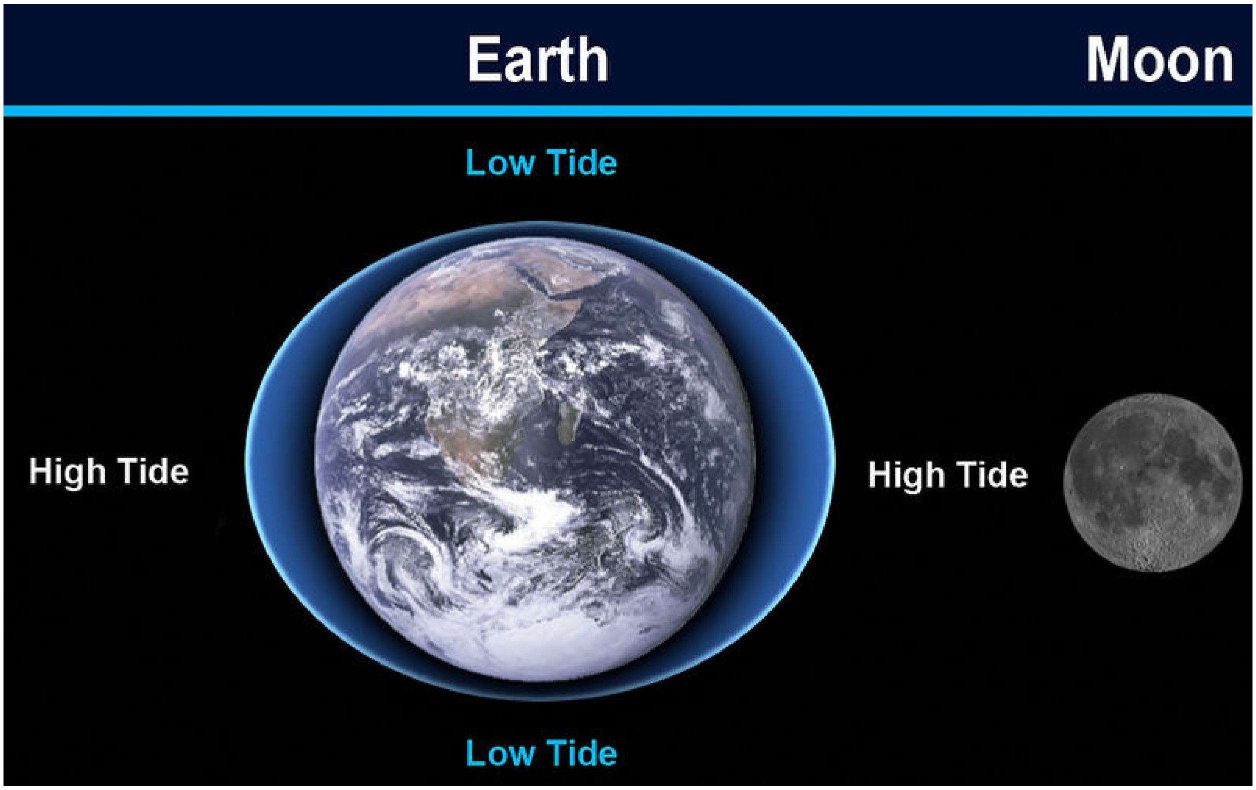


FIGURE 1.34
The gravitational attraction of the Moon to ocean water creates the high and low tides.

Tidal Range

The **tidal range** is the difference between the ocean level at high tide and the ocean level at low tide (**Figure** 1.35). The tidal range in a location depends on a number of factors, including the slope of the seafloor. Water appears to move a greater distance on a gentle slope than on a steep slope.

Monthly Tidal Patterns

If you look at the diagram of high and low tides on a circular Earth above, you'll see that tides are waves. So when the Sun and Moon are aligned, what do you expect the tides to look like?

Waves are additive, so when the gravitational pull of both bodies is in the same direction, the high tides are higher and the low tides lower than at other times through the month (**Figure** 1.36). These more extreme tides, with a greater tidal range, are called **spring tides**. Spring tides don't just occur in the spring; they occur whenever the Moon is in a new-moon or full-moon phase, about every 14 days.

Neap tides are tides that have the smallest tidal range, and they occur when the Earth, the Moon, and the Sun form a 90^o angle (**Figure** 1.37). They occur exactly halfway between the spring tides, when the Moon is at first or last quarter. How do the tides add up to create neap tides? The Moon's high tide occurs in the same place as the Sun's low tide and the Moon's low tide in the same place as the Sun's high tide. At neap tides, the tidal range is relatively small.

