



Eyewitness



# WATER

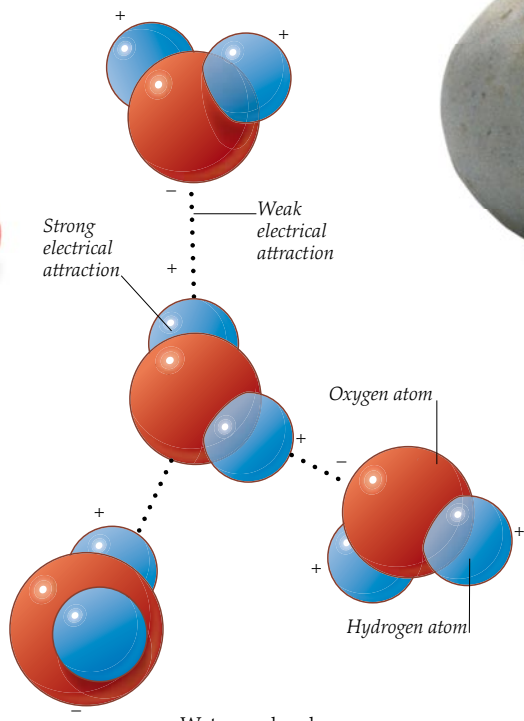


# Eyewitness **WATER**





Sources of water



Water molecules



Snake hatching from its egg



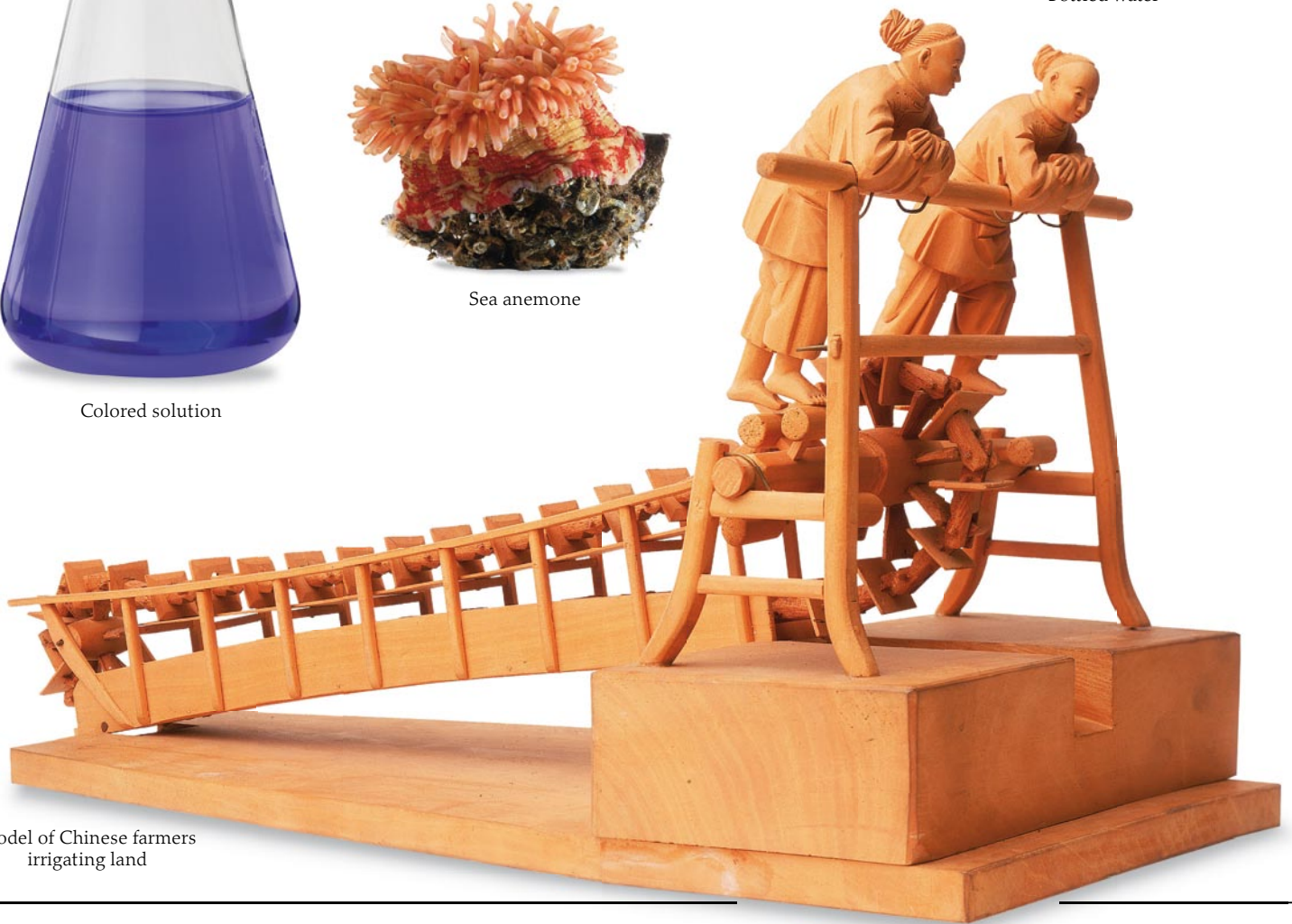
Bottled water



Colored solution



Sea anemone



Model of Chinese farmers irrigating land



Snowflake under  
the microscope



# Eyewitness WATER



Written by  
JOHN WOODWARD



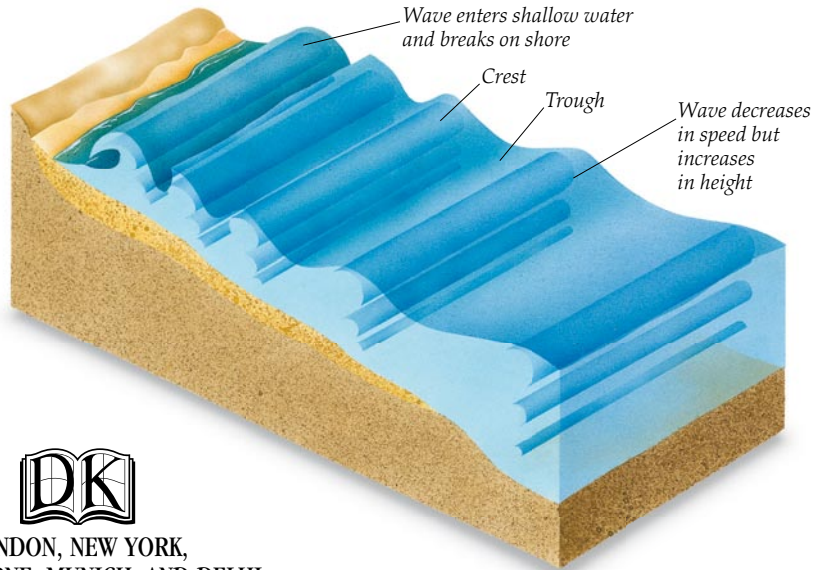
Drop of water



DK Publishing



Seedlings in a hydroponic solution



Waves moving toward the shore



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Model of a sea-going raft



Sea slug

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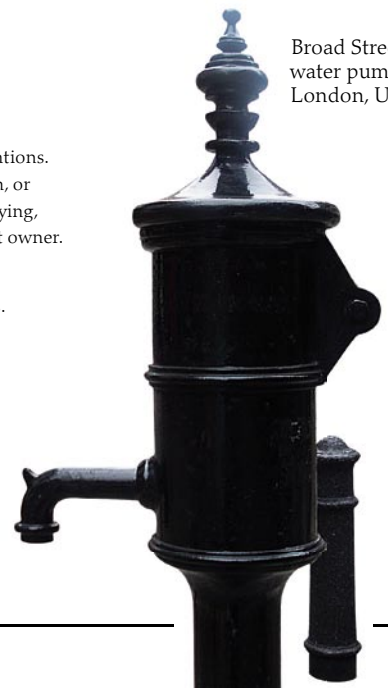
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Model of a submersible

# Watery world

**W**ATER IS THE MOST IMPORTANT FEATURE of our planet. A simple combination of hydrogen and oxygen, water is probably common throughout the universe, but mainly in the form of ice or water vapor. Both of these are known to occur throughout the solar system, but liquid water seems to be very rare because it can exist only within a limited temperature range. This liquid water is vital to all living organisms, from the simplest microbe to the most complex animal, so it is fundamental to the existence of the whole web of life, humanity, and civilization. Without water, Earth would be a sterile ball of rock.



## WET PLANET

Earth is the only planet in the solar system with oceans, rivers, and lakes. It also has vast polar ice sheets and mountain glaciers. The heat of the Sun creates water vapor, which forms a significant part of the atmosphere (the air surrounding Earth), and some of this vapor condenses into water droplets to form visible clouds. So Earth is also the only planet where water is known to exist as ice, liquid water, and water vapor.

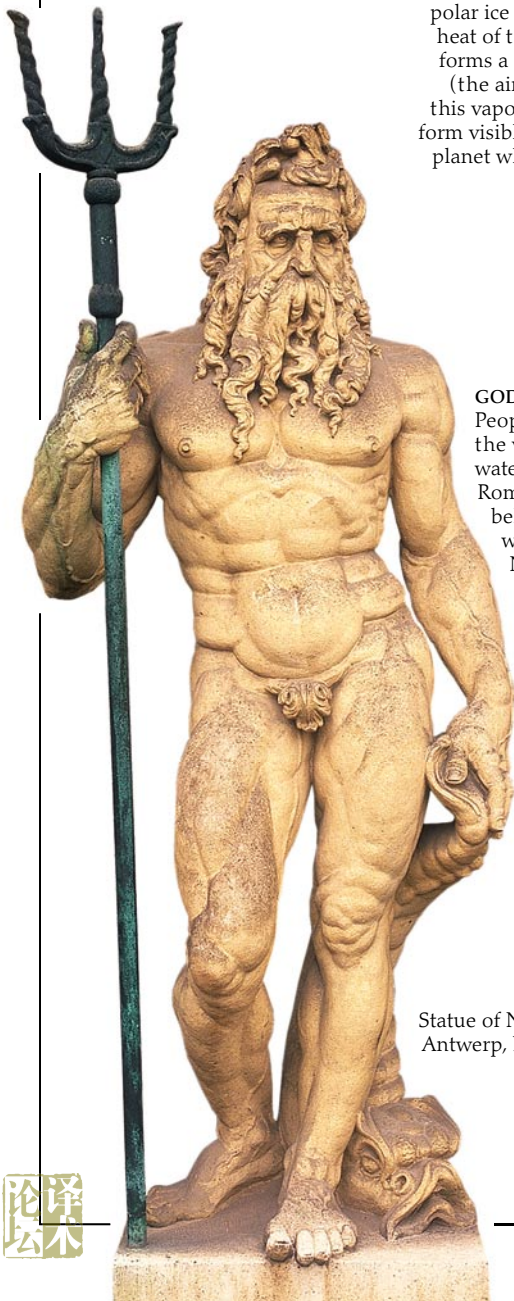
*Oceans contain most of the world's water and cover 71 percent of Earth's surface*

*Clouds consist of tiny droplets of liquid water*

## GOD OF WATER

People have always understood the vital importance of fresh water. During the period of the Roman Empire, many people believed that supplies of fresh water were controlled by Neptune, the god of the sea. At the driest times of the year, they made ritual offerings to him, hoping that he would save them from serious drought.

Statue of Neptune, Antwerp, Belgium



*Ice covers the South and North poles*

*Ice in a Martian crater*



## OTHER WORLDS

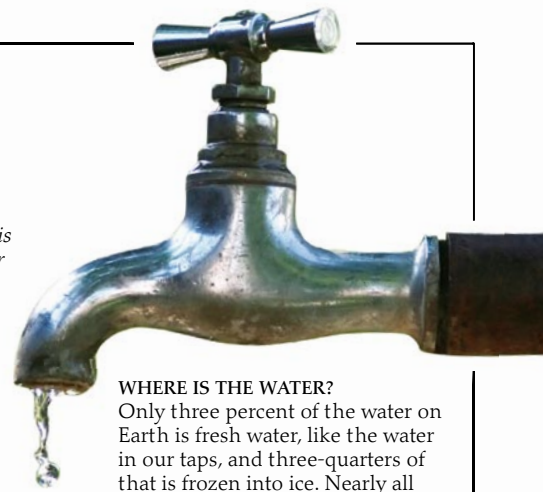
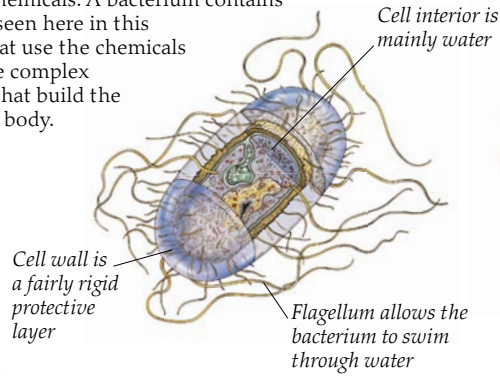
Most of the water in the solar system is in the form of ice or water vapor, and neither can support life. There was once liquid water on Mars, but now there is only ice. There is water vapor on Mercury, but no lakes or seas. However, it is possible that liquid water—and even life—exists on Europa, one of Jupiter's moons.





### VITAL MEDIUM

Water is essential for life on Earth. No other liquid is so good at dissolving other substances, and this is what makes it an ideal medium for the chemistry of life. Simple organisms, such as this bacterium, are little more than bags of water and dissolved chemicals. A bacterium contains structures, seen here in this cutaway, that use the chemicals to make the complex molecules that build the bacterium's body.



### WHERE IS THE WATER?

Only three percent of the water on Earth is fresh water, like the water in our taps, and three-quarters of that is frozen into ice. Nearly all the rest is salty ocean. However, water is constantly evaporating from the oceans, falling as rain, and flowing over the land to the sea, in a continuous cycle.

### THE FOURTH ELEMENT

In the fifth century BCE, the ancient Greek philosopher Empedocles defined water as one of the four elements: earth, air, fire, and water. According to an earlier Greek scholar, Thales, water was the primal substance from which all other substances were made.



16th-century portrait of Empedocles

Hunter with trapped birds



Fragment of a mural from the tomb of Nebamun, Thebes



### GLOWING ICE

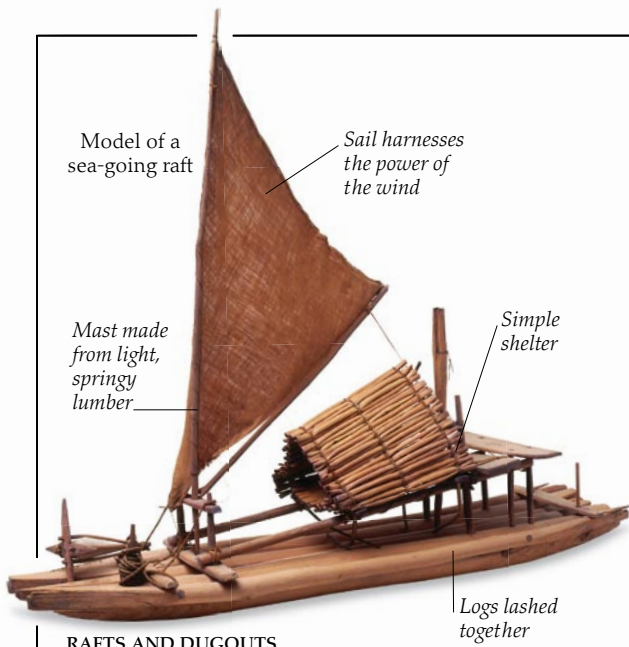
Water is constantly hurtling around the solar system in the form of comets—"dirty snowballs" of ice and dust with elongated orbits that swerve around the Sun before vanishing beyond the outer planets. They appear for a few days in the night sky, trailing clouds of glowing debris, then fade away.

### PRECIOUS LIQUID

Since water is essential for life, it is vital for survival, so people have always lived near sources of fresh water. When the development of farming enabled people to build the first cities, most of these were sited by reliable water sources. The earliest civilizations were based on great rivers like the Euphrates, Tigris, Nile, and Yellow rivers. This wall painting dating from about 3,400 years ago shows an Egyptian hunter in the Nile marshes.



# Water and history



Model of a sea-going raft

Sail harnesses the power of the wind

Mast made from light, springy lumber

Simple shelter

Logs lashed together

## RAFTS AND DUGOUTS

The first water craft were built from logs, either hollowed out as canoes or lashed together as rafts. Using such craft, people were able to spread along rivers and even along coasts. This led to the earliest ocean crossings by the brave people who colonized Australia from Indonesia, some 50,000 years ago.

## FINDING THE WAY

At first sailors relied on local knowledge to find their way and avoid dangerous waters. But over time they depended increasingly on charts such as this 17th-century map of northern Europe. Yet these were no use without some way of finding a ship's position at sea. The invention of the compass for finding magnetic north, the sextant for navigation by the Sun and stars, and the development of clocks that could give accurate times for use in calculating longitude, all made seafaring much safer.



SINCE WATER IS VITAL TO OUR SURVIVAL, it has always played a pivotal role in human history. Most cities and other settlements were sited by sources of fresh water, especially in dry regions. But water has also been used for travel—along rivers, coasts, and eventually out of sight of land. For much of history overland travel could be very difficult, so despite the dangers on the water it was often easier to travel by boat. Many great cities developed on natural harbors and rivers that were large enough for ships to travel on them. These cities became wealthy through maritime trade. Having learned how to cross oceans, people were then able to visit and colonize distant lands.



Statue of James Cook (1728–1779)



Marco Polo sets sail from Venice

## TRADING CITIES

Access to trading routes brought wealth to many coastal and river settlements. Some developed into spectacular cities such as Venice, Shanghai, and New York. Merchants, including the 14th-century Venetian explorer Marco Polo, brought exotic goods, such as this Chinese porcelain vase, back from distant lands.



Chinese vase

## VOYAGES OF DISCOVERY

As knowledge of the oceans and how to cross them grew, seafarers became more ambitious. Explorers such as the English sailor James Cook—here commemorated by a statue in Hawaii, where he was killed—made scientific expeditions to map all the world's oceans, continents, and islands.



Cinnamon



Cloves



Cardamom



Nutmeg



**SPICE ISLANDS**

In the 16th and 17th centuries the spice islands of the East Indies were the only sources of valuable products such as nutmeg and cloves. European traders fought for control over these islands. The first voyage around the world, led by the Portuguese sailor Ferdinand Magellan in 1519–1523, originated as a plan to reach the islands by crossing the Pacific rather than the usual route across the Indian Ocean.

**RIDING THE WINDS**

In the 19th and early 20th centuries huge sailing ships crossed oceans to bring tea from China and grain from Australia. They sailed in some of the stormiest waters on Earth, but the stronger the winds, the faster the passage. The fastest ships raced each other to be the first home—a tradition that is kept alive by the around-the-world yacht races of today.

*Danmark*, a Danish merchant navy training ship, was built in 1933



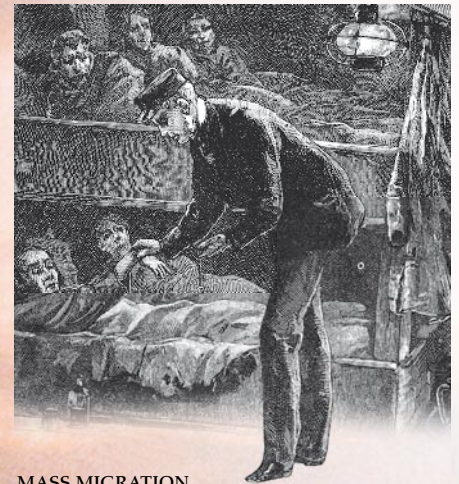
Sharp cutlass

Single-shot pistol



**PIRACY**

Trading ships packed with rich cargo were a constant temptation to pirates, who were often sea captains who had turned to crime. English pirate Edward Teach, or "Blackbeard," was notorious for his terrifying appearance, designed to make his victims surrender without a fight.

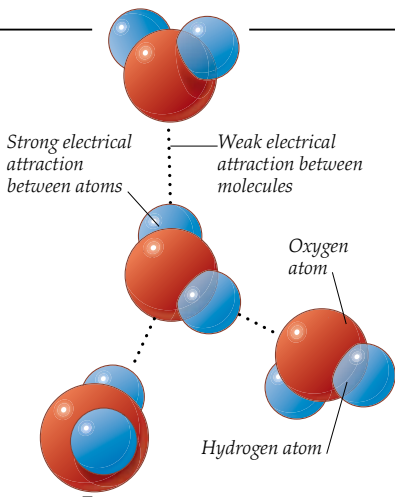


**MASS MIGRATION**

The seas have offered a migration route for people from the earliest times, but regular ships to the Americas and Australia from the mid-18th century permitted mass migrations of people such as these refugees from the Irish famine in the 1840s. Immigrants often traveled in squalid conditions on badly maintained vessels, and many died at sea.

# What is water?

WE ARE ALL SO USED TO WATER that we barely notice its unusual nature. Most of us think of water as a flowing, splashing liquid, but it is also the only natural substance that is found in all three states—liquid, solid (ice), and gas (water vapor)—at the temperatures normally found on Earth. When it turns into ice it actually expands, or gets bigger, unlike all other substances that take up less space when they freeze. Water may also clump together in drops instead of spreading out in thin layers, and it forms elastic films at its surface that can support the weight of small animals. All these properties can be explained by water's chemical makeup.



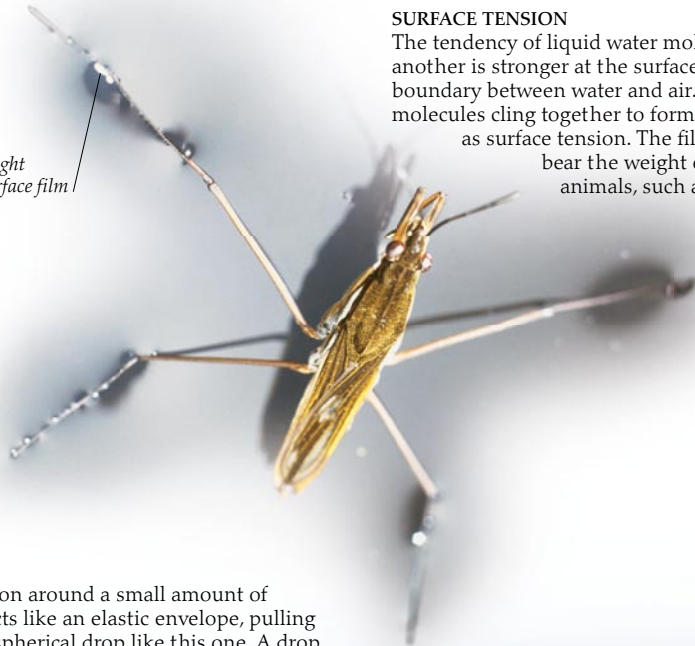
## TRIANGULAR MOLECULES

Water is a mass of molecules, each with two hydrogen atoms and one oxygen atom. The atoms are held together by electrical charges that make them form a triangle. The charges also make the molecules stick to one another like tiny triangular magnets to form liquid water.

## SURFACE TENSION

The tendency of liquid water molecules to stick to one another is stronger at the surface of a pool, at the boundary between water and air. It makes the surface molecules cling together to form an elastic film known as surface tension. The film is strong enough to bear the weight of small aquatic animals, such as this water strider.

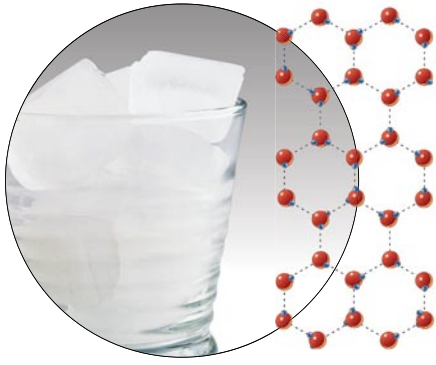
*Insect's weight  
dimples surface film*



## WATER DROPS

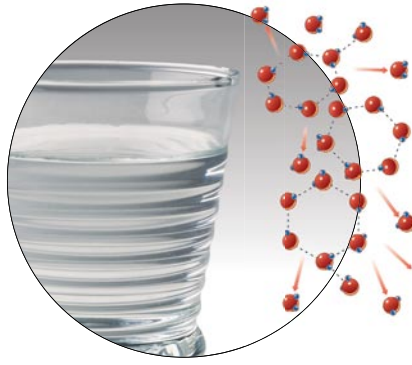
The surface tension around a small amount of airborne water acts like an elastic envelope, pulling the water into a spherical drop like this one. A drop that lands on a surface that repels water, such as a hairy leaf, has a similar spherical form because the envelope of surface tension is not distorted by the water sticking to the leaf. But water molecules can also stick to other materials such as glass, so the surface tension breaks down and the drop spreads out in a thin layer.





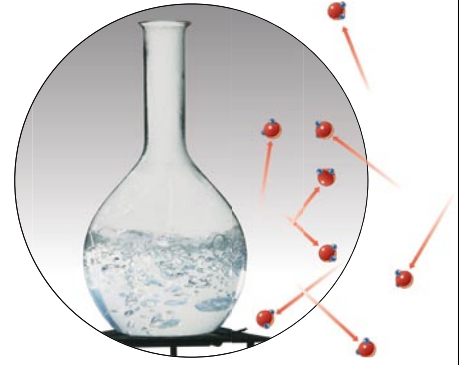
**SOLID ICE**

When water freezes, the molecules lock into an open structure that forms hexagonal ice crystals. The molecules are farther apart than they are in the liquid phase, so water expands as it freezes. This means that ice is not as dense as water, which is why it floats.



**LIQUID WATER**

When ice melts, the regular structure of the molecules in the ice crystals collapses. The molecules move closer to each other, attracted by the electrical forces that hold them together. But they can still move around, which is why water is liquid.



**WATER VAPOR**

The molecules in liquid water are always moving. If the water is heated, this gives the molecules more energy, so they move faster. Eventually they may move fast enough to break free and burst into the air to become an invisible gas, called water vapor.



**FREEZING POINT**

Water freezes at 32°F (0°C), but only if it is pure. Impurities such as dissolved salt lower its freezing point, which is why spreading salt on winter roads reduces the risk of ice forming. The salt in seawater causes this water to freeze at a lower temperature than fresh water, at roughly 28.8°F (-1.8°C).



Visible steam consists of tiny water droplets

**BOILING POINT**

At sea level, water boils at 212°F (100°C). But on mountains where the atmospheric pressure is lower, water evaporates more easily and boils at a lower temperature. This allows people in Tibet to drink their tea while it is still boiling. Higher pressure raises boiling point, enabling water in a pressure cooker to be "superheated" to 248°F (120°C) or more.



**HEAVY WATER**

Water is made of two gases, so it is surprising that a bucket of water is so heavy. It is heavy because all the molecules cling together tightly, making it dense. Its density enables water to support less dense liquids such as oil, or materials that contain air spaces, such as wood.

Oil floats on water  
Water is heavier than oil



**LIQUID, SOLID, GAS**

These icy-furred macaques in a hot pool are experiencing all three phases of water at once. This is possible because ice forms easily in the cold air, and water does not need to reach boiling point for some of its molecules to escape and form water vapor.

# Fresh and saltwater

**WATER IS RARELY PURE.** As it flows from one place to another it carries a wide range of substances with it. This is because the atoms of chemicals dissolve, or disperse, in water more easily than in any other liquid. The dissolved chemicals form a liquid called a solution. Many different liquids, gases, and solids can form solutions. The ocean is a solution of minerals that make it taste salty. Some dissolved minerals make acids and alkalis, which are chemicals that can cause strong reactions. Water also carries small particles that do not dissolve. These mixtures are called suspensions.

Limescale on kettle element



**HARD AND SOFT**  
Rainwater flowing over rocks such as limestone dissolves minerals called carbonates. If this "hard water" is boiled, the carbonates are deposited in the kettle as limescale. Rainwater that flows over insoluble rock such as granite or sandstone is "soft water" that does not cause limescale.



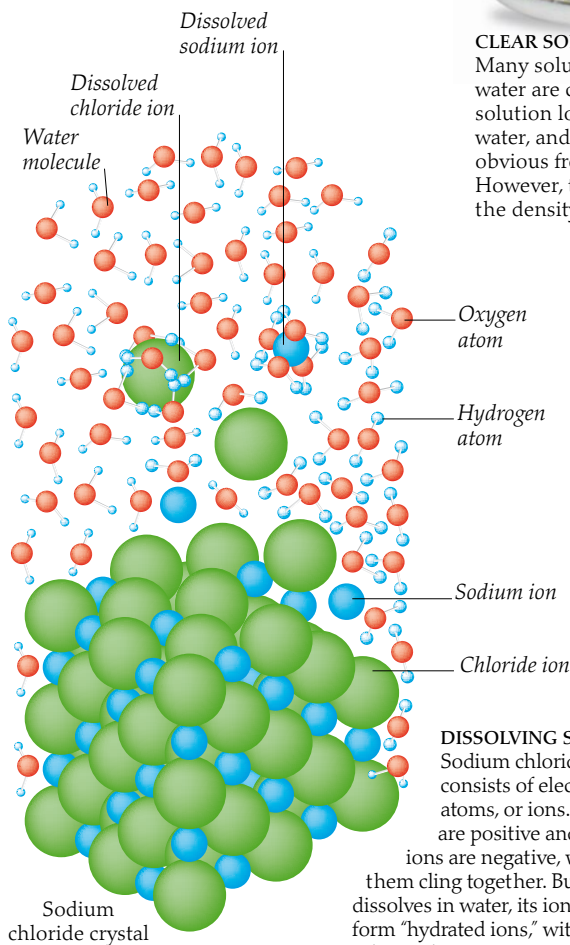
**CLEAR SOLUTION**  
Many solutions of chemicals in water are colorless. A saltwater solution looks just like pure water, and the difference is only obvious from the scent or taste. However, the salt does increase the density of the water.



**COLORED SOLUTION**  
If water dissolves chemicals that are colored, they can form a colored solution. But since the atoms or ions of the original substance are completely dispersed, the solution is transparent, like pure water.



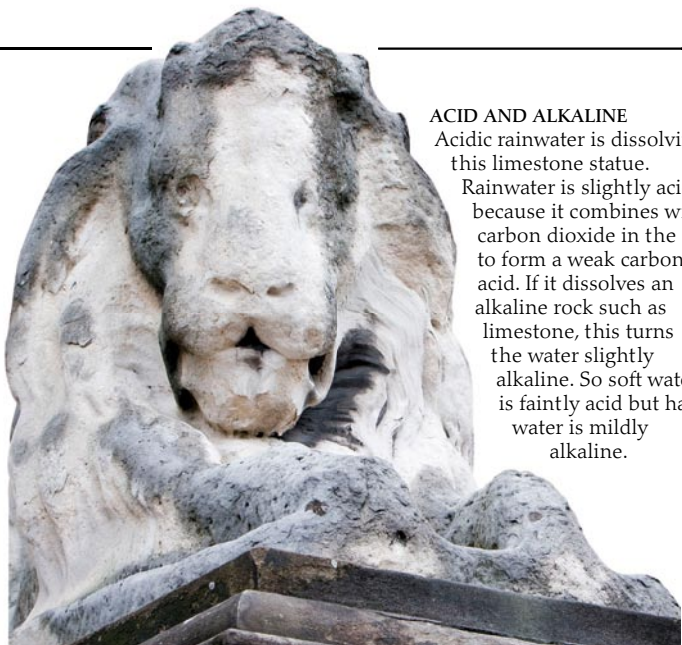
**SUSPENSION**  
Water can also support small particles or droplets without dissolving them. This muddy water is a suspension of soil particles. The particles are too small to see when mixed. They are what makes the water cloudy.



**DISSOLVING SALT**  
Sodium chloride (common salt) consists of electrically charged atoms, or ions. The sodium ions are positive and the chloride ions are negative, which makes them cling together. But when salt dissolves in water, its ions move apart and form "hydrated ions," with each former salt ion clinging to water molecules.



**SALT CRYSTALS**  
The bond holding a water molecule together is stronger than the bond that links it to a salt ion. If salt water evaporates, the water-salt bonds break while the water molecules float away as pure water vapor. If all the water evaporates, the salt ions join up to form white salt crystals like these.



#### ACID AND ALKALINE

Acidic rainwater is dissolving this limestone statue. Rainwater is slightly acid because it combines with carbon dioxide in the air to form a weak carbonic acid. If it dissolves an alkaline rock such as limestone, this turns the water slightly alkaline. So soft water is faintly acid but hard water is mildly alkaline.



*Oxygen produced by the plant will dissolve in water*

#### ATMOSPHERIC GASES

Water dissolves oxygen as well as carbon dioxide from the air. The colder the water, the more oxygen it can contain. All living organisms depend on supplies of oxygen and carbon dioxide, so this ability of water to dissolve atmospheric gases is vital to aquatic plant and animal life.



#### ESSENTIAL NUTRIENTS

The fertilizers used by farmers are made up of nitrates, phosphates, potassium, and other nutrients that plants need to grow. The plants can absorb them only if they are dissolved in water. Since animals depend on plant tissue for food, these nutrient solutions are essential to all life.

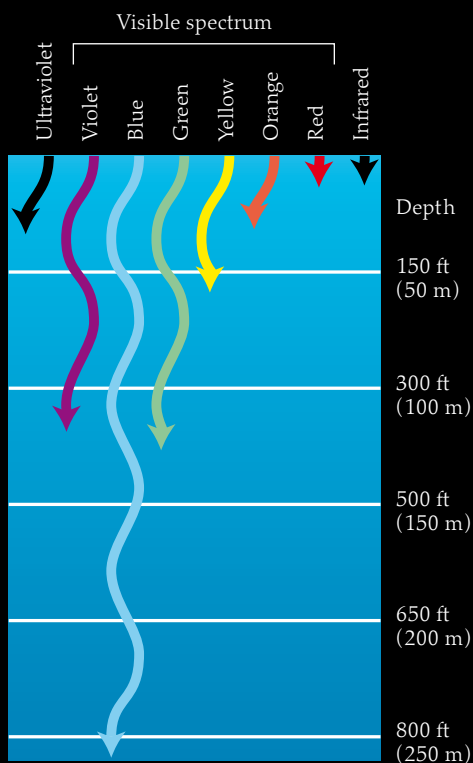
#### SYMBOL OF PURITY

Although water is rarely pure, it has been seen as an emblem of purity for thousands of years. Many religions have purification rituals involving water, often in the form of symbolic washing—as in baptismal rites. Here a devout Hindu bathes in the sacred waters of the Ganges in India, an act that is believed to wash away sins and help gain salvation.



# Light, sound, and pressure

**W**ATER IS PHYSICALLY VERY DIFFERENT from air. Water absorbs light and heat, so they do not penetrate far through deep water, yet it is amazingly efficient at transmitting sound because of its great density compared to air. Water's density makes it heavy, so deep water exerts immense pressure. These properties make water an alien environment for us, even though we need it to survive. But the physical properties of water affect life on land too, because the oceans absorb a lot of the Sun's heat energy and this has a big influence on climate.



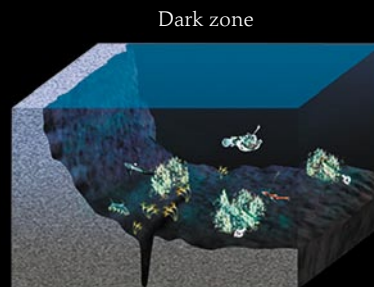
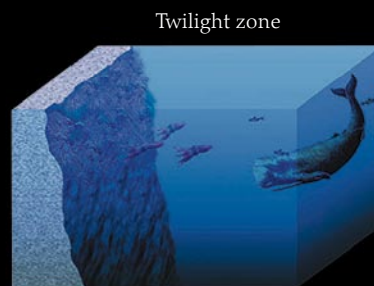
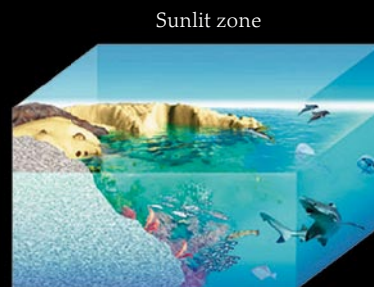
## LIGHT FILTER

White sunlight contains all the colors of the spectrum. When sunlight shines into deep water, some colors are absorbed or filtered out, along with invisible infrared and ultraviolet, leaving only blue. Blue light penetrates much more deeply before being absorbed, leaving darkness.



## BLUE WATER

Since blue light penetrates most deeply into water, everything in the ocean appears blue below a certain depth. Some of this blue light is scattered back to the surface, which is why oceans look blue from space. Seawater is also blue when seen from sea level, and shallow beds of white sand appear turquoise.



## LIGHT ZONES

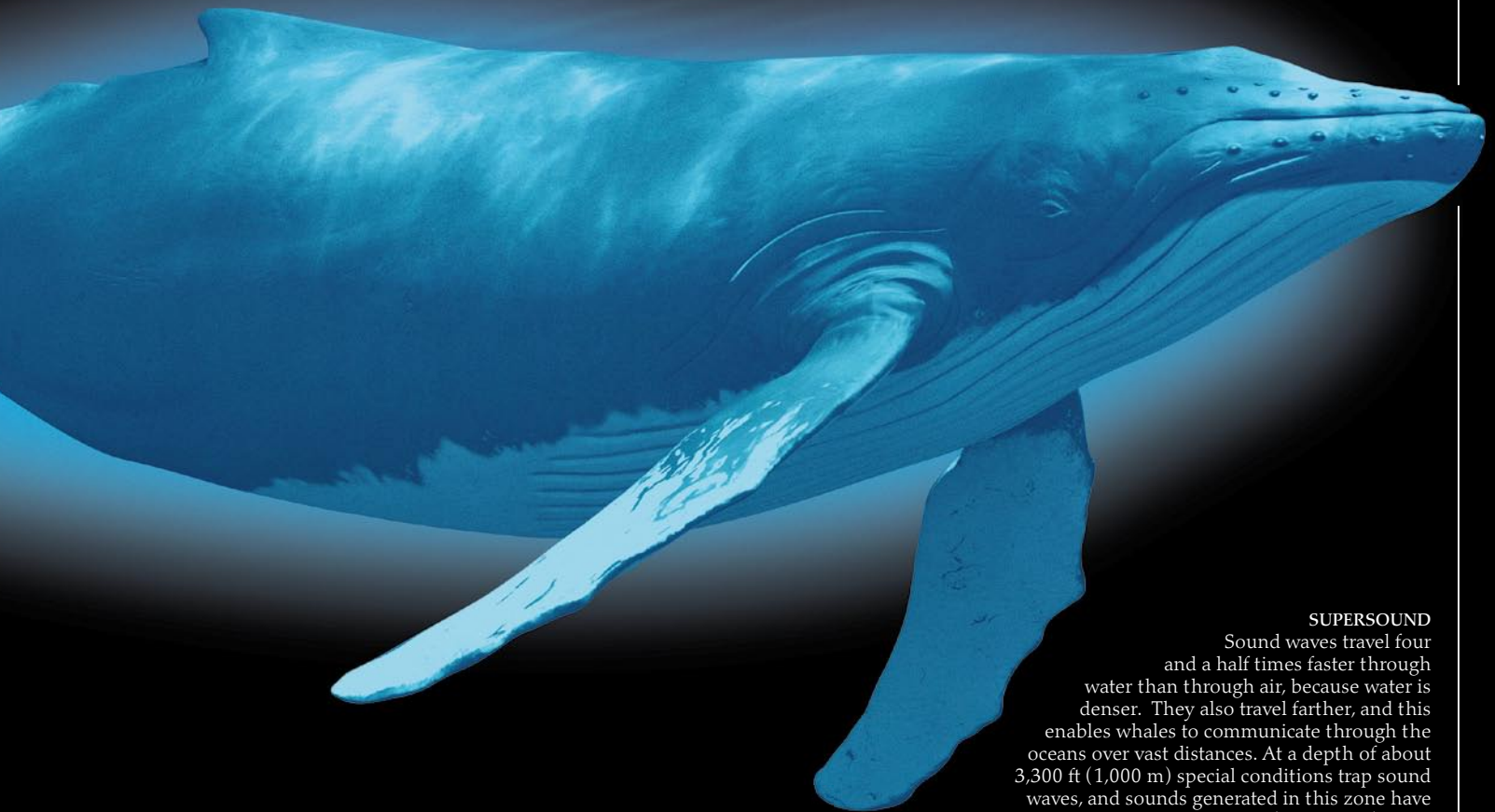
In the oceans, and in deep lakes, the absorption of sunlight creates distinct light zones. Just below the surface lies the sunlit zone, where there is enough light for aquatic plants and algae. In clear, tropical water this zone can be up to about 650 ft (200 m) deep. Deeper than the sunlit zone there is just dim blue light, creating the twilight zone to depths of up to 3,000 ft (900 m). The region below this receives no sunlight at all, so it is known as the dark zone. In murky, muddy conditions the zones occur in much shallower water.

*Line of sensory pores runs along the side of the fish*



## PRESSURE SENSE

Aquatic animals are aware of each other's movements because the water transmits the local changes of pressure that the movements cause. Fish pick up the changes with their pressure-sensitive lateral line system, and this enables shoals to swim in perfectly coordinated formation.

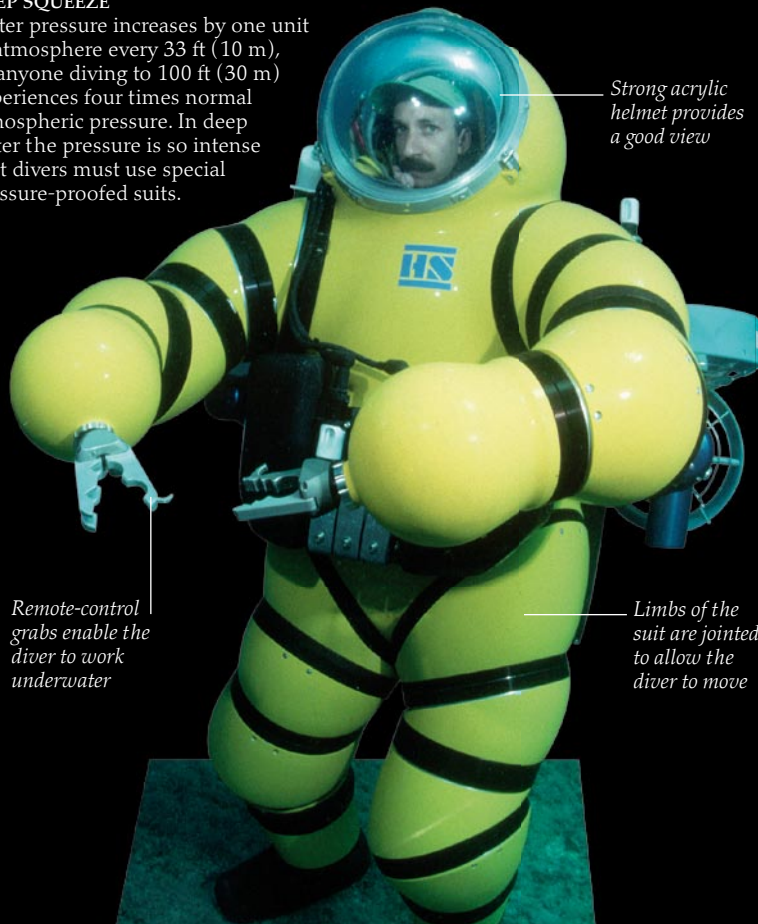


**SUPERSOUND**

Sound waves travel four and a half times faster through water than through air, because water is denser. They also travel farther, and this enables whales to communicate through the oceans over vast distances. At a depth of about 3,300 ft (1,000 m) special conditions trap sound waves, and sounds generated in this zone have been picked up 15,000 miles (25,000 km) away.