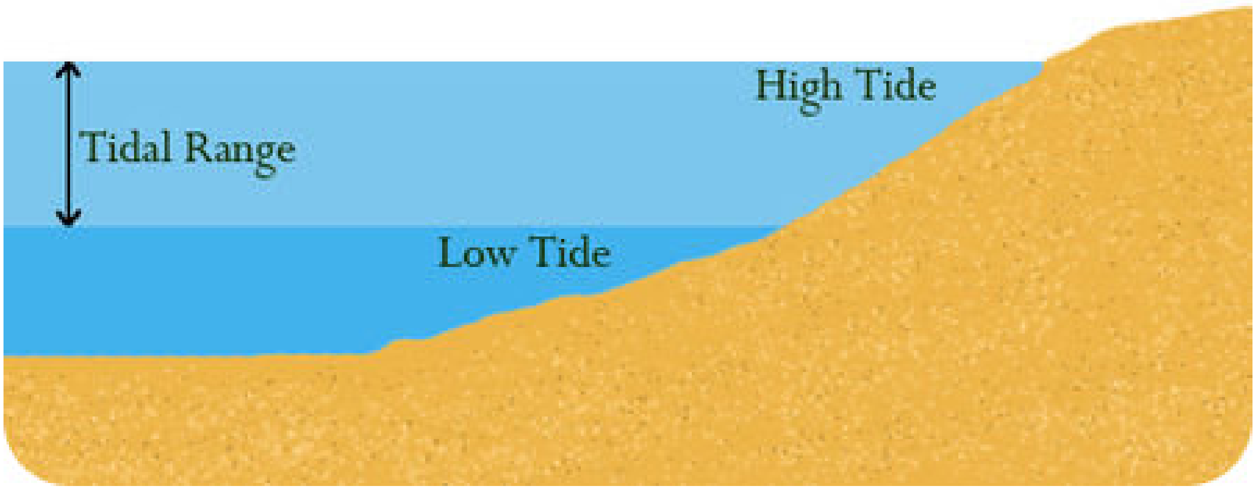


FIGURE 1.35
The tidal range is the difference between the ocean level at high tide and low tide.

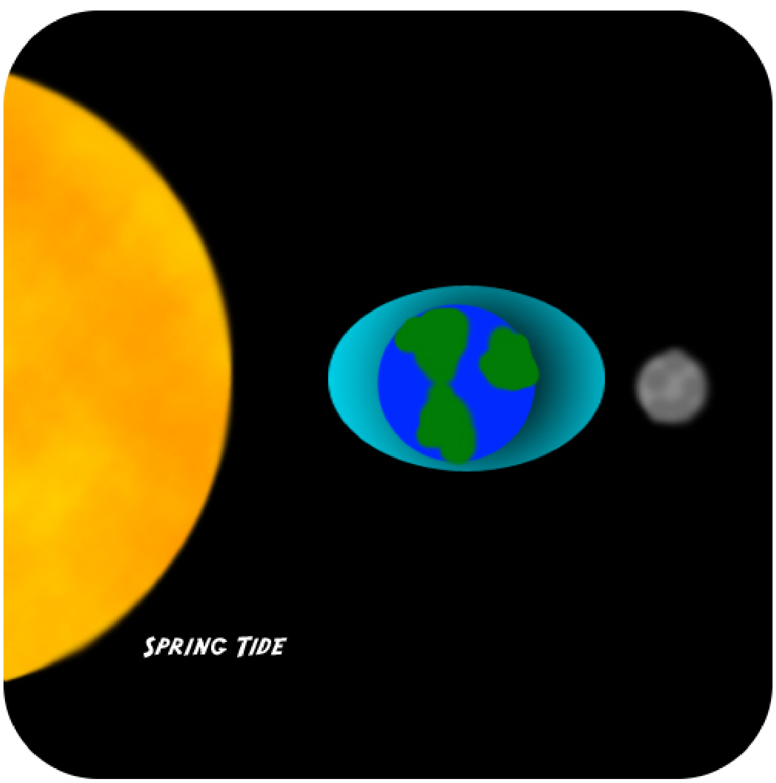


FIGURE 1.36
A spring tide occurs when the gravitational pull of both Moon and the Sun is in the same direction, making high tides higher and low tides lower and creating a large tidal range.

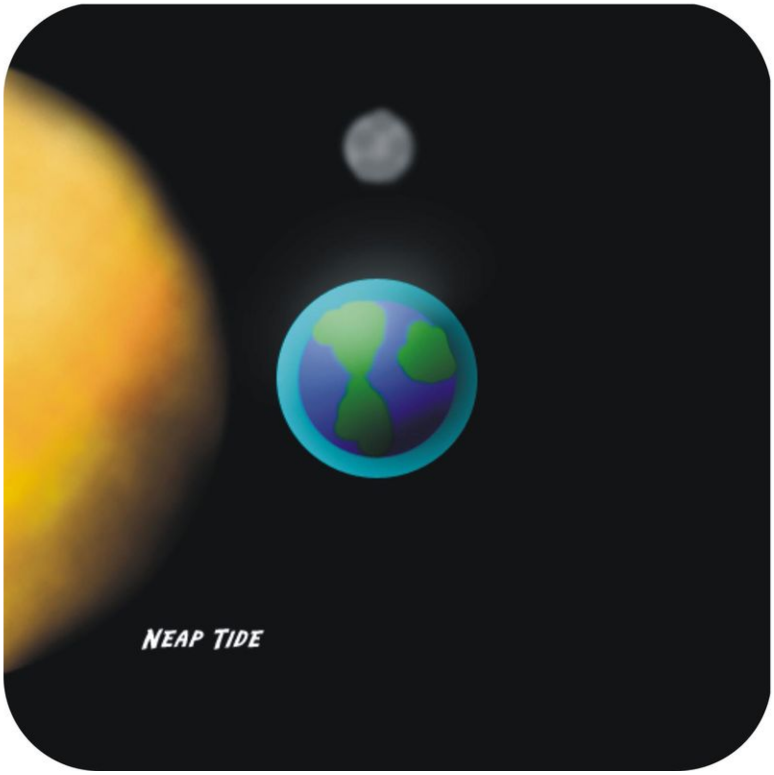


FIGURE 1.37
A neap tide occurs when the high tide of the Sun adds to the low tide of the Moon and vice versa, so the tidal range is relatively small.