**DEEP SQUEEZE**

Water pressure increases by one unit of atmosphere every 33 ft (10 m), so anyone diving to 100 ft (30 m) experiences four times normal atmospheric pressure. In deep water the pressure is so intense that divers must use special pressure-proofed suits.



*Strong acrylic helmet provides a good view*

*Remote-control grabs enable the diver to work underwater*

*Limbs of the suit are jointed to allow the diver to move*

*Delicate organs are fluid-filled so cannot be crushed*

*Fine tentacles are supported by the water*



*Jelly-filled bell acts as fluid skeleton*

**PRESSURE-PROOF**

Gases can be squeezed into a smaller space by intense pressure, but liquids cannot. The bodies of sea creatures like this jellyfish are up to 95 percent liquid, and contain no gas. This means that they are not affected by the water pressure in deep water, and can live near the ocean floor where the pressure would crush an air-breathing animal.



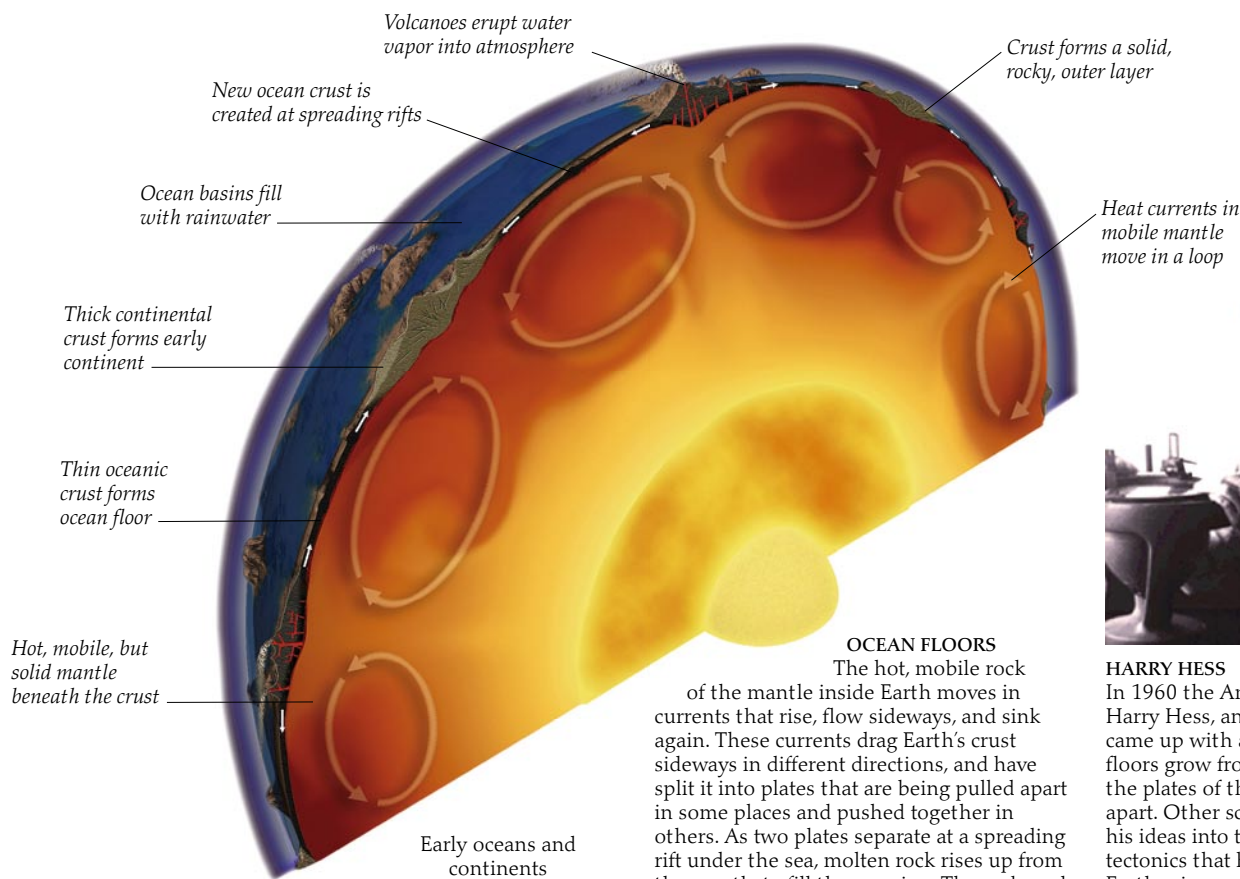


**VOLCANIC WATER**

Most of the water on Earth was probably released as water vapor by massive volcanoes some 4.2 billion years ago. It originally formed part of the atmosphere, but as the planet cooled the vapor condensed into rain that poured down to create a global ocean.

# Oceans and seas

OCEANS COVER MORE THAN TWO-THIRDS of the planet, to an average depth of 2½ miles (3.8 km), and contain 97 percent of the world's water. The first ocean formed very early in Earth's history. The oldest known rocks, which are at least 4 billion years old, have features that show they originally formed on an ocean floor. This means that oceans probably existed before the continents and may have covered the whole globe. This ocean was split up by continents forming from volcanic eruptions and slowly drifting around the world on the moving plates of Earth's crust—a process that depends on water seeping through the ocean floors and making the rocks slide more easily.



**HARRY HESS**

In 1960 the American geologist Harry Hess, an ex-navy commander, came up with a theory of how ocean floors grow from spreading rifts as the plates of the Earth's crust pull apart. Other scientists developed his ideas into the theory of plate tectonics that has revolutionized Earth sciences.

**OCEAN FLOORS**

The hot, mobile rock of the mantle inside Earth moves in currents that rise, flow sideways, and sink again. These currents drag Earth's crust sideways in different directions, and have split it into plates that are being pulled apart in some places and pushed together in others. As two plates separate at a spreading rift under the sea, molten rock rises up from the mantle to fill the opening. The rock cools and solidifies when it meets the water, creating new crust that widens the ocean.

**FRESH TO SALT**

The first ocean filled with fresh rainwater formed from water vapor released by volcanoes. Next, the first continents began to build up from chains of volcanic islands. Erosion by heavy rain washed mineral salts off the new land and into the ocean, making it salty for the first time. The deep gullies in the sides of this volcanic island show that this is still happening. Other agents—mainly living organisms—remove salt and store it in seafloor sediments, so the salt content of the oceans has stabilized.





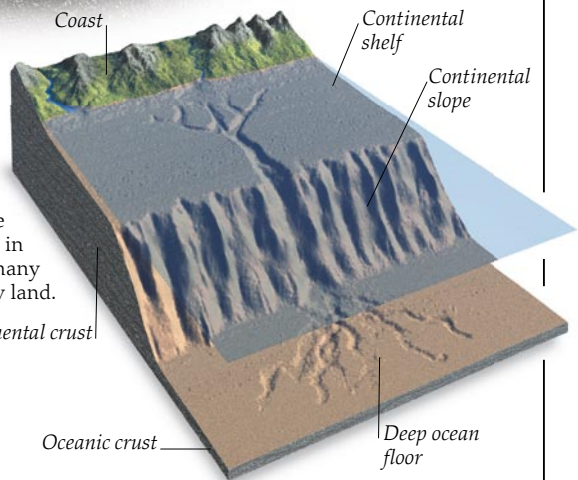
**THE ROLE OF WATER**

Water seeping through the ocean floors lowers the melting point of the hot rock of Earth's mantle, just as salt lowers the melting point of ice. This turns the rock into molten basalt, like this lava from a Hawaiian volcano. The molten rock acts like oil, enabling the great plates of the Earth's crust to slide around the globe. Without water, there might be no plate tectonics, and Earth would look very different.

**SHALLOW SEAS**

Coastal waters are much shallower than open oceans because they cover the submerged edge of a continent—the continental shelf.

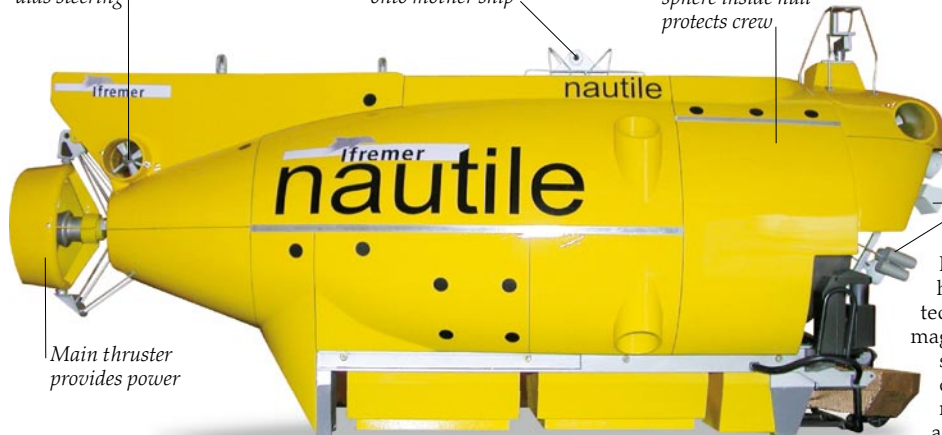
This extends to the continental slope, which descends to the true ocean floor. At times of low sea level in the past, such as during ice ages, many continental shelves were dry land.



Side thruster aids steering

Lifting point for hoisting onto mother ship

Strong titanium sphere inside hull protects crew



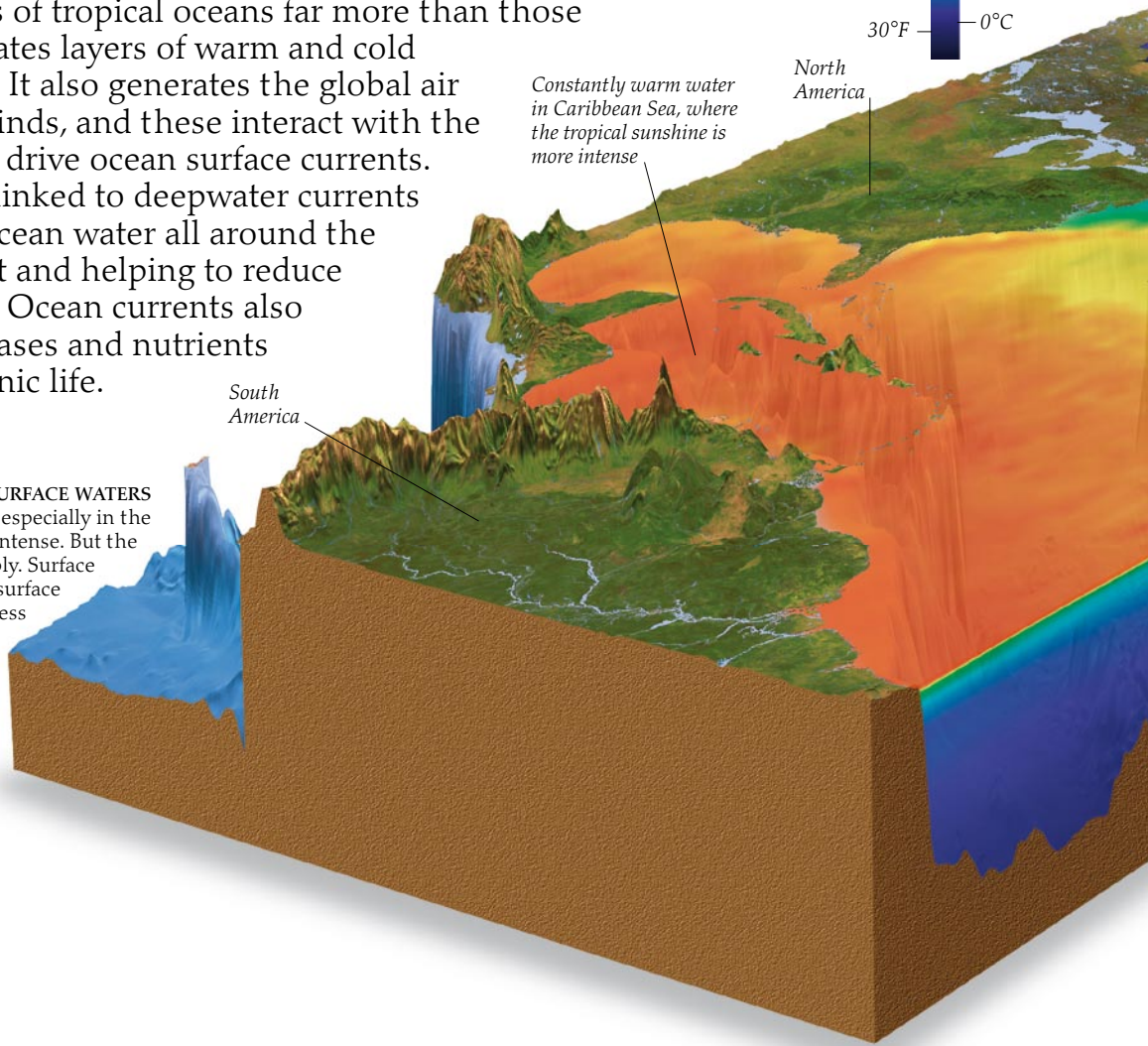
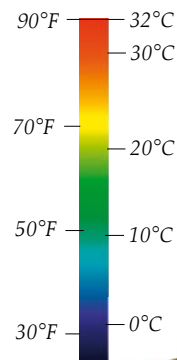
Lights and cameras

**EXPLORING THE DEEP**

Most of what we know about the ocean floors has been discovered using remote sensing techniques such as sonar (depth sounding), magnetic surveys, gravity measurements, and submarine earthquake detection. But deepwater submersibles, such as *Nautile*, now allow scientists to visit the ocean floor and see it for themselves.

# Ocean layers and currents

OCEAN WATER DOES NOT ALL LOOK THE SAME. The blue water of the warm tropics (around the equator) is very different from the gray-green of cold coastal seas, or the drifting pack ice of polar oceans. These differences are caused by the heat of the Sun, which warms the surface waters of tropical oceans far more than those nearer the poles, and creates layers of warm and cold water at different depths. It also generates the global air movements that cause winds, and these interact with the spinning of the planet to drive ocean surface currents. The surface currents are linked to deepwater currents in a system that carries ocean water all around the world, redistributing heat and helping to reduce extremes of temperature. Ocean currents also transport the dissolved gases and nutrients that are essential to oceanic life.



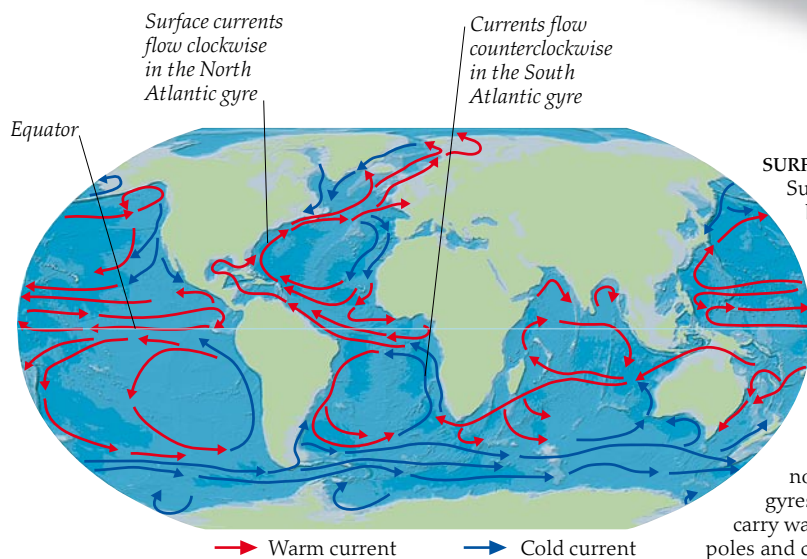
## SURFACE WATERS

Sunlight warms the ocean surface, especially in the tropics where the sunshine is more intense. But the warmth does not penetrate very deeply. Surface water absorbs the heat to form a warm surface layer. This expands and becomes less dense, so it floats on the denser, heavier cold water. These two layers are separated by a transition zone called the thermocline.



## INVISIBLE BARRIER

In cold oceans seasonal storms tend to break down the thermocline. This allows surface waters to mix with the cold, nutrient-rich water from below. The nutrients encourage plankton growth, turning the water cloudy green. In most warm oceans the thermocline stops nutrient-rich water reaching the surface, so tropical waters are usually clear blue.



## SURFACE CURRENTS

Surface currents are driven by the winds, which blow toward the west near the equator, and toward the east in temperate zones. The winds tend to drag the surface waters of the oceans with them, creating huge clockwise circular currents, or gyres, in the north, and anticlockwise gyres in the south. These carry warm water toward the poles and cold water to the tropics.



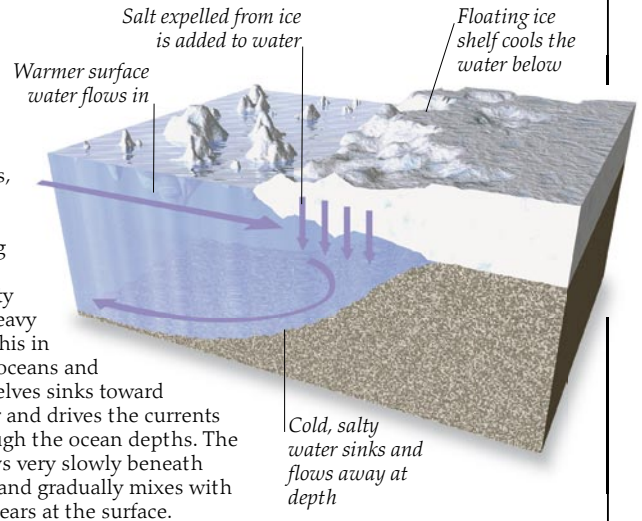
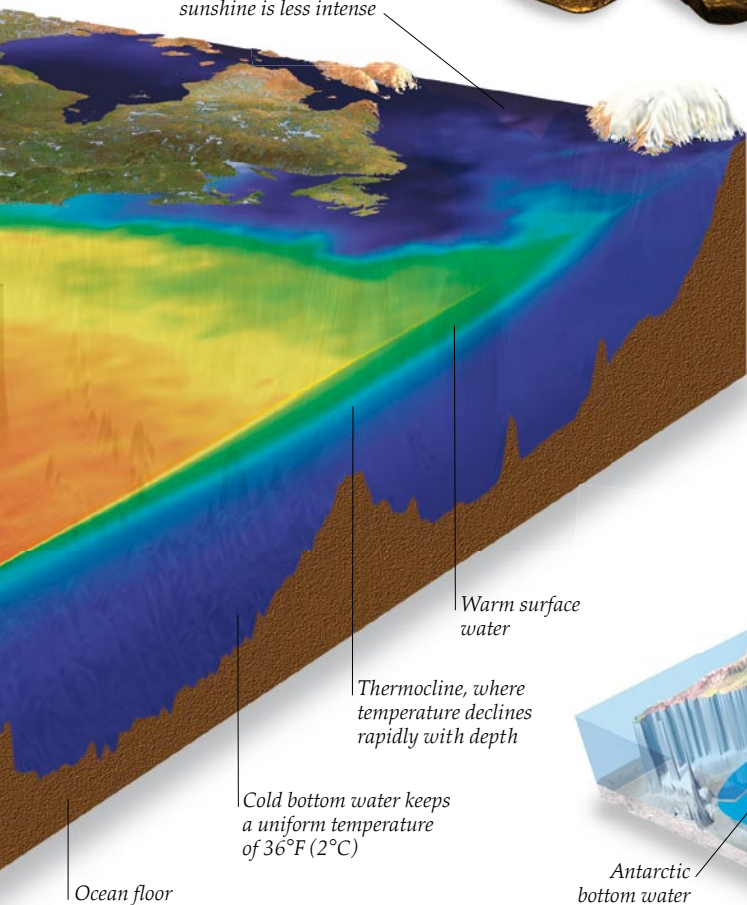


Spanish gold coins

**OCEANIC HIGHWAY**

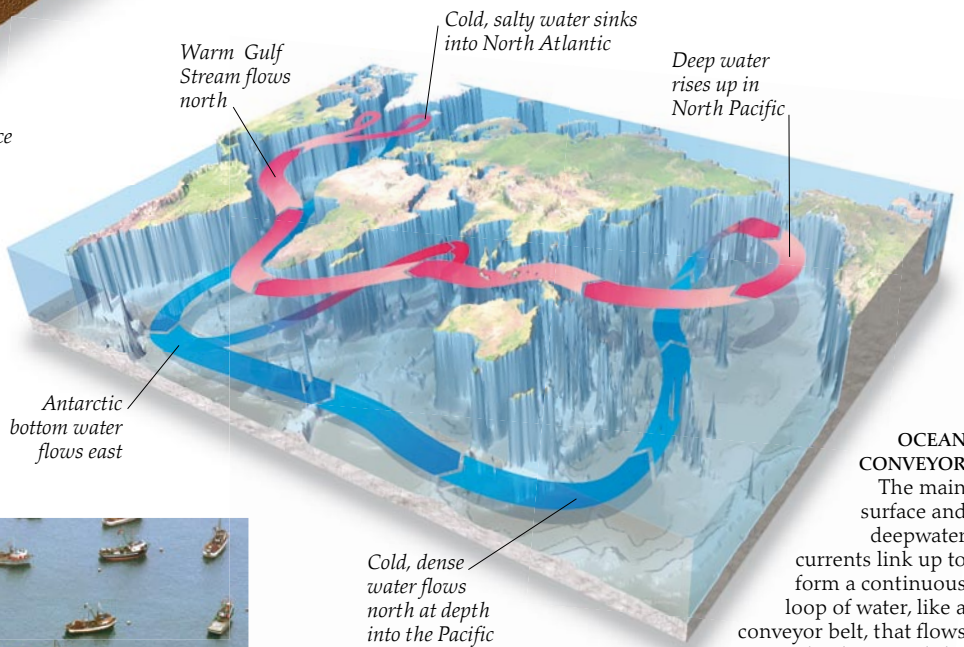
In the 16th to 18th centuries, Spanish treasure galleons sailed to the Caribbean on the North Equatorial Current—the westward-flowing part of the North Atlantic gyre. After loading silver and gold they sailed back to Spain on the Gulf Stream, the eastward-flowing part of the gyre. So the wealth of Spain, and other trading nations in the days of sail, relied on ocean currents.

Constantly cold water off Greenland, where the sunshine is less intense



**DEEPWATER CURRENTS**

When it freezes, ocean water leaves its salt behind, making the remaining water more salty and heavier. Heavy water such as this in the cold polar oceans and beneath ice shelves sinks toward the ocean floor and drives the currents that flow through the ocean depths. The cold water flows very slowly beneath warmer water, and gradually mixes with it until it reappears at the surface.



**OCEAN CONVEYOR**

The main surface and deepwater currents link up to form a continuous loop of water, like a conveyor belt, that flows very slowly around the globe. This is known as the thermohaline circulation. Over centuries it shifts vast amounts of water and heat around the world, as well as vital dissolved nutrients and oxygen.



**UPWELLING ZONES**

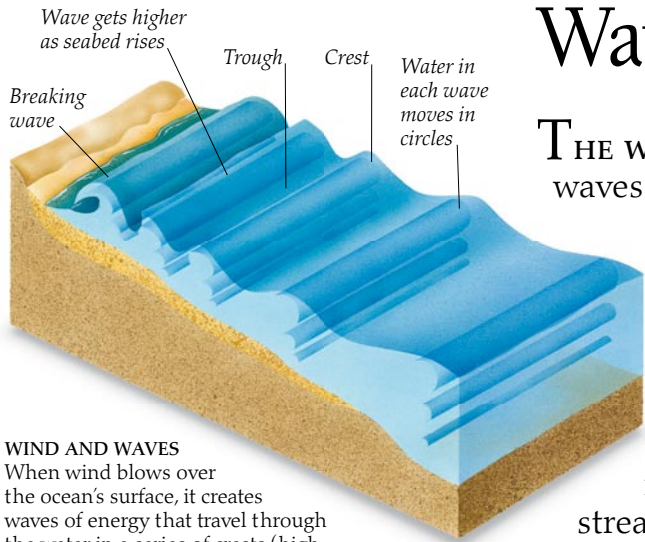
In certain places, deepwater currents well up toward the surface. In tropical oceans they overcome the barrier of the thermocline, drawing nutrients up to the sunlit surface where they feed plankton growth. Upwelling zones, such as this one off Peru, teem with life and are rich fisheries that attract many fishermen.



**KEEPING TRACK**

Surface currents can be tracked by recording the things that float on them, especially if these have a known source. A cargo of plastic ducks that was lost in the Pacific in 1992 has so far drifted 17,000 miles (27,500 km) on ocean currents. Scientists tracking the ducks are learning much about the direction and speed of the currents. Deepwater currents are monitored by taking water samples at depth.

# Waves and tides



## WIND AND WAVES

When wind blows over the ocean's surface, it creates waves of energy that travel through the water in a series of crests (high points) and troughs (low points). Each wave lifts water particles around in circles. As waves approach a shore, the circulation of water at the bottom of the wave is slowed by the seabed and the top spills over.

THE WINDS THAT DRIVE OCEAN CURRENTS also whip up waves. Ocean waves are ripples of energy. Unlike currents, they do not move water any great distance, but as they move, they carry energy forward through the ocean. Waves can be very destructive, because of their height—which can be enough to overwhelm even big ships—and because of the weight of water that crashes forward when they break on the shore. By contrast the tides that rise and fall every day shift masses of seawater along coastlines, creating tidal streams that can flow much faster than ocean currents. Where they flow through narrow channels and around headlands they can create dangerous races and whirlpools.



## ROGUE WAVES

Out at sea, two wave systems may meet. The waves either cancel each other out or combine to create huge rogue waves up to 100 ft (30 m) high. Such waves are big enough to engulf big ships and even sink them. Here a scene from the film *The Perfect Storm* shows a fishing boat about to be overwhelmed.



## DESTRUCTIVE FORCE

When a wave reaches shallow water it gets shorter and steeper until its crest topples forward and breaks. All its energy then smashes on the shore, forcing water into cracks in exposed rock and blowing the rock apart by hydraulic pressure. The water also picks up rock fragments and smashes them against exposed shores to speed up erosion.

## BEACH BUILDING

All the rocky debris created by wave action is broken into smaller fragments. As these are tumbled in the surf they are reduced to pebbles and sand. These are swept along the shore to places where the waves are less violent and do not carry them back out to sea. The big stones are dropped first to form shingle banks, but finer particles are carried to more sheltered parts of the coast where they form beaches of grit or sand.



Earthquake causes uplift of seafloor

Water suddenly elevated

Wave is long but low in deep ocean

Wave becomes tall and destructive in shallow water



### TSUNAMIS

The most notorious waves are tsunamis, which are triggered by submarine earthquakes and explosive eruptions of volcanic islands. Tsunamis have relatively low crests out at sea, which are a long way apart, but they build up into very high waves with deep troughs as they approach the shore. They can cause immense damage as they sweep inland, as in 2004 when the Asian Tsunami killed about 230,000 people.



### LOCAL TIDES

On most coasts the tide rises and falls twice a day, leaving boats like these stranded at low tide. But local geography, such as the shape of the coast or the seabed, can reduce this to once a day, or even eliminate tides altogether. It can also concentrate the tidal flow to cause huge tides, and this may create dangerously fast local currents.

### EARTH



Moon's gravity creates a tidal bulge

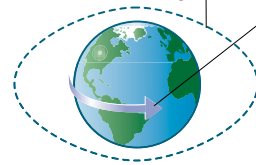
### MOON



Second tidal bulge forms on the other side of Earth



Combined tidal bulges,



Earth spins while its tidal bulges stay aligned with the Moon



### HIGH AND LOW TIDES

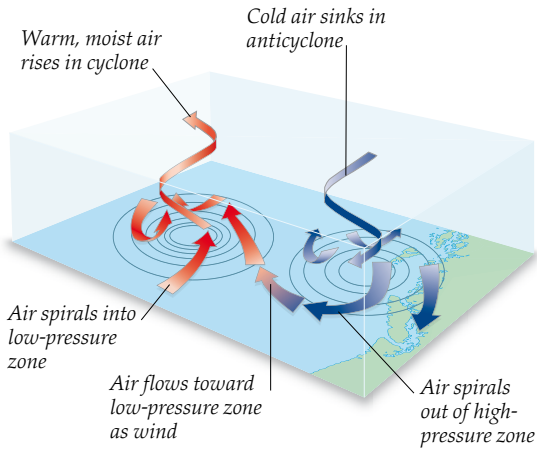
Tides are caused by the gravity of the Moon stretching Earth's oceans into an oval shape because its pull is strongest on the side of Earth facing the Moon and weakest on the opposite side. This makes tidal bulges form on both sides of the globe. As the Earth spins on its axis most coastal localities pass through both tidal bulges every day, so they experience two high tides and two low tides. The Sun's gravity also plays a role. If the Sun pulls in the same direction as the Moon, the tides are more extreme.

### RIDING THE WAVES

The farther waves travel while still being blown by the wind, the bigger they get. This means that persistent strong winds over broad oceans like the Pacific can generate huge waves. Where these break on oceanic islands, such as Hawaii, they provide surfers with the best wave-riding conditions on Earth.



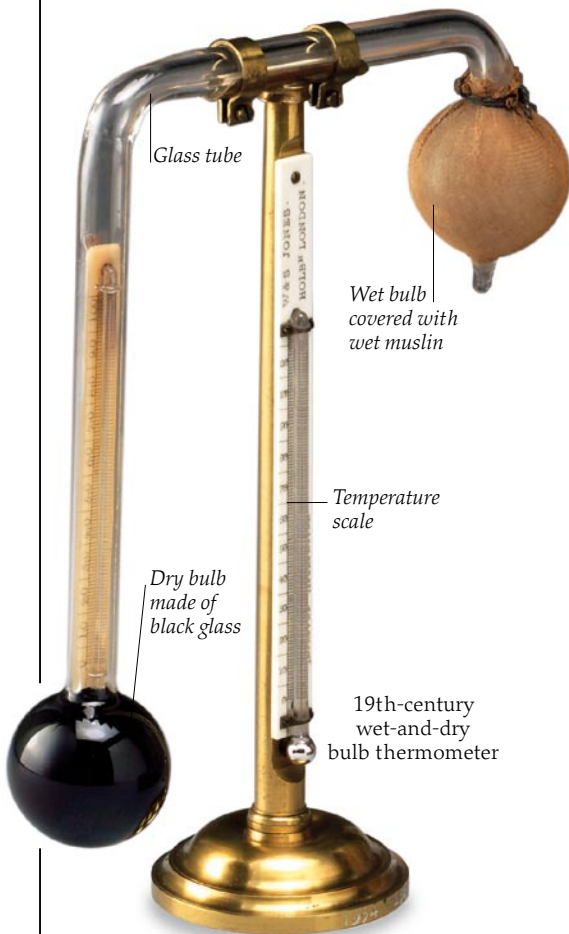
# Water and weather



## HEAT AND PRESSURE

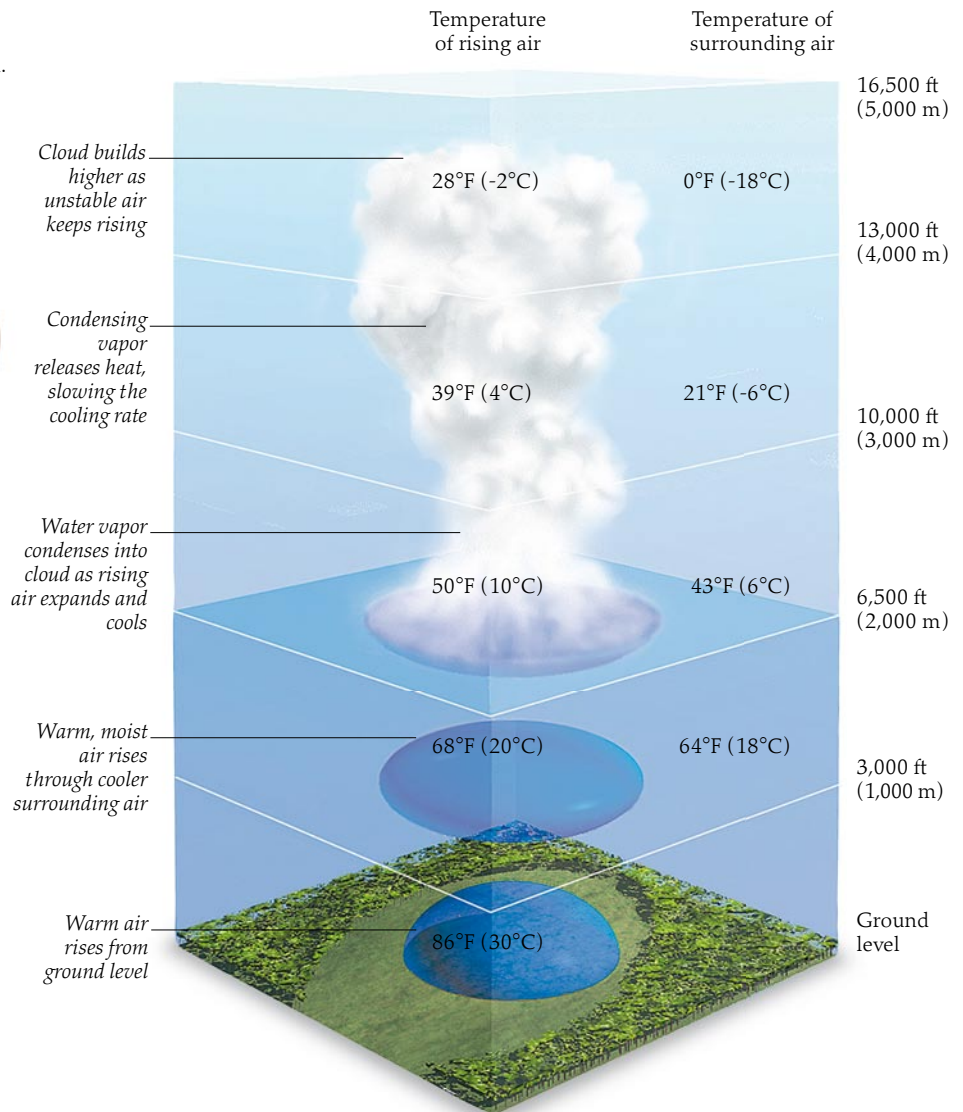
Sun-warmed water evaporates and rises into the air as water vapor. The warm air spirals upward, carrying the water vapor with it. Rising warm air creates low-pressure areas called cyclones. Meanwhile, cool air may be sinking in a nearby high-pressure zone, or anticyclone. Air moves from higher to lower pressure, and we feel this as wind. High pressure usually brings dry, fine weather, and low pressure usually brings rain.

**W**ATER IS A VITAL ELEMENT OF THE WEATHER. The water vapor that evaporates from oceans, lakes, rivers, and forests condenses and often freezes to form the clouds, rain, and snow that are such an obvious feature of weather systems. But the processes of evaporation and condensation that lead to rainfall and snowfall also absorb and release energy that is converted into wind. The most extreme forms of weather, such as thunderstorms and hurricanes, are largely driven by energy stored and released in this way. So water does not just provide us with rain—it also helps power the whole weather machine.



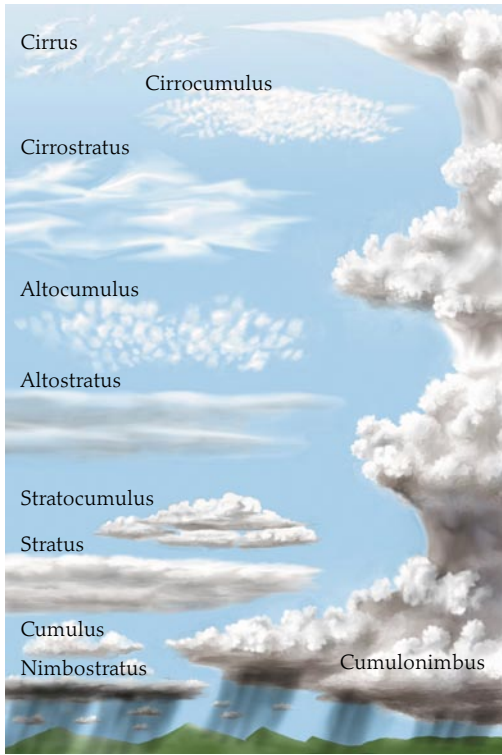
## MEASURING HUMIDITY

Moisture in the air is called humidity. It can be measured with a wet-and-dry bulb thermometer such as this one. The dry bulb is an ordinary thermometer. The wet bulb is surrounded by wet muslin. As this dries out it cools the bulb. The drier the air, the cooler the wet bulb becomes. So the greater the difference in readings between the two bulbs, the lower the humidity.



## CLOUD FORMATION

As warm, moist air rises, it expands and cools. The water vapor cools too, and condenses into tiny water droplets that form clouds. The condensation process releases heat that slows the cooling rate, so the air in the cloud is warmer than the surrounding air. The warm air continues to rise, building the cloud higher, until there is no water vapor left, or the rising air becomes cooler than the air surrounding it.



High level,  
above 20,000 ft  
(6,000 m)

Middle level,  
6,500–20,000 ft  
(2,000–6,000 m)

Low level,  
0–6,500 ft  
(0–2,000 m)

### TYPES OF CLOUDS

There are ten basic types of clouds, with names that indicate their appearance or effect: for example, cirrus (curl), stratus (layer), cumulus (heap), and nimbus (rain). Most occur at either low, medium, or high level, but the colossal cumulonimbus clouds that cause thunderstorms tower up to 10 miles (16 km) in the air.



### RAIN AND SNOW

Rising and falling air currents inside clouds hurl the tiny cloud droplets around so they collide and form bigger droplets. These may eventually get heavy enough to fall as rain. The same thing happens with the microscopic ice crystals that form high-level clouds, making them stick together to form snowflakes.



### LUKE HOWARD

The system of naming clouds is based on the cloud classification devised in 1802 by English manufacturing chemist and amateur meteorologist Luke Howard. His *Essay on the Modification of Clouds*, which was published in 1803, was the first scientific study of cloud types. Howard's system proved so simple and effective that it is still used by meteorologists today.



Surface of  
hailstone is  
typically  
uneven



### HAIL

Raindrops tossed around inside storm clouds can rise to altitudes where they freeze solid. They then fall back, pick up more water, and are hurled upward again. The layers of ice form hailstones that eventually tumble out of the sky. The bigger the cloud, the bigger the hailstones can become.



### STORM CLOUDS

Where evaporation is intense, masses of water vapor rise, cool, and condense to form big clouds. This releases heat energy, which warms the air and makes it rise higher, carrying more water vapor with it. This condenses, releasing more heat. If there is enough water vapor this can create huge cumulonimbus storm clouds. Eventually the weight of water in the cloud builds up to the point where the rising air currents cannot support it, and it is released as torrential rain.

### HURRICANES

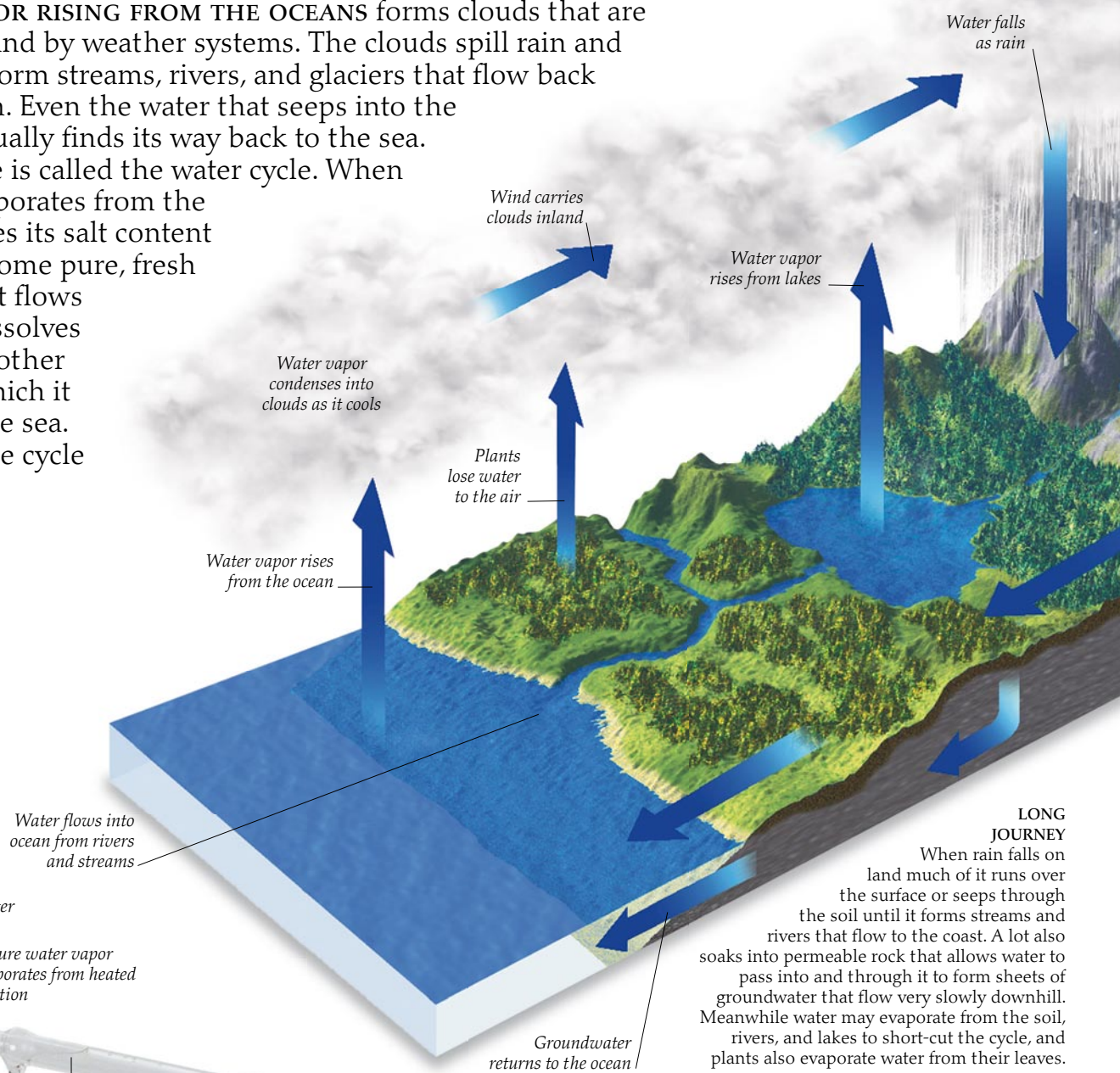
The biggest storm clouds grow over tropical oceans, where they form deep low-pressure systems that draw in extremely strong winds. These tropical cyclones or hurricanes also cause oceanic storm surges that resemble local but intense tsunamis. These can flood low-lying coasts, as in New Orleans in 2005 and Myanmar (Burma) in 2008.