This animation shows the effect of the Moon and Sun on the tides: http://www.onr.navy.mil/Focus/ocean/motion/tides1.htm .

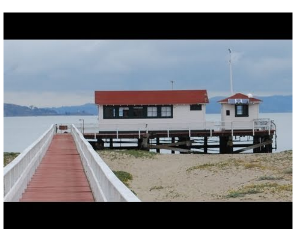
A detailed animation of lunar tides is shown here: http://www.pbs.org/wgbh/nova/venice/tides.html .

Here is a link to see these tides in motion: http://oceanservice.noaa.gov/education/kits/tides/media/tide06a_450.gif .

A simple animation of spring and neap tides is found here: http://oceanservice.noaa.gov/education/kits/tides/media/supp_tide06a.html .

Studying ocean tides' rhythmic movements helps scientists understand the ocean and the Sun/Moon/Earth system. This QUEST video explains how tides work, and visits the oldest continually operating tidal gauge in the Western Hemisphere.

Watch it at http://www.kqed.org/quest/television/science-on-the-spot-watching-the-tides .



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Summary

- The primary cause of tides is the gravitational attraction of the Moon, which causes two high and two low tides a day.
- When the Sun's and Moon's tides match, there are spring tides; when they are opposed, there are neap tides.
- The difference between the daily high and the daily low is the tidal range.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=gftT3wHJGtg

1. If the moon only goes around Earth once per day why are there two high tides per day?
2. If you are standing on the shore and it is high tide, what are the two possible locations for the moon relative to where you are?
3. What is the secondary reason for the tides? Why are these tides weaker than the moon's tides?
4. Why is it good that the moon is not closer to the Earth?

Explore More Answers

1. The moon pulls the water that is closest to it toward it to make one high tide. The second is made because the moon pulls the earth toward it leaving behind the water on the other side of the planet.
2. The moon must be either directly overhead or on the exact opposite of the planet.
3. The sun also causes tides. They are weaker because the sun is so far away.
4. The Earth's tidal forces would pull rocks off the moon.

Review

1. Using the terminology of waves, describe how the gravitational attraction of the Moon and Sun make a high tide and a low tide.
2. Describe the causes of spring and neap tides.
3. What are the possible reasons that the Bay of Fundy has such a large tidal range?

Review Answers

1. The Moon pulls the water toward it and creates the crest of a wave. This is the high tide. The trough of the wave is at 90-degrees and it is the low tide. When Moon and Sun are both in the same or exactly opposite locations the crests add up and make a higher high tide. When they are at 90-degrees the crests and troughs add together and the high and low tides are not as different from each other.
2. Spring tides are when the high tides from the moon and the sun add up. Neap tides are when the moon and sun are perpendicular to each other and so the high and low tides are not very different from each other.
3. The slope of the continental margin is very shallow so it takes a long distance for the elevation to change very much.

1.15 Surface Ocean Currents

- Define major and local surface currents.
- Explain how major and local surface currents are created.

Why is so much trash so far from land?

The Great Pacific Garbage Patch is a region in the center of the north Pacific Ocean where plastic bits and chemicals are concentrated. Trash from the countries bordering the region enters the oceans and is transported into the center of the North Pacific Gyre, where it remains. Seabirds may get sick from ingesting so much plastic instead of food. More about the patch can be found in the chapter Human Impacts on Earth's Systems.

Surface Currents

Ocean water moves in predictable ways along the ocean surface. **Surface currents** can flow for thousands of kilometers and can reach depths of hundreds of meters. These surface currents do not depend on weather; they remain unchanged even in large storms because they depend on factors that do not change.

Surface currents are created by three things:

- global wind patterns
- the rotation of the Earth
- the shape of the ocean basins

Surface currents are extremely important because they distribute heat around the planet and are a major factor influencing climate around the globe.

Global Wind Patterns

Winds on Earth are either global or local. Global winds blow in the same directions all the time and are related to the unequal heating of Earth by the Sun —that is, more solar radiation strikes the Equator than the polar regions —and the rotation of the Earth —that is, the **Coriolis effect**. Coriolis was described in the chapter Earth as a Planet. The causes of the global wind patterns will be described in detail in the chapter Atmospheric Processes.

Water in the surface currents is pushed in the direction of the major wind belts:

- trade winds: east to west between the Equator and 30^oN and 30^oS
- westerlies: west to east in the middle latitudes
- polar easterlies: east to west between 50^o and 60^o north and south of the Equator and the north and south pole

Shape of the Ocean Basins

When a surface current collides with land, the current must change direction. In the **Figure** 1.38, the Atlantic South Equatorial Current travels westward along the Equator until it reaches South America. At Brazil, some of it goes north and some goes south. Because of Coriolis effect, the water goes right in the Northern Hemisphere and left in the Southern Hemisphere.

Gyres

You can see on the map of the major surface ocean currents that the surface ocean currents create loops called **gyres** (**Figure** 1.39). The Antarctic Circumpolar Current is unique because it travels uninhibited around the globe. Why is it the only current to go all the way around?

This video shows the surface ocean currents set by global wind belts: http://www.youtube.com/watch?v=Hu_Ga0JYFNg (1:20).