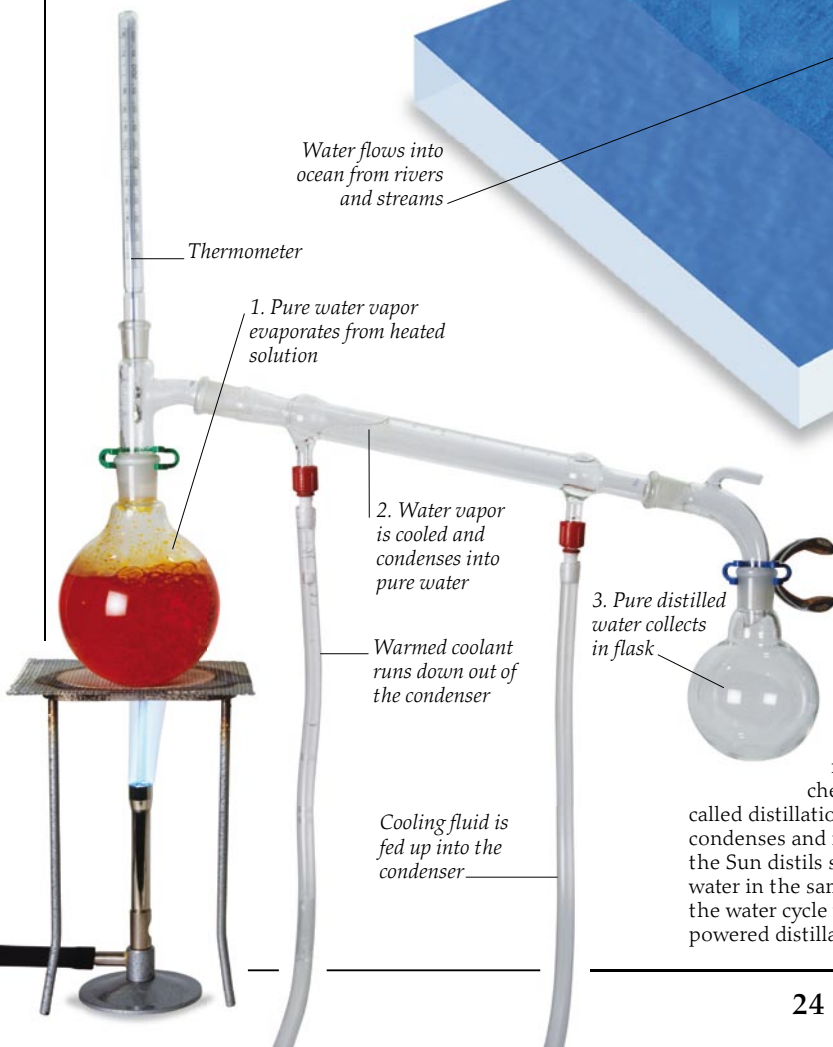


# The water cycle

WATER VAPOR RISING FROM THE OCEANS forms clouds that are carried over land by weather systems. The clouds spill rain and snow, which form streams, rivers, and glaciers that flow back into the ocean. Even the water that seeps into the ground eventually finds its way back to the sea. This sequence is called the water cycle. When the water evaporates from the oceans it leaves its salt content behind to become pure, fresh water, but as it flows overland it dissolves minerals and other substances which it carries into the sea. From there the cycle starts again.

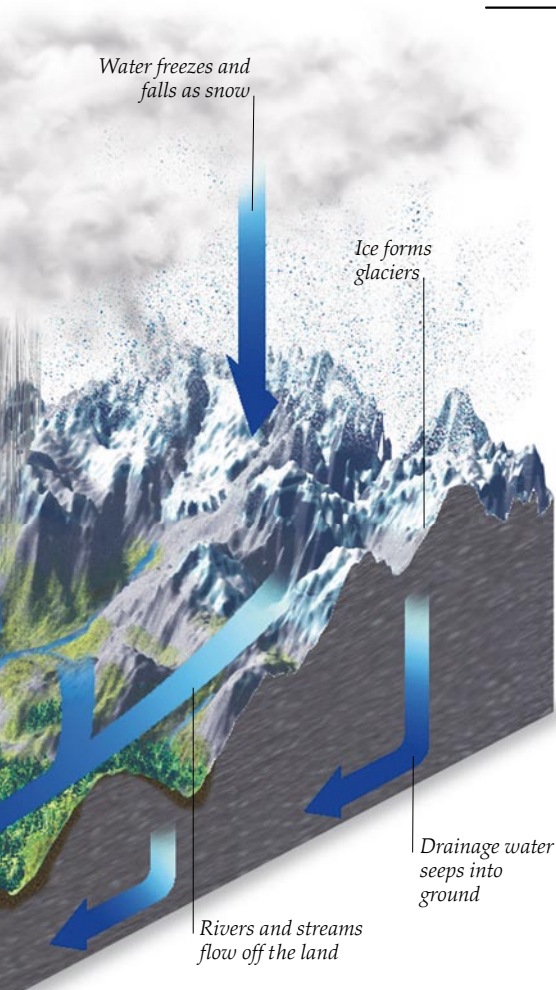


**LONG JOURNEY**  
When rain falls on land much of it runs over the surface or seeps through the soil until it forms streams and rivers that flow to the coast. A lot also soaks into permeable rock that allows water to pass into and through it to form sheets of groundwater that flow very slowly downhill. Meanwhile water may evaporate from the soil, rivers, and lakes to short-cut the cycle, and plants also evaporate water from their leaves.



**DISTILLATION**  
If a solution of water and another chemical is heated, the water evaporates and leaves the chemical behind. This happens because the heat that makes liquid water turn to gas breaks the bonds between the water molecules and the other chemical. The process is called distillation if the water vapor condenses and is collected. The heat of the Sun distills salty seawater into pure water in the same way. So this part of the water cycle works as a solar-powered distillation system.



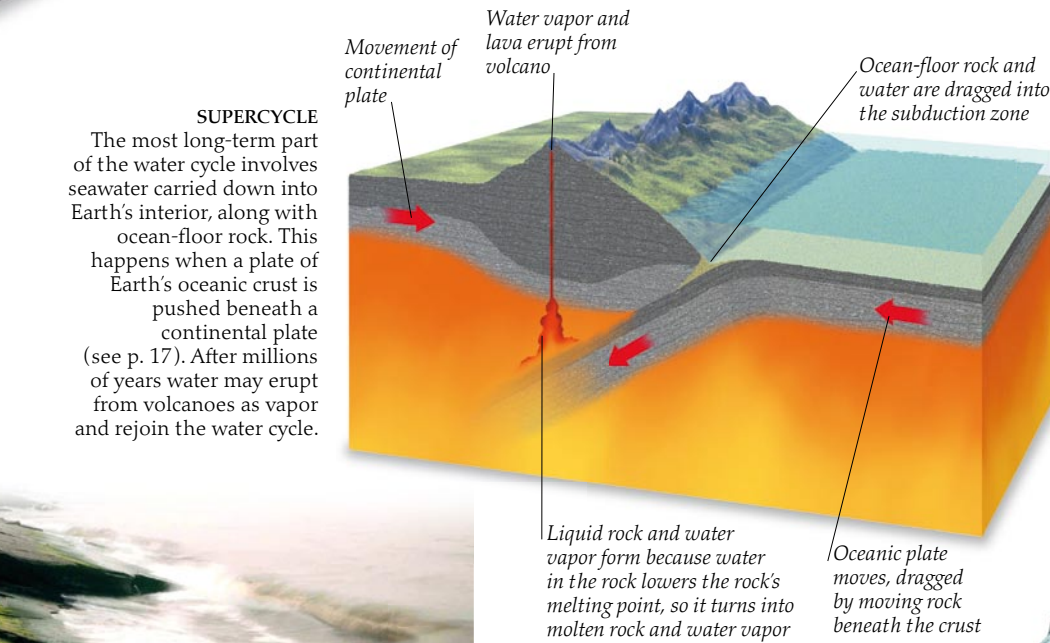


#### DAYS, YEARS, CENTURIES

Some parts of the water cycle have a fast turnover, such as heavy rain that can drain off a small rocky island within hours of falling. Other parts of the cycle take much longer. For example, groundwater that takes many years to flow back to the sea. Some water that soaks deep into rocks stays there for centuries. Much of the water that falls as snow is compressed into dense blue glacier ice. It is locked up for thousands of years before rejoining the cycle.

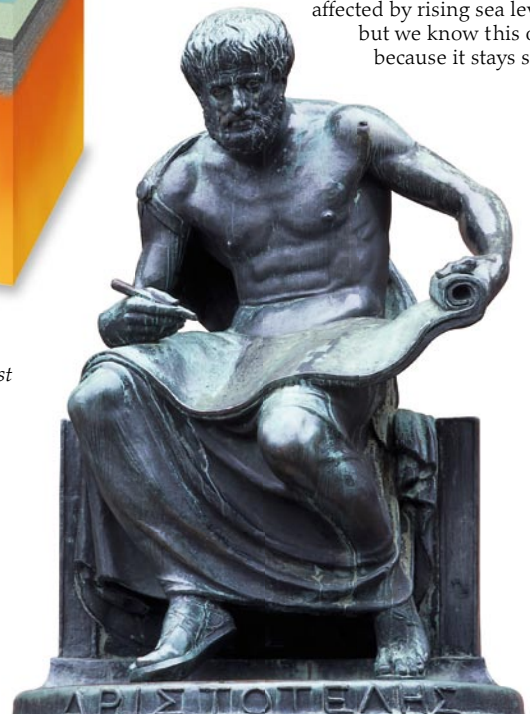
#### SHORT CUT

In hot climates, much of the rain that falls never makes it back to the ocean. In deserts, rainwater evaporates almost as soon as it hits the ground. A lot of the rain that falls on tropical rain forests is pumped right back into the atmosphere by the trees (see p. 45).



#### CLASSICAL SCHOLAR

The ancient Greek philosopher Aristotle (384–322 BCE) had some interesting ideas about the water cycle. He believed that seawater seeped inland, lost its salt content, and emerged to help feed the flow of rivers. In fact, seawater can get into groundwater in low-lying coastal regions affected by rising sea levels, but we know this only because it stays salty.



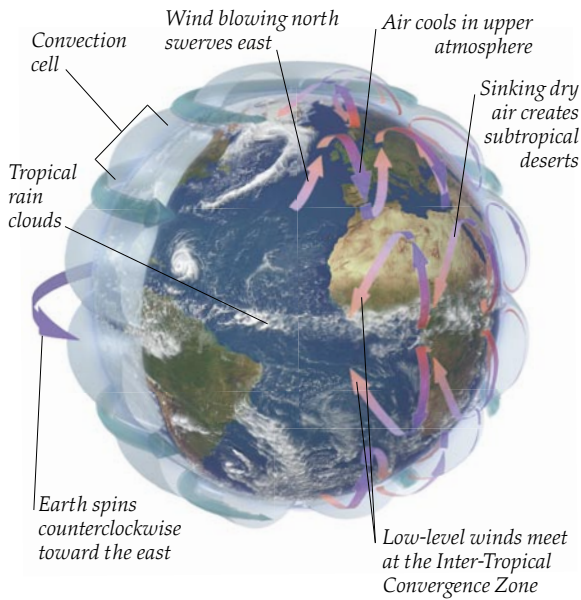
#### EARLY UNDERSTANDING

The Chinese understood the water cycle as long ago as 500 BCE. At Baiheliang in southwest China a massive stone slab in the Chang Jiang (Yangtze River) is engraved with vivid carvings of fish and about 30,000 Chinese characters that record the water level over 1,200 consecutive years. The Chinese knew that the size of the annual harvest was linked to these water levels.



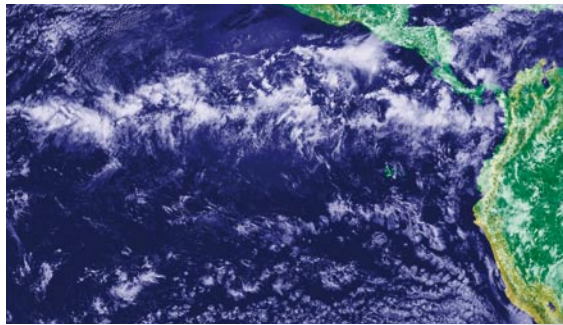
# Water and climate

THE CLIMATES OF THE WORLD are created by the heat of the Sun or lack of it, the position and size of the continents, and the changing weather, which is driven by solar power and the energy stored in water vapor. The climate helps define the character of a landscape—whether it is green and lush, barren and dusty, or buried beneath ice and snow. Where there is plenty of liquid water, plants can flourish and support a lot of animals. But where the water has either evaporated or frozen, life is either put on hold or cannot survive. The water-fueled weather machine even affects the ocean and its ability to support marine life.



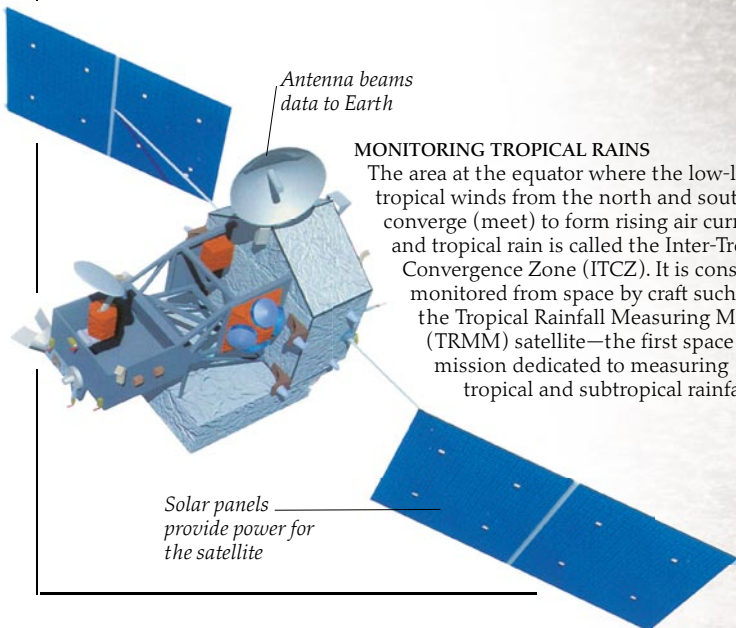
## GLOBAL AIR CURRENTS

The Sun warms the planet's surface, heating the air in the lower atmosphere so that it rises, flows sideways, cools, and sinks in loops called convection cells. These cells transport heat and water vapor, and create low-level winds. Because of the Earth's spin, these winds swerve toward the west or east to carry moist oceanic air and rainfall over the continents.



## TROPICAL RAINS

Air currents rise in the tropics near the equator, flow north and south at high altitude, sink in the subtropics, then flow back toward the equator at low level, and meet again. The warm, moist, tropical air rises and builds up storm clouds, seen as a distinct band in this satellite image. The clouds spill torrential rain, creating rain forests where it falls on land.



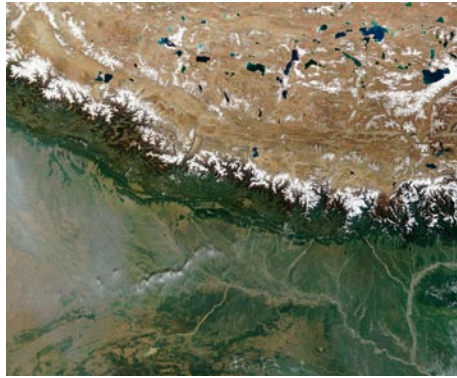


**SUBTROPICAL DESERT**

As air flows away from the rain-forest zone at high altitude, it loses all its water vapor. The dry air sinks over the subtropics to the north and south, heats up, and absorbs any moisture from the ground to create arid deserts with very little vegetation like the Sahara, seen here, and the barren heart of Australia.

**RAIN SHADOWS**

Oceanic weather carries rain from the sea over the land, but if it runs into high mountains, they catch most of the rain. When the air gets beyond the mountains it is much dryer, so the land is not as lush and green, and is in what is called a rain shadow. The rain shadow effect can be seen in this satellite image of the Himalayas, where most of the rain falls south of the mountain ridge.



**WILLIAM FERREL**

The 19th-century American meteorologist William Ferrel showed how some of the air that sinks over the subtropics flows toward the poles, swerving east. These warm winds run into polar air, generating cyclones that sweep east off the oceans and bring rain to northern Europe and northwestern America.



**MONSOON SEASON**

Since big continents are much colder than oceans in winter, they cool the air and make it sink. In Asia this makes dry air flow south over India, causing months of drought. But in summer the continent warms up, warming the air so it rises and draws moist air in from the ocean. The wind changes direction in a seasonal shift called a monsoon, and the drought is replaced by torrential rain. Monsoon rains are the only source of water for 70 percent of the crops in India, so many people celebrate the arrival of the rains.



**OCEANS AND CONTINENTS**

Since water takes a long time to warm up and cool down, oceans never get as cold or as warm as continents. The climates of regions that lie close to big oceans are influenced by this, so they have mild winters and cool summers. This ice-covered house in British Columbia, Canada, is far from the ocean, in an area where winters are colder, and summers are much hotter.

**DRAGON'S BREATH**

The summer monsoon rains are vital to agriculture over most of southern Asia. For the Chinese, the rains were symbolized by the dragon, a creature of the heavens and of the rivers. At times they could be violent—just like the fire-breathing dragon—but they were also the bearers of the precious, essential gift of water.





# Drought and flood

**W**ATER IS BOTH A VITAL RESOURCE and a destructive force. When unusual weather brings too little rain, crops wither, farm animals can die, and people may starve. When there is too much rain, flash floods can leave trails of destruction, and rising rivers can overflow their banks and swamp whole landscapes. The floodwater can make sewers overflow and contaminate drinking water supplies, wreck power plants and leave people without electricity, and destroy homes and transportation links. Both extremes of drought and flood have been part of human experience for centuries, but as climates change and populations grow, droughts and floods seem to be becoming more frequent, and are having more devastating impacts.

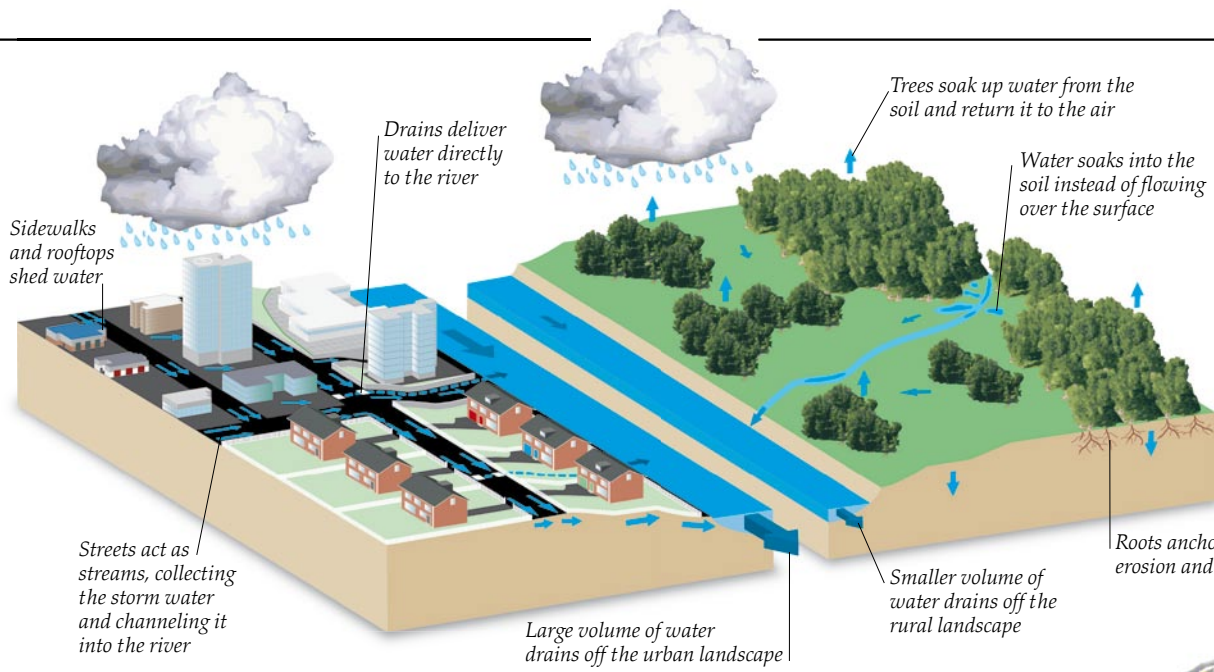
## RISING WATERS

The heat that causes droughts also makes ocean water evaporate and form huge rainclouds, so while some areas may suffer years of drought, others are deluged with rain. Rivers burst their banks, and as the groundwater level rises the landscape is submerged. The flood that swamped the German city of Dresden was one of many caused by record rainfall in 2002.

## HEAT AND DUST

If heat causes the moisture in the ground to evaporate faster than it is replaced by rainfall, over a long period, this causes a drought. As groundwater levels fall, shallow-rooted crops and grasses wither and die. Farm animals run out of both food and water, and may die, too—like these cattle in Kenya in 2006. In extreme cases whole landscapes can turn to desert, causing famine and mass migrations of people.



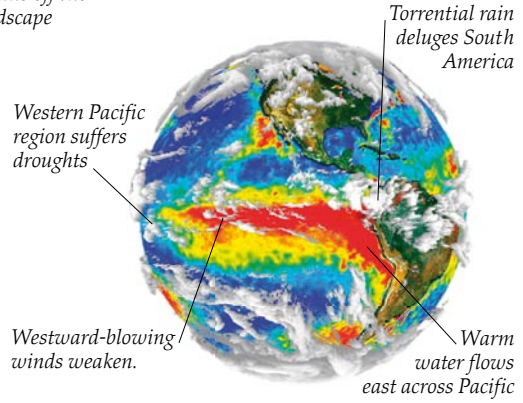


**FLASH FLOODS**  
 Torrential downpours can cause flash floods that sweep downhill, carrying everything before them. This rarely happens where natural vegetation soaks up the rainfall, but it is common in urban areas where the water has nowhere to go except down drains. Drains are soon blocked by debris, and the water surges down city streets.

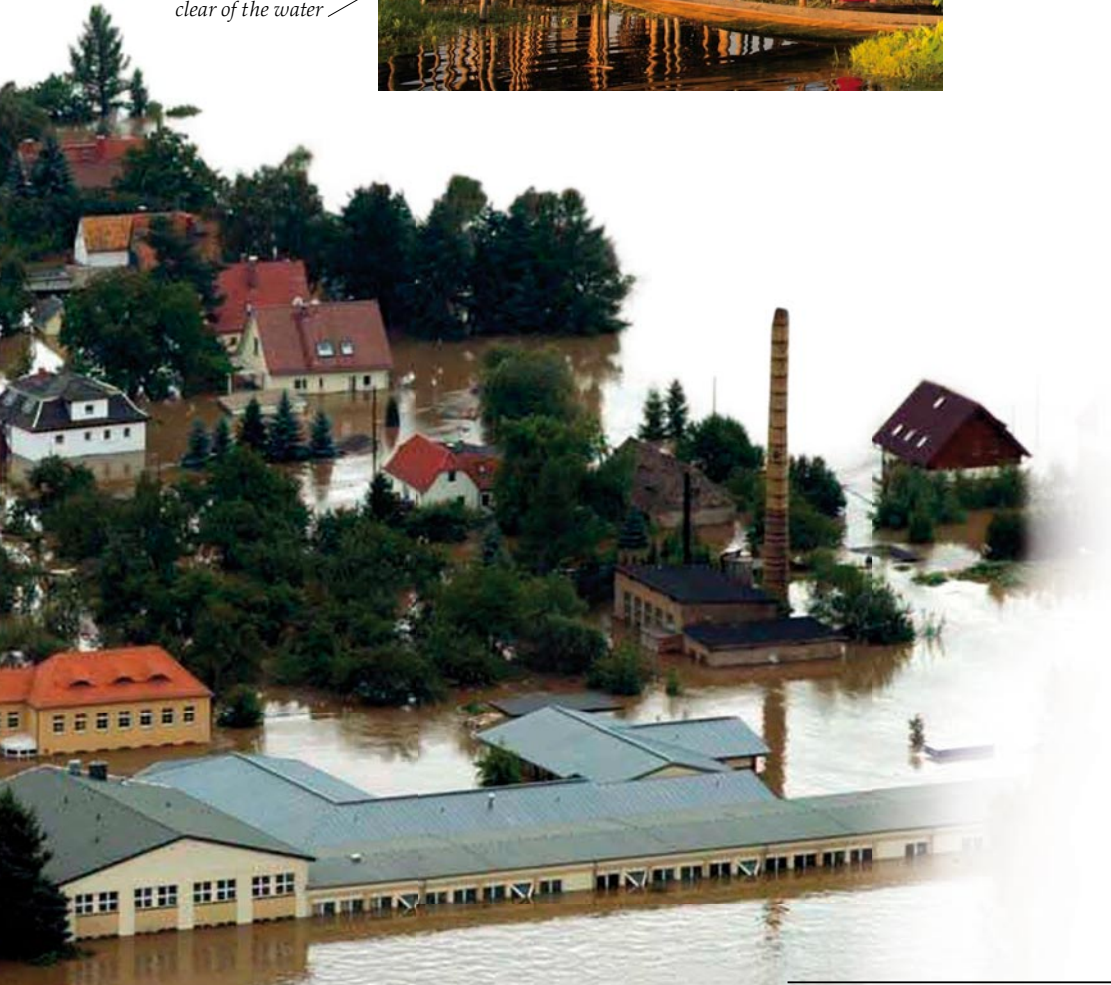
**RISING ABOVE THE FLOODS**  
 People who live in areas that suffer regular floods have developed ways of protecting themselves and their homes. They often build their houses on stilts, like these in Myanmar (Burma), and some villages are floating communities that rise and fall with the water.



Stilts keep the house clear of the water



**NATURAL CYCLES**  
 Droughts and floods are often caused by natural climate cycles. The most notorious is El Niño. This phenomenon occurs when winds blowing west over the tropical Pacific weaken, allowing warm water—seen here in red—to flow east. The water evaporates, building up clouds that cause torrential rain and flooding in South America.



**CLIMATE CHANGE**  
 Air pollution and the destruction of rain forests are changing the atmosphere in ways that are making average global temperatures rise. This is likely to cause more intense storms and flooding in some places, and longer droughts in others. Sea levels will also rise as ice sheets melt, adding to the problem.

# Erosion and weathering

**T**HE LAND GRADUALLY wears away, and water plays a key role in this. Water breaks down rock into smaller particles as it freezes and thaws, as well as by chemical reactions that dissolve the minerals holding rocks together. These are weathering processes. If water transports the particles and dissolved minerals from one place to another, the process is known as erosion. The particles and dissolved minerals are carried downhill to the oceans. Here the particles form seafloor sediments that are eventually compressed into sedimentary rocks. The minerals are recycled by marine life, which may also contribute to the formation of new rocks.

## RELENTLESS GRIND

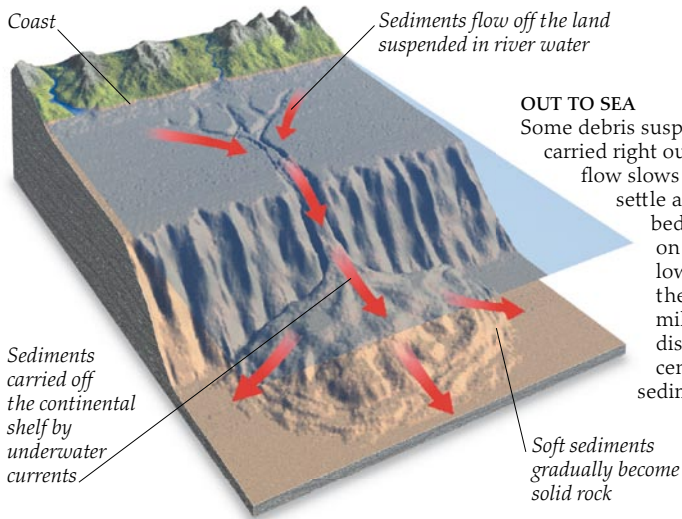
The more exposed a rock is, the more vigorously it is attacked. Softer rocks like sandstone are eroded faster than hard ones like granite, but this leaves the hard rocks more exposed and eventually they are ground away, too. As water or ice flowing off the land carries the rock debris away it carves deep valleys, gorges, and canyons.

Antelope Canyon, Arizona, eroded over thousands of years by torrents of sandy water during desert storms

## DUMPING THE LOAD

Rock debris is swept away by rivers and glaciers. Rivers abandon heavy rocks when they slow down, followed by smaller stones, sand, and finally very small mud particles. By contrast, moving ice may carry boulders and fine particles as far as it flows, dumping them only when the ice melts away. Boulders dumped by ice are known as glacial erratics. This erratic in Yorkshire, UK, was dropped here about 13,000 years ago.





**OUT TO SEA**

Some debris suspended in river water is carried right out to sea. As the river flow slows and stops, the particles settle as sediment on the sea bed. More sediment settles on top, compressing the lower layers and squeezing the water out of them. Over millions of years, minerals dissolved in the water cement them into solid sedimentary rock.



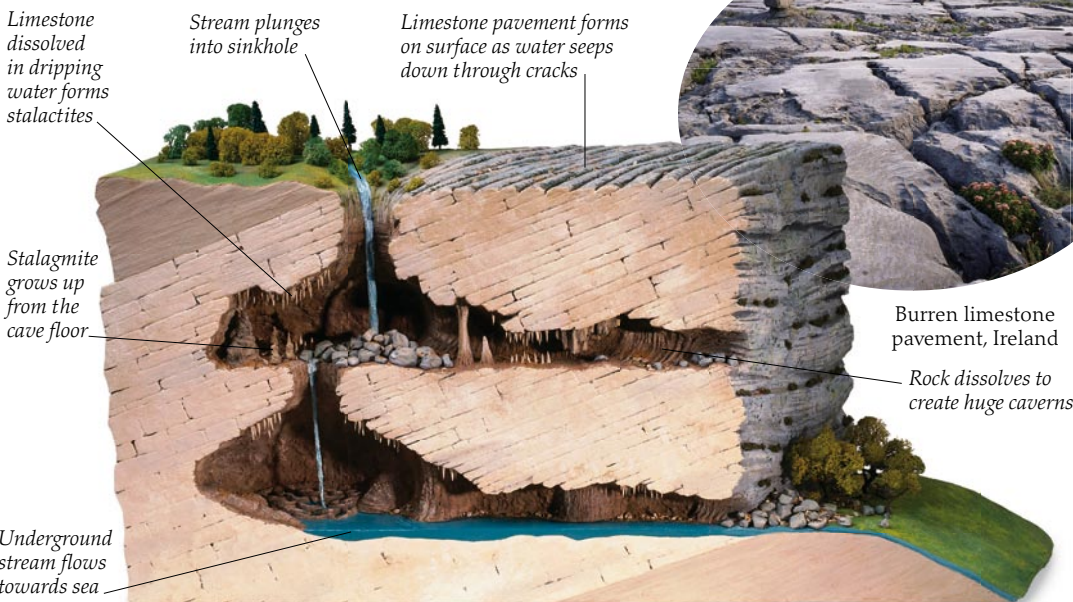
Granite



China clay

**ROCK DECAY**

Rainwater is slightly acid, and weathers rocks by dissolving some of their minerals. It even attacks hard granite by gradually breaking down its mica and feldspar crystals to form iron oxide, carbonate salts, and clays such as china clay. All that is left are tough quartz crystals, which survive as sand.



Shelly limestone



**SOLUBLE LIMESTONE**

Limestone is pushed up to the surface by earth movements. It forms dramatic landscapes, because it is easily dissolved by rainwater. Exposed rock on the surface forms fissured limestone pavements, and deep cracks are enlarged into complex cave systems. Underground streams carry the dissolved minerals away to the oceans, where they are recycled by marine life.

**CARBONATE RECYCLING**

The weathering of many rocks, including granite and limestone, produces dissolved minerals called carbonates. These are carried into the sea where marine organisms use them to build their shells and skeletons. When they die, their remains settle on the seabed, and build up in layers that are compressed to form carbonate rocks such as limestone, which often contains visible shell fragments.



**ANCIENT REEF**

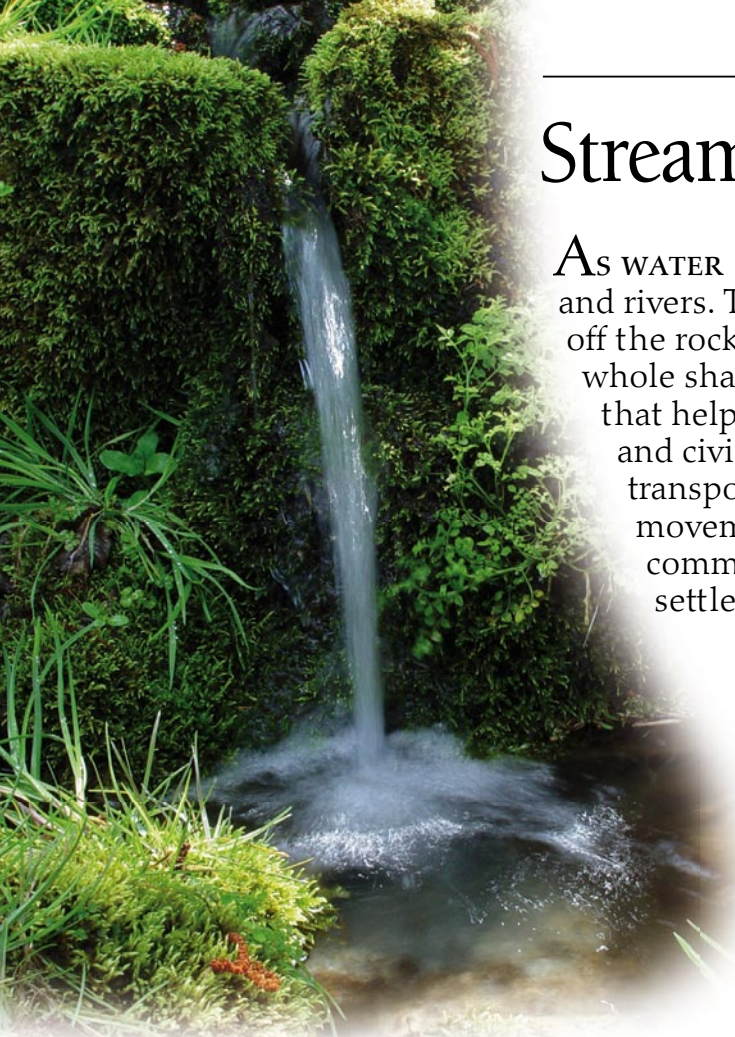
The Yucatán Peninsula in Mexico was once a vast underwater reef created by corals that used dissolved carbonates to make limestone. Raised above sea level and exposed to tropical rain, the limestone has been undermined over thousands of years by underground streams fed by sinkholes called cenotes. These were vital water sources for the ancient Mayan civilization.





# Streams and rivers

AS WATER DRAINS OFF THE LAND it creates a network of streams and rivers. These carve deep valleys through the uplands and carry off the rocky debris to the lowlands. Over time, this changes the whole shape of the land. They also transport the plant nutrients that help make the lowlands fertile, so they are vital to farming and civilization. The lower reaches of rivers are important transportation routes, but they also act as barriers to overland movement. So river ports and bridges have always been commercially and strategically important, attracting settlements that have grown into towns and cities.



## TRICKLES AND SPRINGS

Rainwater draining downhill forms trickles and rivulets, which link up to form streams that cut shallow channels. In places water that has soaked into the ground meets a layer of impermeable (waterproof) rock and emerges as a freshwater spring. Many great rivers can be traced back to springs of this kind, which are sometimes named as the river source.

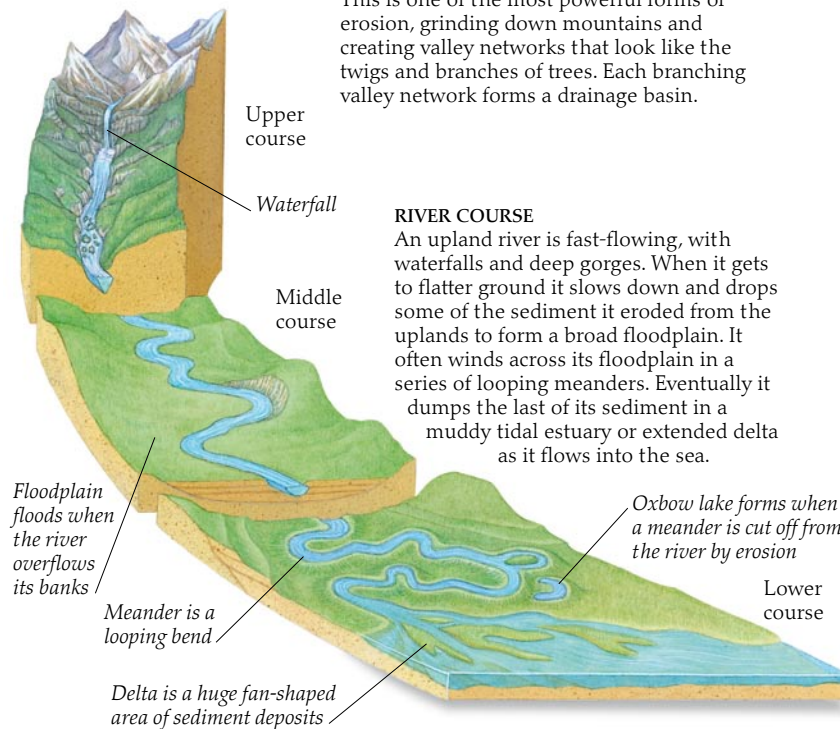


## FERTILE PLAINS

Heavy rain or melting snow can swell lowland rivers so they flood the surrounding landscape. Since the floodwater stops flowing, it drops all the small particles it is carrying, and when the flood recedes it leaves a layer of fine sediment. Over the centuries this develops into very fertile soil. If flooding is controlled, floodplains make excellent farmland.

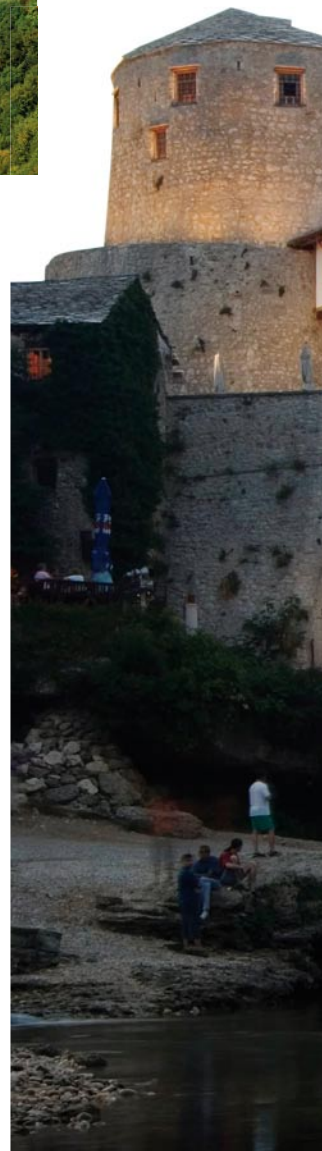
## SCULPTING THE LAND

As streams flow downhill from upland ridges, particles of sediment suspended in the water scour the rock to carve valleys in the hillsides. This is one of the most powerful forms of erosion, grinding down mountains and creating valley networks that look like the twigs and branches of trees. Each branching valley network forms a drainage basin.



## RIVER COURSE

An upland river is fast-flowing, with waterfalls and deep gorges. When it gets to flatter ground it slows down and drops some of the sediment it eroded from the uplands to form a broad floodplain. It often winds across its floodplain in a series of looping meanders. Eventually it dumps the last of its sediment in a muddy tidal estuary or extended delta as it flows into the sea.





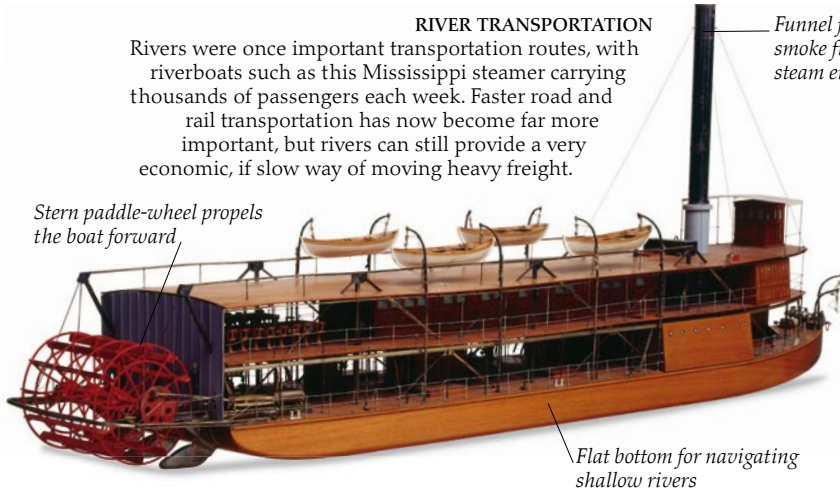
**RIVER MANAGEMENT**  
 Since floodplains make such good farmland and are often the sites of riverside towns, efforts are made to control flooding. These include raised banks and barrages that control the flow of water downstream. Tidal rivers can also flood because of very high sea levels. In the UK, the Thames Barrier (left) protects London from unusually high tides.

**RIVER TRANSPORTATION**

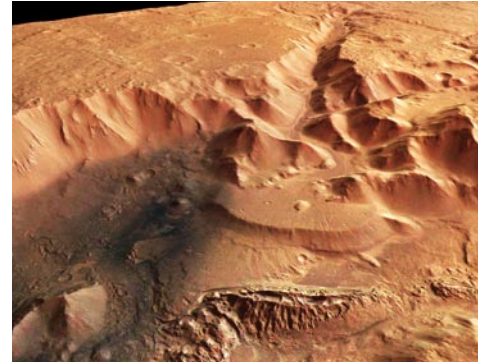
Rivers were once important transportation routes, with riverboats such as this Mississippi steamer carrying thousands of passengers each week. Faster road and rail transportation has now become far more important, but rivers can still provide a very economic, if slow way of moving heavy freight.