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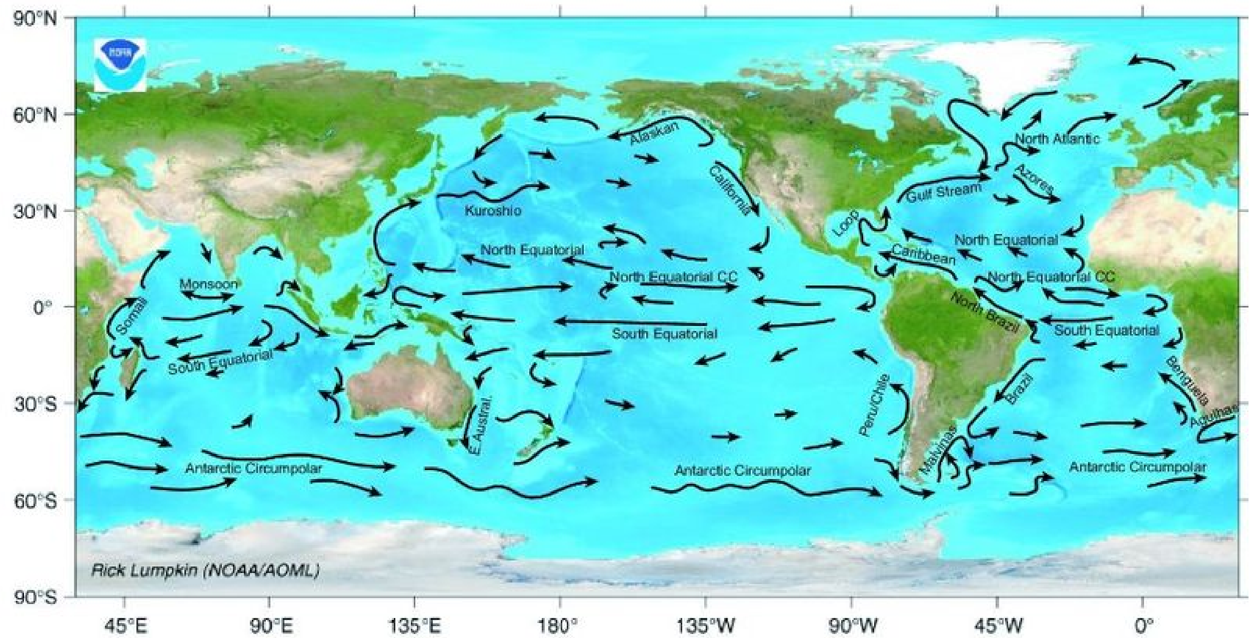


FIGURE 1.38
The major surface ocean currents.

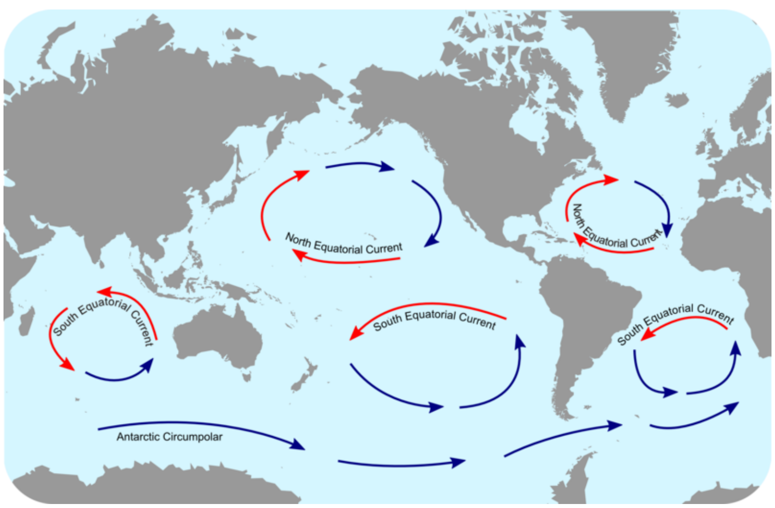


FIGURE 1.39
The ocean gyres. Why do the Northern Hemisphere gyres rotate clockwise and the Southern Hemisphere gyres rotate counterclockwise?

Local Surface Currents

The surface currents described above are all large and unchanging. Local surface currents are also found along shorelines (**Figure** 1.40). Two are **longshore currents** and **rip currents**.

Rip currents are potentially dangerous currents that carry large amounts of water offshore quickly. Look at the rip-current animation to determine what to do if you are caught in a rip current: http://www.onr.navy.mil/Focus/ocean/motion/currents2.htm . Each summer in the United States at least a few people die when they are caught in rip