*Funnel for smoke from the steam engine*

*Stern paddle-wheel propels the boat forward*



*Flat bottom for navigating shallow rivers*

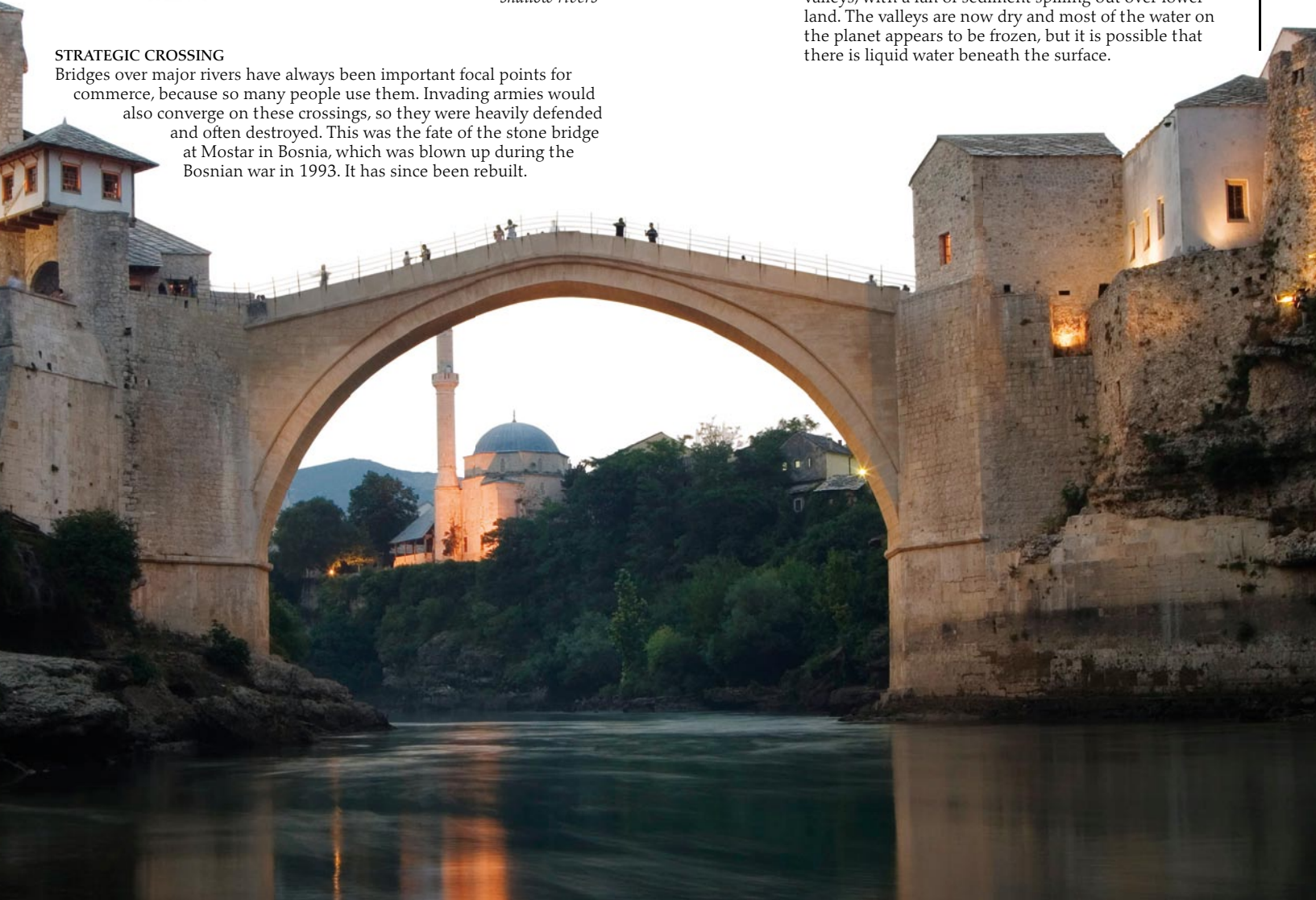


**RIVER ON MARS**

Branching valleys on Mars show that big rivers once flowed across its surface. This image shows one of these valleys, with a fan of sediment spilling out over lower land. The valleys are now dry and most of the water on the planet appears to be frozen, but it is possible that there is liquid water beneath the surface.

**STRATEGIC CROSSING**

Bridges over major rivers have always been important focal points for commerce, because so many people use them. Invading armies would also converge on these crossings, so they were heavily defended and often destroyed. This was the fate of the stone bridge at Mostar in Bosnia, which was blown up during the Bosnian war in 1993. It has since been rebuilt.





#### STILL WATER

Upland lakes like Lake Tahoe in the United States have cold, pure water with few of the dissolved nutrients that support aquatic life, so they are often crystal clear. By contrast, many lowland lakes are much warmer and richer in nutrients, so they contain a lot of plankton, which makes the water cloudy.

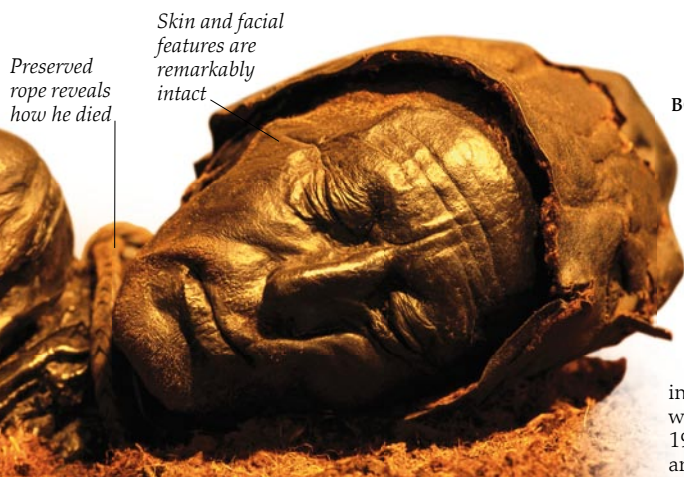


#### WILDLIFE HABITATS

Lakes and swamps are important habitats for wildlife such as this reed warbler, which nests in reedbeds and feeds its young on the teeming insects that hatch from the water. Over the years many wetlands have been drained and turned into rich farmland, but many others are now protected wildlife reserves.

#### EVOLVING WETLANDS

Fine mud settles among aquatic plants fringing lowland lakes, making the water shallower. Grassy plants colonize the shallow water, turning the lake into a swamp. Eventually water-tolerant woody plants such as these swamp cypresses take root in the mud, creating a wet woodland. Wet woodlands that receive heavy rain may be colonized by sphagnum moss that builds up in layers to create a peat bog.

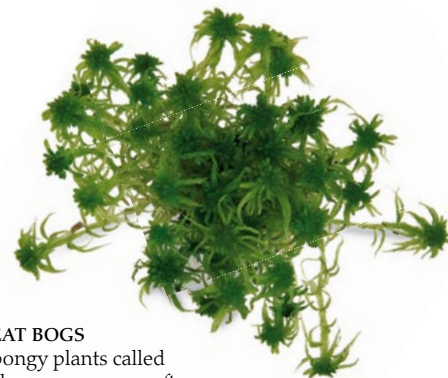


Preserved rope reveals how he died

Skin and facial features are remarkably intact

#### BOG BURIAL

The waterlogged conditions in peat bogs and swamps prevent the activity of microbes that make things decay, so these wetlands can preserve wood and other materials. Some bogs in Scandinavia even preserve the remains of sacrificial victims such as Tollund Man, who died in the 4th century BCE. He was found in Denmark in 1950 with a rope still tied around his neck.



#### PEAT BOGS

Spongy plants called sphagnum mosses often spread over cold wetlands. As old moss dies the waterlogged conditions stop it from decaying, and its remains build up into a peat bog such as the one that preserved Tollund Man.

# Lakes and swamps

FRESH WATER DOES NOT ALWAYS KEEP FLOWING toward the sea in streams and rivers. It can collect in ponds and lakes, or form wetlands such as peat bogs and swamps, which are also called marshes. Their nature varies according to climate, geology, and the plants and animals that live in them. They range from the cold, mosquito-infested peat bogs of northern mountains and Arctic tundra to the hot soda lakes of the African Rift Valley, with their spectacular flocks of flamingos. Some lakes are like freshwater seas, so broad that they extend way beyond the horizon. By contrast, many pools and wetlands are temporary, flooding only after heavy rain and drying up again within a few weeks.

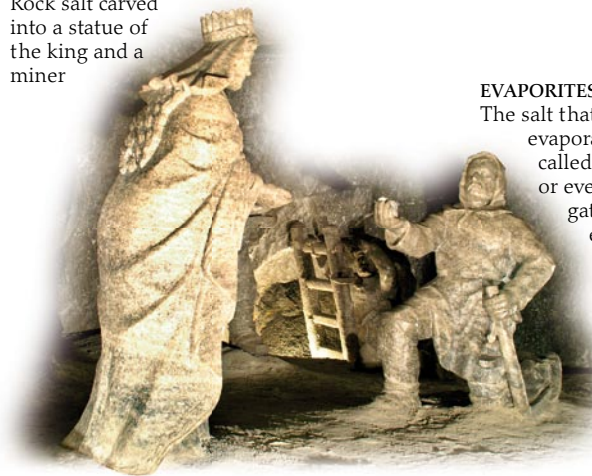


**SALT LAKES**

In hot climates, water may form lakes that have no outlet because the water just evaporates. As it evaporates it leaves any dissolved salt behind. As more water flows in and evaporates, the salt content increases until the water is up to ten times as salty as the ocean. The Dead Sea in the Middle East is so salty that you can read a newspaper while floating in it.



Rock salt carved into a statue of the king and a miner



**EVAPORITES**

The salt that is left behind as salt lakes evaporate can build up in deep layers called evaporites. As the lake shrinks or even disappears the salt can be gathered and sold. Ancient evaporites have been found buried beneath later rocks, and are exploited by sinking salt mines. The salt in a Polish salt mine has been used to create this sculpture.

Mangrove tree with roots exposed at low tide



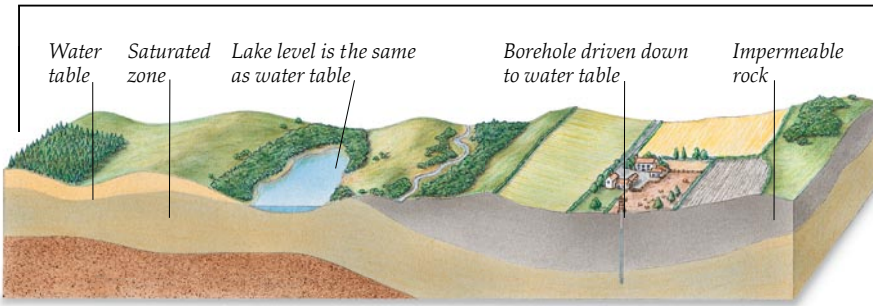
**INLAND SEA**

Some lakes are so vast that they could easily be mistaken for inland seas. The five Great Lakes in North America—near the center of this satellite image— together form the largest continuous mass of fresh water on Earth, containing some 5,909 cubic miles (24,620 cubic km) of water.

**SALTMARSHES AND MANGROVES**

Sheltered tidal shores are often colonized by salt-tolerant plants. On cool coasts these form grassy or shrubby saltmarshes, but in tropical regions trees known as mangroves form dense, tidal swamp forests.

The waterlogged mud is low in oxygen, so it is hostile to most plants, but the mangroves survive thanks to special roots that grow up like snorkel tubes to suck in vital oxygen.



# Hidden water

A LOT OF RAINFALL SINKS into the ground, where it is soaked up by the soil. Some flows downhill and emerges to join streams. But some seeps straight down into permeable layers of rock, sand, or gravel that allow water to pass into and through them. This hidden groundwater is a precious resource, because it flows away toward the sea more slowly than surface water, and only the groundwater closest to the surface evaporates into the air. So during dry seasons there are always reserves of water available, if you dig deep enough. There is even water deep below the surface in deserts, some of it thousands of years old.

## THE WATER TABLE

Water draining down through soil, sand, and many rocks eventually reaches a layer of impermeable rock such as granite. This stops the water from sinking any farther, so the layers above it gradually become full, or saturated, with water. The upper limit of this saturated zone is called the water table.



## PRECIOUS WATER

If you dig a hole that is deep enough to reach the water table, the bottom of the hole will fill with water to form a well. The water level in the well is that of the local water table. This 150-year-old well in Bhopal, India, proved a lifeline during a drought in 2003, when most other water sources in the city dried up.

Heathland forms on the infertile land



Minerals washed out of the upper layer

Some minerals form a dark layer

Deep layer contains minerals

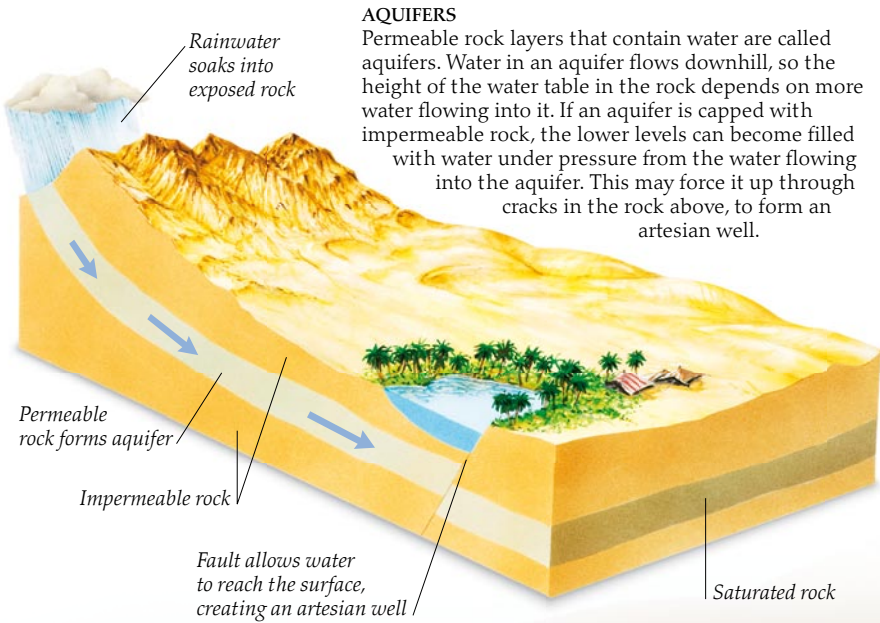
## SOILS AND DRAINAGE

Sandy or stony soil drains faster than fine-grained clay soil. As the water drains away it takes soluble alkaline minerals with it, making the upper layers acid and infertile. Only certain types of plants can cope with these conditions, often forming distinctive heathlands.



## FLUCTUATING LEVELS

In wet seasons the water table can lie very near the ground surface, saturating the soil to create a swamp. During long droughts the water table can sink so far below the surface that even big lakes dry up. But the soil nearly always contains some water—especially if it has a lot of clay. Clay always consists of at least 17 percent water, however dry and cracked it looks.



**AQUIFERS**

Permeable rock layers that contain water are called aquifers. Water in an aquifer flows downhill, so the height of the water table in the rock depends on more water flowing into it. If an aquifer is capped with impermeable rock, the lower levels can become filled with water under pressure from the water flowing into the aquifer. This may force it up through cracks in the rock above, to form an artesian well.



**SPRINGS**

If an impermeable rock layer emerges as an outcrop on a hillside, then any groundwater above it emerges too, at a spring. The water often flows from a row of springs tracing the top of the impermeable layer, and this is known as a spring line. The water is usually very clear because it has been filtered through the layers above the impermeable rock. If it contains minerals dissolved from the rocks, it is prized as mineral water.

**FOSSIL WATER**

Some natural underground water reservoirs were formed long ago and capped by impermeable rock. Fossil water can escape to the surface through a fault (above), or if wind erosion strips away the rock on top. In the desert, this may create an oasis (below). The water in some oases is up to 20,000 years old. One of the biggest desert reservoirs lies beneath the eastern Sahara, with an estimated volume of 36,000 cubic miles (150,000 cubic km).



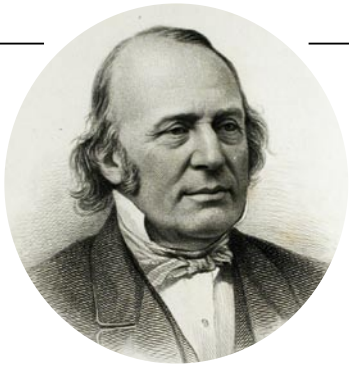
**HYDROTHERMAL VEINS**

Deep inside the Earth, water heated by contact with hot rock dissolves minerals. As the water flows away through cracks in the rock, it cools and the minerals crystallize in the cracks to form hydrothermal veins. Most of these veins consist of common minerals like quartz, but some contain precious metals, which are often mined.



**MINERAL WATERS**

Volcanically heated mineral water may emerge at the surface. It is often still warm, forming a thermal spring. Such mineral waters are believed to be good for the health. In the past, "taking the waters" was a popular therapy at spa towns such as Malvern in England, as seen here in 1855.



**LOUIS AGASSIZ**

In 1837 the Swiss zoologist Louis Agassiz put forward the idea that Earth experienced ice ages in the past. He came to this conclusion once he figured out that a lot of the landforms in northern Europe had been created by the erosive power of giant glaciers and the effects of frozen groundwater.

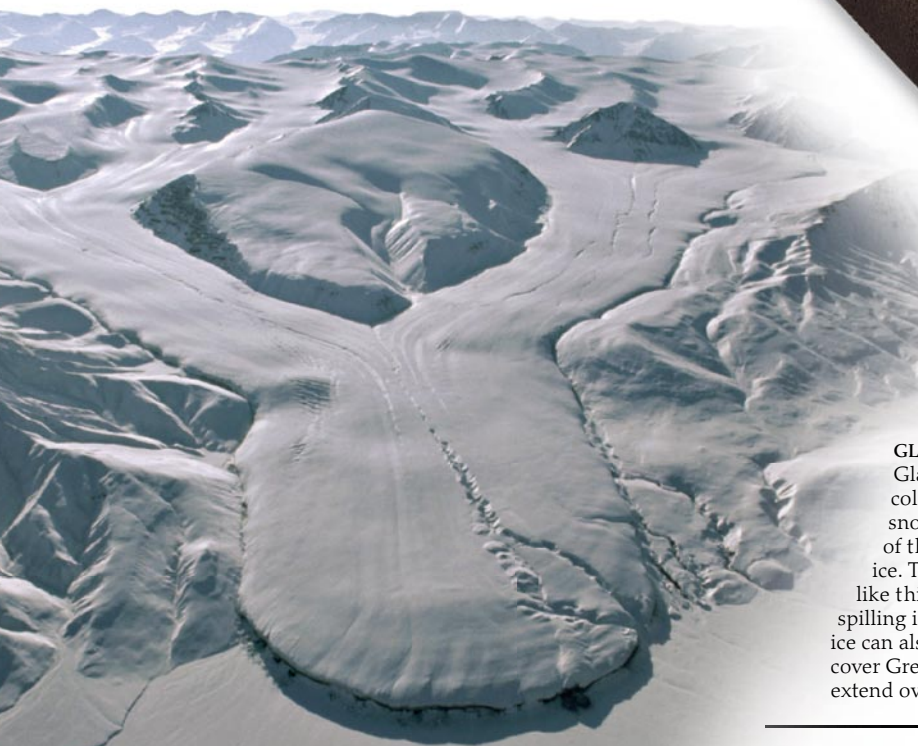
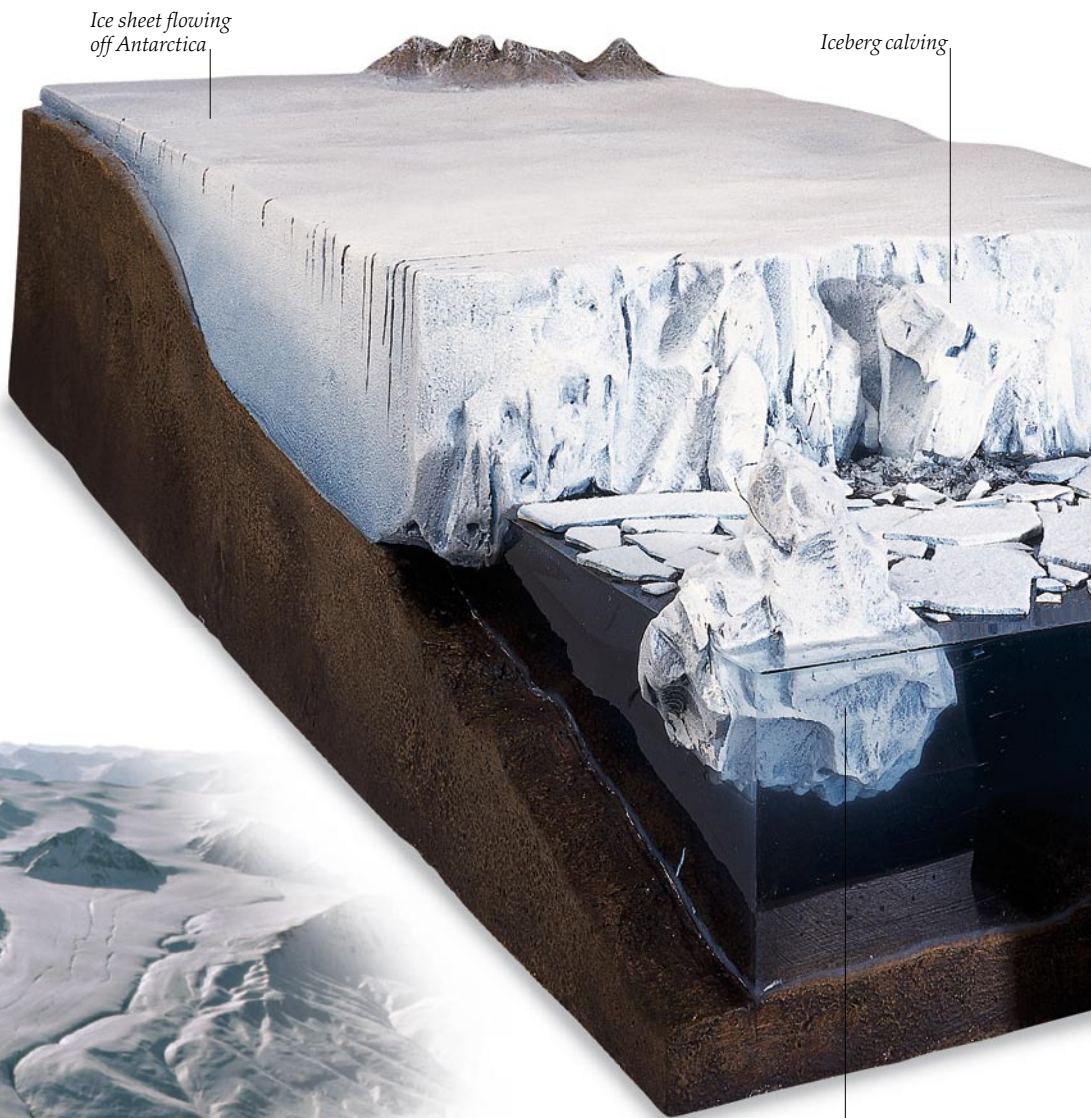
# Frozen water

**I**N THE LOW TEMPERATURES of polar regions and on high mountains, most of the water in the environment is frozen into ice—either on land in the form of glaciers and ice sheets, or on the ocean as floating sea ice and icebergs. The landscape is also often thick with snow, which may survive in the cold climate for many years. The possibility that this polar and mountain ice might melt is one of the main risks associated with climate change, partly because meltwater flowing off continents into the oceans could cause catastrophic rises in sea level.



**FROZEN SEAS AND LAKES**

The ice on polar seas and winter lakes is formed by cold air freezing the surface of the water. On oceans the freezing process goes through various stages, including soupy grease ice, thin plates of pancake ice as seen here, and thick pack ice. On lakes and ponds where there is less water movement, the ice sheet is usually continuous.