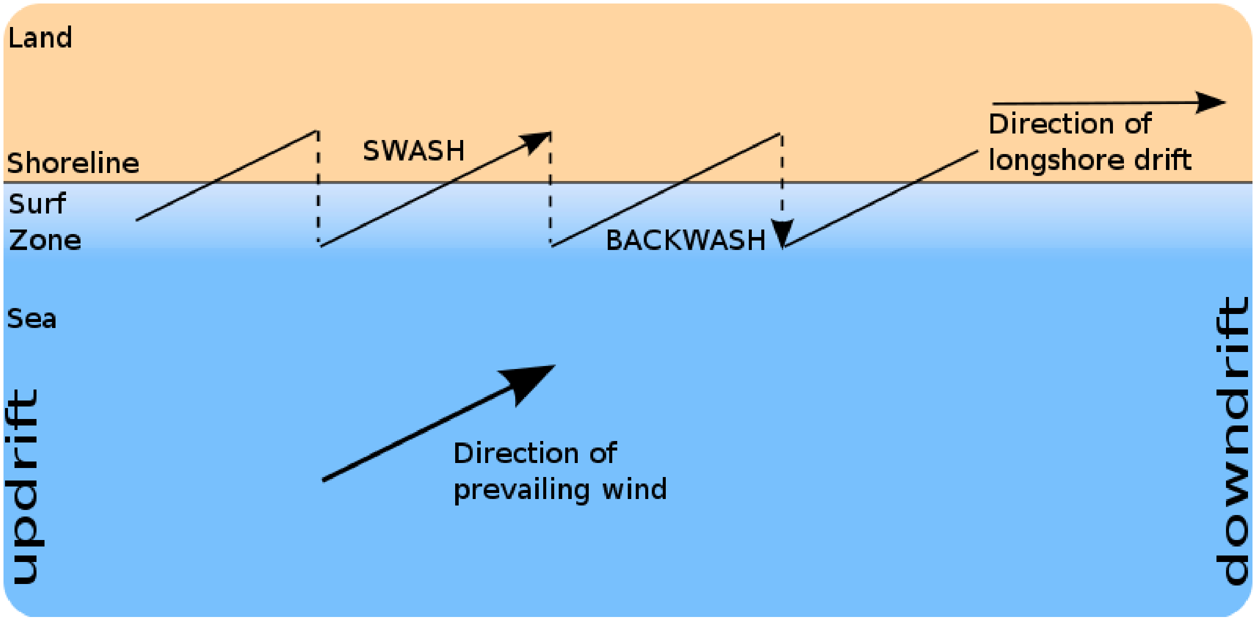


FIGURE 1.40
Longshore currents move water and sediment parallel to the shore in the direction of the prevailing local winds.

currents.

This animation shows the surface currents in the Caribbean, the Gulf of Mexico, and the Atlantic Ocean off of the southeastern United States: http://polar.ncep.noaa.gov/ofs/viewer.shtml?-gulfmex-cur-0-large-rundate=latest .

Summary

- Major surface ocean currents are the result of global wind patterns, Earth's rotation, and the shape of the ocean basins.
- Major surface currents circle the oceans in five gyres.
- Local surface currents, like longshore and rip currents, move near shorelines.

Making Connections

MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/54192

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=ZP5BtLSU9z4

1. Which direction do currents move across the equator both north and south? What direction does the counter current flow?
2. What is unique about the Antarctic Circumpolar Current and why?
3. What are gyres?
4. Where are currents that move heat from the equator to the higher latitudes flowing relative to the continents?
5. Why is the Caribbean so hot and humid?
6. Why does the Gulf Stream cool before it reaches Europe?
7. Why is it warmer and more pleasant to swim off of the Eastern Seaboard than off of California?
8. What are the western boundary currents due to?

Explore More Answers

1. Toward the west; back toward the east.
2. The current just continues around the planet because it doesn't run into a continent.
3. Circulation patterns caused by Coriolis Effect and continental barriers.
4. They travel up the west side of the ocean basins.
5. Hot air comes in from the equatorial current and heats up.
6. It is hit by two currents coming from the north, the Labrador and E Greenland currents.
7. Off of California the currents are coming from the north and so they are cold. The Eastern Seaboard is getting the Gulf Stream, which is warm.
8. The eastern portions of the continents are hit with water

Review

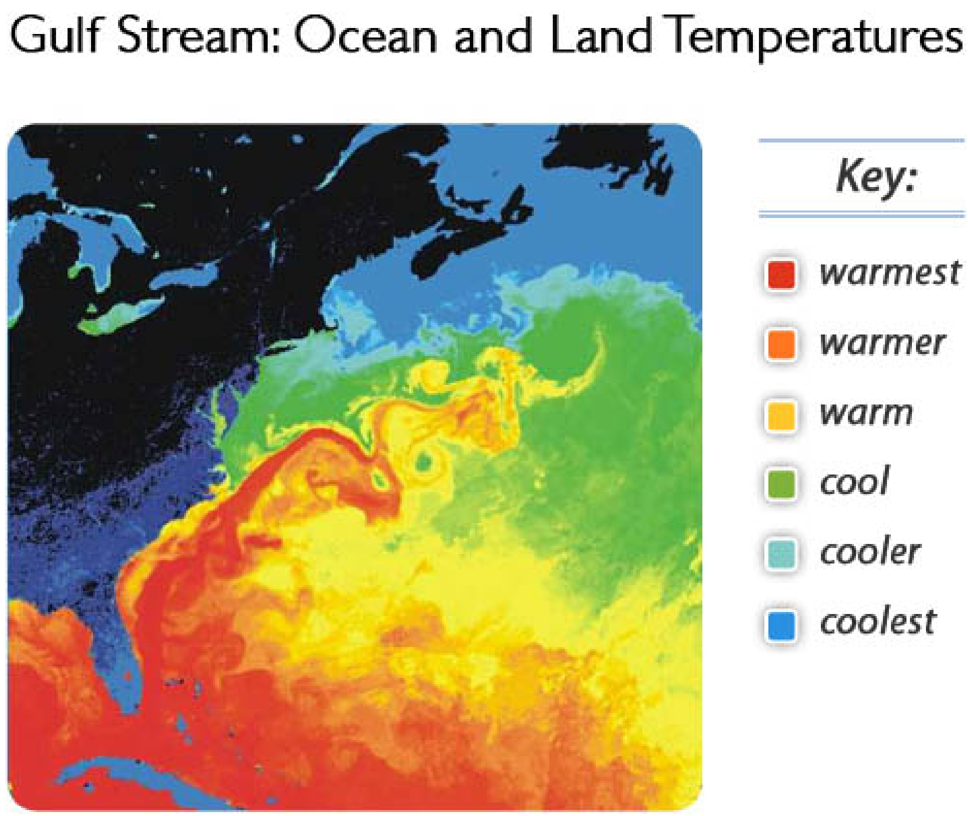
1. Describe the motion of a water particle that is stuck in a gyre in the North Pacific.
2. What should you do if you get stuck in a rip current?
3. What would happen if a major surface current did not run into a continent? Note that this is what happens with the Antarctic Circumpolar Current.

Review Answers

1. The water molecule just goes around and around the gyre.
2. Swim parallel to the shore and then try to swim in once you're out of the rip current.
3. The current would just go around the planet like the Antarctic Circumpolar Current does.

1.16 How Ocean Currents Moderate Climate

- Explain how ocean currents like the Gulf Stream influence Earth's climate.



Why is northwestern Europe relatively warm?

The Gulf Stream waters do a lot for Europe. The equatorial warmth this current brings to the North Atlantic moderates temperatures in northern Europe. In a satellite image of water temperature in the western Atlantic it is easy to pick out the Gulf Stream, which brings warmer waters from the Equator up the coast of eastern North America.

Effect on Global Climate

Surface currents play an enormous role in Earth's climate. Even though the Equator and poles have very different climates, these regions would have more extremely different climates if ocean currents did not transfer heat from the equatorial regions to the higher latitudes.

The Gulf Stream is a river of warm water in the Atlantic Ocean, about 160 kilometers wide and about a kilometer deep. Water that enters the Gulf Stream is heated as it travels along the Equator. The warm water then flows up the east coast of North America and across the Atlantic Ocean to Europe (see opening image). The energy the Gulf Stream transfers is enormous: more than 100 times the world's energy demand.

The Gulf Stream's warm waters raise temperatures in the North Sea, which raises the air temperatures over land between 3 to 6°C (5 to 11°F). London, U.K., for example, is at about six degrees further south than Quebec, Canada.

However, London's average January temperature is 3.8°C (38°F), while Quebec's is only -12°C (10°F). Because air traveling over the warm water in the Gulf Stream picks up a lot of water, London gets a lot of rain. In contrast, Quebec is much drier and receives its precipitation as snow.

FIGURE 1.41
London, England in winter.

FIGURE 1.42
Quebec City, Quebec in winter.

Summary

- Water in the Gulf Stream travels along the Equator and is heated as it goes.
- The Gulf Stream brings warm water north along the Atlantic coast of the United States and then across the northern Atlantic to the British Isles.
- A tremendous amount of energy is transferred from the equatorial regions to the polar regions by ocean currents.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=J7kIGdhW9jQ

1. What drives ocean and atmospheric circulation? What does the ocean store more of than the atmosphere?
2. What are surface ocean currents driven by? What are deeper ocean currents driven by?
3. What is the importance of upwelling nutrients in the ocean?
4. What causes El Nino and La Nina? What happens during these events?
5. How does heat exchange between ocean surface and atmosphere influence climate?
6. How do hurricanes form in the oceans? Where does the heat come from to power them?
7. What kind of life would be on Earth if there were no oceans?

Explore More Answers

1. heat; heat
2. surface winds; density
3. They provide rich food resources for surface life.
4. Changing wind patterns displace warm and cool water in the equatorial Pacific. The replacement of cold water by warm water leads to air temperature swings and changes in humidity, which alters weather by steering storms to different locations.
5. One example is that the Gulf Stream brings moderate temperatures to Europe.
6. Thunderstorms in the tropics become organized into large rotating systems with strong winds that grow into hurricanes. They intensify over the hot water.
7. The ocean is the primary storehouse of Earth's water. Without water there would be no life.

Review

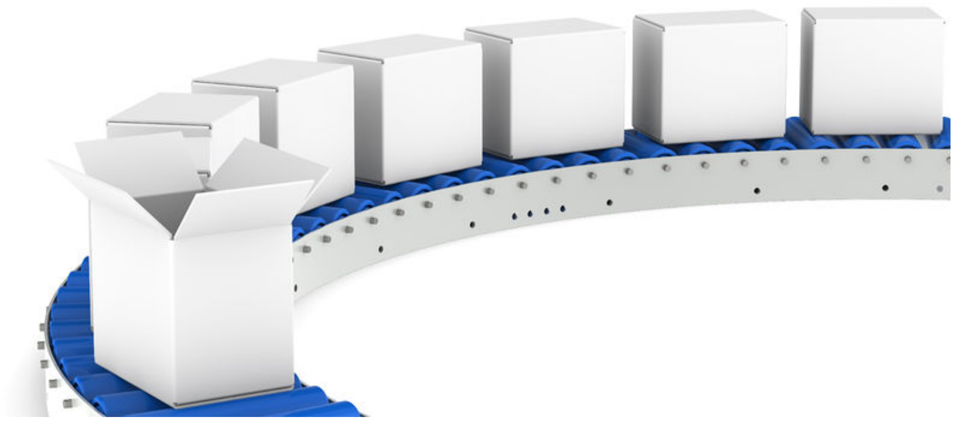
1. Explain why England is relatively mild and rainy in winter but central Canada, at the same latitude and during the same season, is dry and frigid.
2. Where else do you think ocean currents might moderate global climate?
3. What would Earth be like if ocean water did not move?

Review Answers

1. The Gulf Stream brings heat and moisture from the tropics up the eastern part of North America and over to the British Isles. Global winds blowing west to east bring that warm moist air into England. The Gulf Stream's energy keeps temperatures warmer and the humidity makes it wetter than Canada.
2. All of the major currents move warmer water to colder regions and cooler water to warmer regions so this moderation happens all over the planet.
3. Temperatures would not be moderate, but would be hot in the equatorial regions and cold in the polar regions with gradational differences in between.

1.17 Deep Ocean Currents

- Describe the processes that drive deep ocean currents.



How are ocean currents like a conveyor belt?

Seawater doesn't just circulate around the surface, it moves through the deep sea. Just like at the surface, normal circulation patterns transport much of the water. Seawater is moved as if on a conveyor through the surface and deep ocean, a trip that takes hundreds of years.

Deep Currents

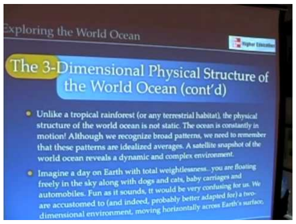
Thermohaline circulation drives deep ocean circulation. Thermo means heat and haline refers to salinity. Differences in temperature and in salinity change the density of seawater. So thermohaline circulation is the result of density differences in water masses because of their different temperature and salinity.

What is the temperature and salinity of very dense water? Lower temperature and higher salinity yield the densest water. When a volume of water is cooled, the molecules move less vigorously, so same number of molecules takes up less space and the water is denser. If salt is added to a volume of water, there are more molecules in the same volume, so the water is denser.

Downwelling

Changes in temperature and salinity of seawater take place at the surface. Water becomes dense near the poles. Cold polar air cools the water and lowers its temperature, increasing its salinity. Fresh water freezes out of seawater to become sea ice, which also increases the salinity of the remaining water. This very cold, very saline water is very dense and sinks. This sinking is called **downwelling**.

This video lecture discusses the vertical distribution of life in the oceans. Seawater density creates currents, which provide different habitats for different creatures: http://www.youtube.com/watch?v=LA1jxeXDsdA (6:12).



MEDIA

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Two things then happen. The dense water pushes deeper water out of its way and that water moves along the bottom of the ocean. This deep water mixes with less dense water as it flows. Surface currents move water into the space vacated at the surface where the dense water sank (**Figure** 1.43). Water also sinks into the deep ocean off of Antarctica.

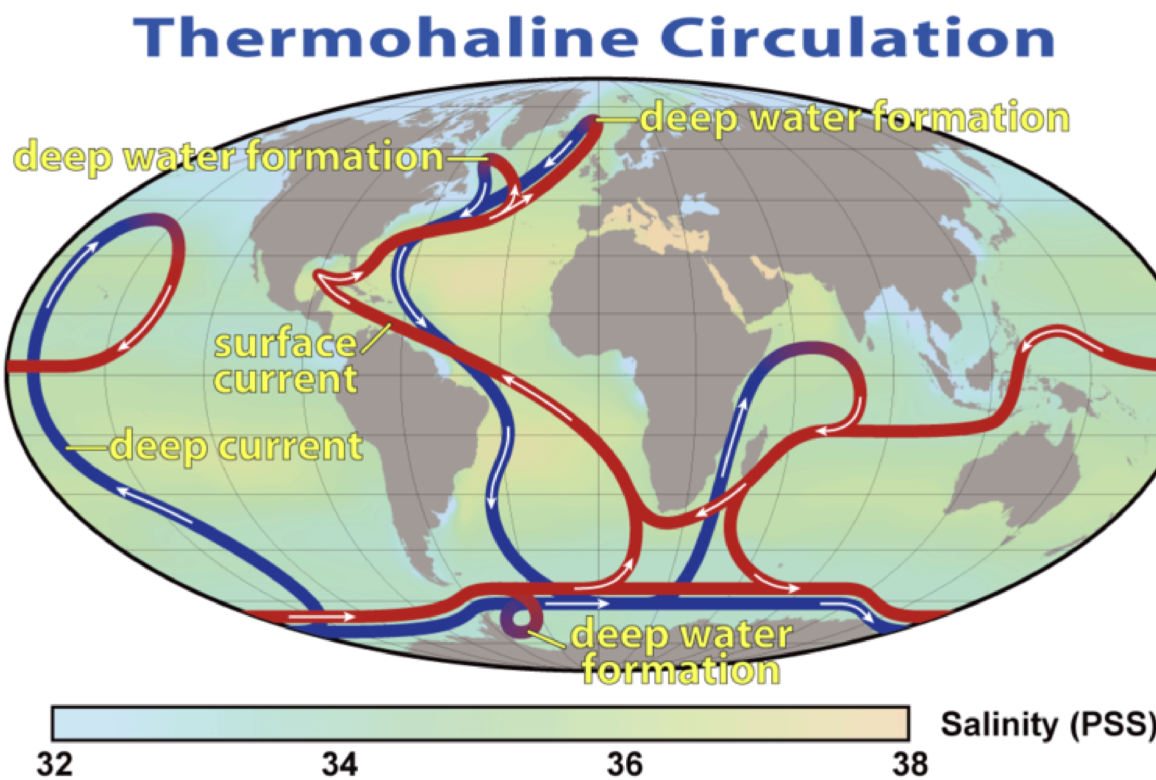

FIGURE 1.43

Cold water (blue lines) sinks in the North Atlantic, flows along the bottom of the ocean and upwells in the Pacific or Indian. The water then travels in surface currents (red lines) back to the North Atlantic. Deep water also forms off of Antarctica.

Upwelling

Since unlimited amounts of water cannot sink to the bottom of the ocean, water must rise from the deep ocean to the surface somewhere. This process is called **upwelling** (**Figure** 1.44).

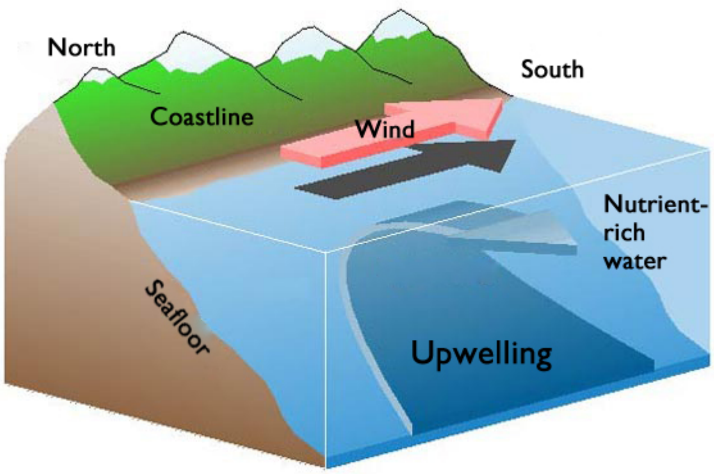

FIGURE 1.44
Upwelling forces denser water from below to take the place of less dense water at the surface that is pushed away by the wind.

Generally, upwelling occurs along the coast when wind blows water strongly away from the shore. This leaves a void that is filled by deep water that rises to the surface.

Upwelling is extremely important where it occurs. During its time on the bottom, the cold deep water has collected nutrients that have fallen down through the water column. Upwelling brings those nutrients to the surface. Those nutrients support the growth of plankton and form the base of a rich ecosystem. California, South America, South Africa, and the Arabian Sea all benefit from offshore upwelling.

An animation of upwelling is seen here: http://oceanservice.noaa.gov/education/kits/currents/03coastal4.html .

Upwelling also takes place along the Equator between the North and South Equatorial Currents. Winds blow the surface water north and south of the Equator, so deep water undergoes upwelling. The nutrients rise to the surface and support a great deal of life in the equatorial oceans.

Summary

- Cooling or evaporation of fresh water from the sea surface makes surface water dense and causes it to sink.
- Downwelling of cold, dense water drives thermohaline circulation.
- Upwelling takes place at some coastlines or along the Equator and brings cool, nutrient-rich water to the surface.

Making Connections

MEDIA
Click image to the left for use the URL below.
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Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=SnKoo3WhJu0 Watch to 6:45

1. When ice forms from seawater what is the composition of the ice? How does that change the composition of seawater nearby?
2. What are the characteristics of the seawater that is left behind? What happens to it as a result of these characteristics?
3. What do the Antarctic Bottom Water and the North Atlantic Deep Water contain and why? Why does cold water trap more gas?
4. Why are the cold polar regions so rich in life?

Explore More Answers

1. The ice is almost all fresh water so the seawater nearby is more saline.
2. It is cold and saline so it is dense. As a result it sinks and forms Antarctic Bottom Water.
3. The deep water contains nutrients and carbon dioxide. Cold water is moving slower and the gas molecules can be incorporated.
4. The carbon dioxide and nutrients trapped in the cold water support a large food web since phytoplankton can photosynthesize if there is a little sunlight.

Review

1. Why is upwelling important?
2. How does downwelling drive thermohaline circulation?
3. What would happen if water in the north Pacific no longer became cold and dense enough to sink?

Review Answers

1. Upwelling brings cold nutrient rich water up to the surface, which supports phytoplankton growth and a rich ecosystem.
2. Dense water pushes the water that is already at the bottom along. Some of it moves through the deep ocean and some of it will upwell.
3. This would stop thermohaline circulation and perhaps end the ocean conveyor belt or at least reduce it.

Summary

What makes the dot blue, of course, is water. Water cycles through multiple reservoirs —glaciers, lakes, oceans, groundwater, and life, among others. As it cycles, it changes state between solid, liquid, and gas. Water is almost always moving, imperceptibly slowly as an ice crystal in a glacier or at rapid speeds in flooding stream or an ocean current. Surface water cycles through streams and into ponds and lakes. When too much water falls, the stream or even lake may flood. Water from the surface may filter through the ground to enter an aquifer. Streams eventually enter the ocean, which has motions of its own. Water travels in surface currents and may undergo downwelling to cycle through the deep ocean. Ocean currents are important to the planet, for example they moderate climate by bringing warm equatorial water toward the poles and cold polar water toward the Equator.

1.18 References

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