**GLACIERS AND ICE SHEETS**

Glacier ice forms from snow that falls in such cold conditions that it does not melt. As more snow falls on top, its weight squeezes air out of the snowflakes and welds them into solid ice. The ice tends to creep downhill as glaciers, like this one flowing off an Arctic island and spilling into a frozen sea. In polar regions glacier ice can also form vast ice sheets such as those that cover Greenland and Antarctica. Where ice sheets extend over the sea, they are called ice shelves.

*Iceberg floats with most of its mass underwater, like all icebergs*



**ICE CORES**

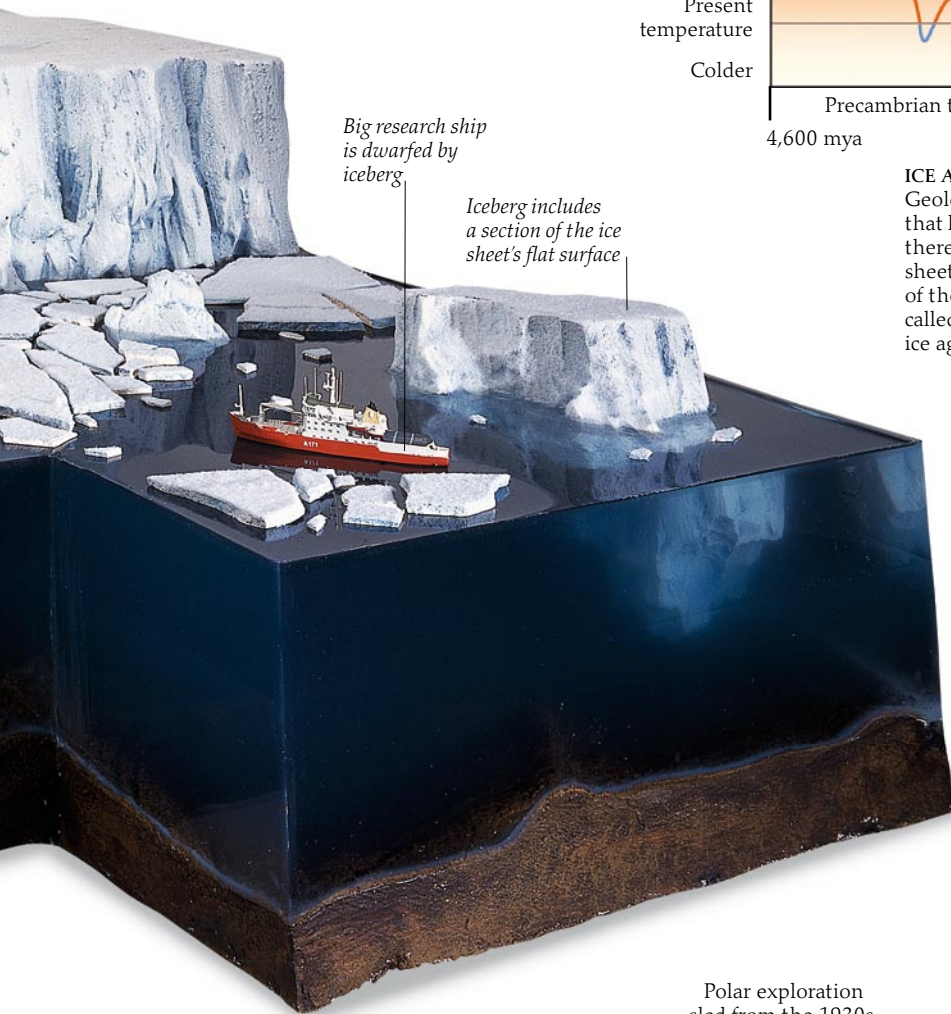
Thick ice sheets build up in regions where the temperature is permanently below freezing, so the compacted snowflakes may be thousands of years old. The oldest ice found so far dates back to about 650,000 years ago. The ice contains pockets of air and particles of pollen and dust that were trapped when the ice first formed. Scientists extract columns, or cores, of ice from the ice sheets, and analyze the air and particles within to discover valuable information about past climates.

Hollow drill bit is used to extract ice core

**PERMAFROST**

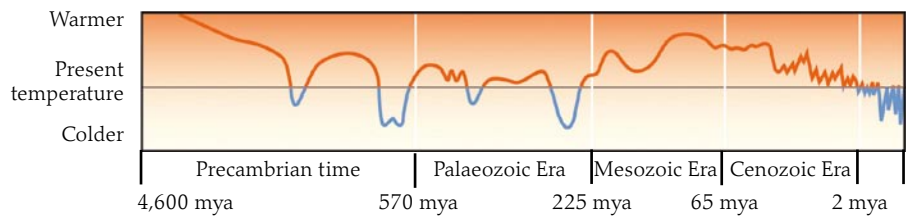
In the Arctic tundra, water seeping into the ground freezes solid. It may thaw near the surface in summer, but the deeper levels stay frozen. This permafrost layer prevents water from draining away, so the summer meltwater forms vast tracts of swampland. The permafrost contains the deep-frozen remains of extinct animals such as this baby mammoth, whose 40,000-year-old remains were found in Siberia in 1977.

Skin preserved by the ice



Big research ship is dwarfed by iceberg

Iceberg includes a section of the ice sheet's flat surface



**ICE AGES**

Geologists divide Earth's long history into different time periods that lasted millions of years. During some of these time periods there were episodes when much of the planet was covered by vast sheets of ice and snow. These episodes are known as ice ages. Each of these ice ages had cold phases, called glacials, and warm phases called interglacials. We are now experiencing an interglacial in an ice age that started about 2 million years ago (mya).



**ICE AND SEA LEVEL**

During the last ice age, so much water was locked up as ice that sea level fell by 300 ft (100 m). This turned shallow seas like the Bering Strait between Asia and North America into dry land (pale brown above). Sea level rose again when the ice melted. Further melting caused by global warming may make it rise even more.

**ICEBERGS**

When glaciers and ice sheets flow to the sea, chunks of ice break off and float away as icebergs. So icebergs are not sea ice but glacier ice formed from compressed snow. They float with about 90 percent of their bulk underwater, so they are much bigger than they look. Some of the icebergs that break off, or calve, from Antarctic ice sheets are vast, floating ice islands that may drift for years before melting away into the ocean.

Polar exploration sled from the 1930s, loaded with supplies

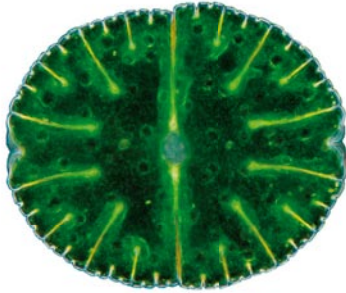
**POLAR EXPLORATIONS**

Icebound landscapes are virtually lifeless, because most forms of life cannot function in places where all liquid water is turned to ice. Warm-blooded animals and people can survive, but only with difficulty. So polar exploration is dangerous, and many brave explorers have died there.





# Water of life



## SINGLE CELL

The simplest life-forms are single-celled, microscopic packets of watery fluid like this desmid. Single-celled organisms use chemicals dissolved in water to make substances called proteins. The proteins make up part of the structure of the cell and enable it to grow and reproduce.

## PHOTOSYNTHESIS

Plants use sunlight's energy to make their own food from air and water in a process called photosynthesis. Chlorophyll, a green chemical in the plant, absorbs the energy and uses it to split water into hydrogen and oxygen. The hydrogen is combined with carbon dioxide from the air to make sugar, an energy-rich food.



## PRODUCERS AND CONSUMERS

While some living things produce food, others—including all animals—consume it. They eat the food producers, or consume them secondhand by eating other consumers. They break down the carbohydrates, proteins, and other complex substances, and combine the ingredients with water to build new tissues.



*Plant makes sugar and proteins that are eaten by the caterpillar for energy*

*Caterpillar's food is broken down by digestion so the animal can absorb sugar and other nutrients*

**ALL LIVING ORGANISMS DEPEND ON WATER.** Most life-forms live in water, and all life forms on Earth are composed almost entirely of water. Many chemicals dissolve in water, allowing them to mix together and react to create the complex molecules of life. Water's ability to dissolve many substances also makes it an excellent medium for transporting dissolved chemicals, including nutrients, gas, and waste, into and out of living cells. All living organisms must retain a certain level of water to sustain normal life processes. If a living organism loses too much water, it dies. Water's unique life-giving properties mean it is likely that life itself began in water.

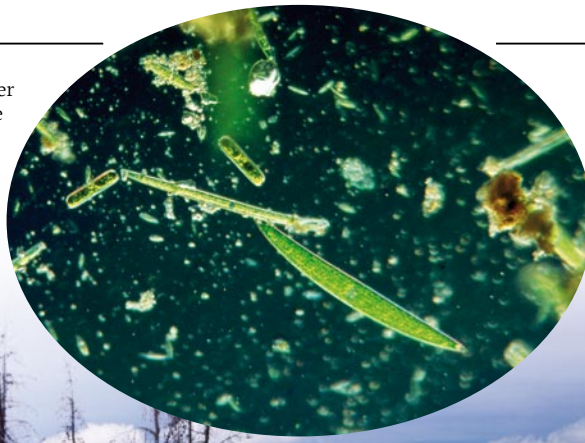
*Mats of microscopic bacteria flourish in the hot, chemically rich water*



## LIFE BEGINS

Earth may have looked like this in its early history about 3.5 billion years ago. At this time cyanobacteria, some of the first photosynthetic organisms, began to build up column-shaped stromatolites in the seas, as seen here. The first life forms were even simpler than cyanobacteria, and probably appeared through chemical reactions in hot pools of water about 3.8 billion years ago.

Pond water under  
the microscope



#### CRADLE OF LIFE

Most life is either oceanic or depends on cool rainwater. But some bacteria—the simplest living organisms—live in extreme environments such as this hot spring in Yellowstone National Park, where the acidified water can be a scalding 175°F (80°C). These bacteria are very similar to fossils of the earliest known life forms, so it is likely that life began in hot water like this.

#### LIVING WATER

Water is the main ingredient of all living things, which could not function without it. Water is also the habitat where most of them live. A single drop of pond water often contains hundreds of microscopic organisms, such as these euglenas, desmids, and diatoms. Together they form a tiny living world supported by light, air, and water.



# Living in water

SINCE WATER IS VITAL TO LIFE, it makes an ideal habitat for living organisms—especially simple ones that absorb dissolved nutrients and gases through their skins. But it is also a good environment for many other reasons. Liquid water is never very cold and only rarely very hot. It enables many animals to thrive without having to move around, because unlike air, it carries a lot of food that can be caught easily as it drifts by. It also supports the weight of animals, so they do not need strong skeletons. So it is no surprise that the greatest diversity of life flourishes in the world's oceans, lakes, and rivers.



## AQUATIC PLANTS

Water is essential to plants, which use it to make food. Some plants, such as this water lily, are adapted to live either on or under the water of rivers and lakes, where they never risk drying out. Their specialized roots can take in oxygen from the water. All plants use oxygen to extract energy from their food.

## MICROSCOPIC PLANKTON

The smallest aquatic organisms are bacteria and microscopic algae, such as these diatoms. They drift in sunlit water as plankton, and make food by photosynthesis, just like green plants. They are eaten by tiny animals that drift around with them, and both are eaten by larger plankton-eaters such as freshwater insects and fish. So plankton support all other aquatic animals.



## CRAWLERS AND GRAZERS

Many aquatic animals such as snails, crabs, starfish, and this amazingly well-camouflaged sea slug live by crawling about on the seabed, or over seaweeds and coral reefs. They graze on algae or rooted animals that cannot escape, or they scavenge the remains of marine animals.



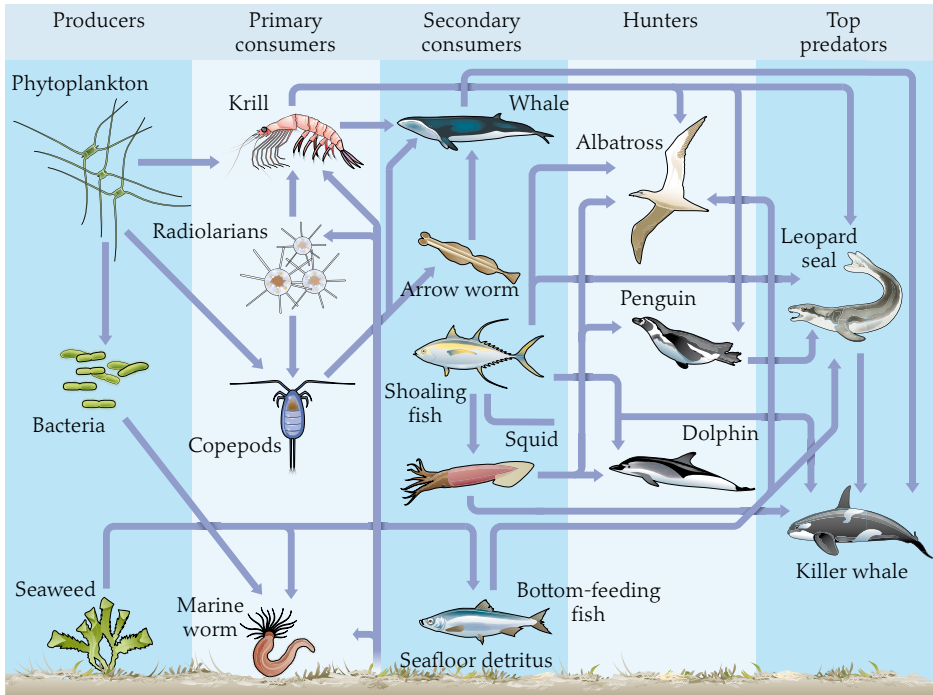
## ROOTED TO THE SPOT

Many aquatic animals such as this sea anemone cling to rocks and let the water bring them a steady supply of food. A lot of these animals live as plankton when they are young, drifting in the water and settling only when they turn into adults.

## LIVING REEF

Clear tropical seas contain very little plankton (see p. 18), so tropical corals must add to their food supply by teaming up with microscopic organisms, or microbes. The microbes live inside the coral and make sugar from water and oxygen. They pass some sugar to the coral in exchange for protein-building nutrients. The sugar gives corals the energy to build coral reefs.





**AN OCEANIC FOOD WEB**

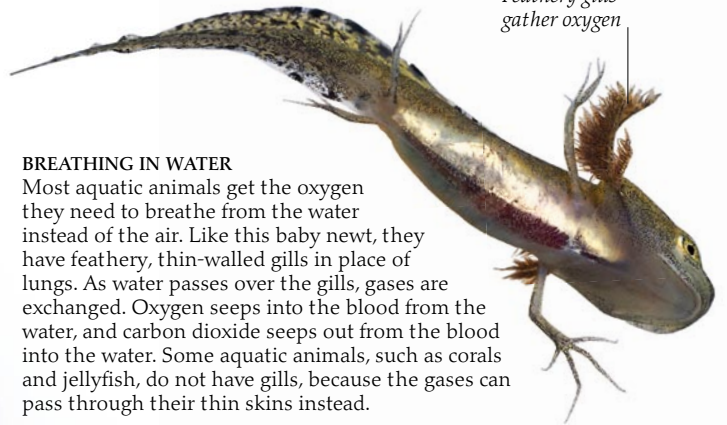
In the ocean, producers are eaten by primary consumers such as copepods. These are eaten by secondary consumers such as squid, which are hunted by animals such as dolphins. Dolphins may fall prey to top predators such as killer whales. However, life is more complicated than this, because most animals also eat creatures at other levels in the system. So instead of being part of a simple food chain, oceanic animals interact in a complex food web.

**THE WRONG TYPE OF WATER**

Most aquatic animals live either in fresh water or in salty seas. If they enter the wrong type of water, their body fluids gain or lose water until their salt content matches that of the environment. They swell up or dry out, and die. But some fish, such as these salmon, have adapted to avoid this when they migrate upriver from the sea to breed.

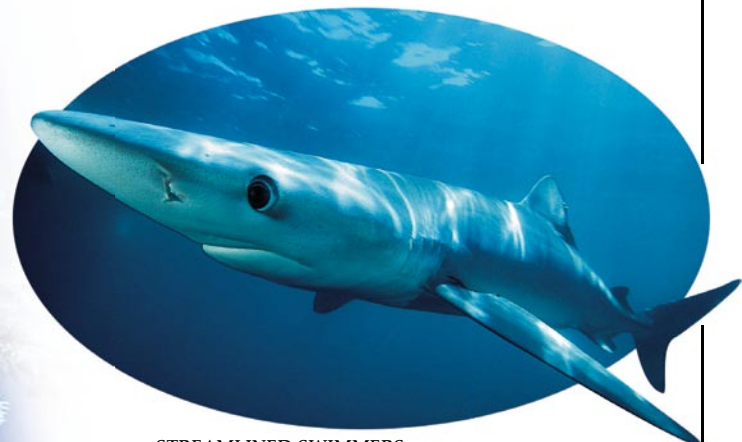


*Feathery gills gather oxygen*



**BREATHING IN WATER**

Most aquatic animals get the oxygen they need to breathe from the water instead of the air. Like this baby newt, they have feathery, thin-walled gills in place of lungs. As water passes over the gills, gases are exchanged. Oxygen seeps into the blood from the water, and carbon dioxide seeps out from the blood into the water. Some aquatic animals, such as corals and jellyfish, do not have gills, because the gases can pass through their thin skins instead.



**STREAMLINED SWIMMERS**

Water supports animals physically as well as providing them with food and oxygen. It is almost as dense as their bodies, so they can float above the ocean floor without using a lot of energy. But the density of water also makes moving through it difficult, so excellent streamlining is essential for animals that want to move fast. High-speed hunters such as this blue shark can swim at 25 mph (40 kph) or more.

# Roots and leaves



*Pseudomonas*  
bacteria

## TOUGH MICROBES

Microscopic single-celled bacteria like these can function only if they are wet, so on land they need to live in damp places. However, some of these microbes are able to survive drying out. They lie dormant (inactive), sometimes for several months, then revive and start multiplying when they get wet again.

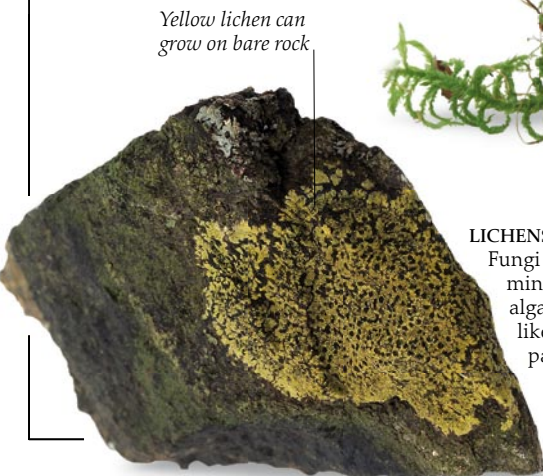
THE FIRST ORGANISMS TO LIVE ON LAND were microscopic bacteria, algae, and fungi, which lived in permanently wet places where they were surrounded by water. Eventually, simple plants such as mosses evolved the ability to absorb and store water, but they were still confined to damp habitats, and could not grow very high above the source of their moisture. The evolution of plants with veins for pumping water through their roots, stems, and branches solved this problem, enabling the growth of tall trees. As plants developed more effective ways of surviving drought they were able to colonize most of the land.



Thalloid  
liverwort

## GREEN CUSHIONS

Mosses and liverworts were the first green plants to appear on land about 470 million years ago. Most mosses and liverworts are low-growing plants that absorb water over their whole surface, often forming compact spongy cushions that store water after rainfall. They can survive dry periods, but they need water to grow and reproduce.



Yellow lichen can  
grow on bare rock.

## LICHENS

Fungi are very good at soaking up rainwater and dissolved minerals. Some form partnerships with microscopic algae that are able to make food by photosynthesis, like plants, but need a reliable water supply. These partnerships are called lichens. They can live almost anywhere, including bare rock, lying dormant during dry periods and growing slowly when they are wet.



Open cap  
shrivels up  
after scattering  
spores

Closed cap  
holds spores

## FUNGI

Fungi are utterly different from plants. They cannot make their own food, so they absorb food made by other organisms. They need a lot of water, forming extensive root networks that soak up water from soil or waterlogged timber. The mushrooms that appear on the surface are temporary reproductive structures that scatter their spores.

Fly agaric  
mushrooms

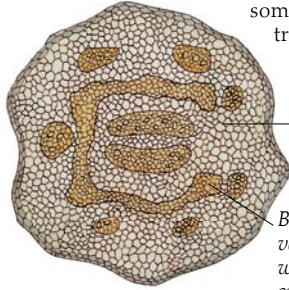
Soil conceals  
extensive root  
system



Fern frond contains vein network

**PIPED WATER**

Around 400 million years ago, ferns evolved the vein networks that carry water up their stems to their leaves, where it is used to make sugar. The veins, shown here in the cross-section illustration, allowed ferns to grow well above the ground on tall stems, and evolve into some of the first trees 300 million years ago.



Cortex helps support the stem

Bundles of veins carry water or sugary sap

Section through fern stem



Dried-up resurrection plant



Revived resurrection plant

**SURVIVING DROUGHT**

Water is vital to plants, but many are able to survive long periods of drought. Some, such as prickly cacti and similar succulent plants, store water in their stems and leaves. Other drought-resistant plants can dry out and miraculously revive when they get wet again. The "resurrection plant" of the American deserts is a type of moss that can survive for months like this.

**FOSSIL FUEL**

Over 200 million years ago, forests of tree ferns grew on swampy land. When the trees died and fell into the swamp, the watery conditions stopped them from decaying. The dead ferns formed deep layers of peat, which over millions of years became coal. Coal from mines such as this one powered the steam engines of the industrial revolution in the 18th and 19th centuries. Today, most electricity plants are powered by coal.

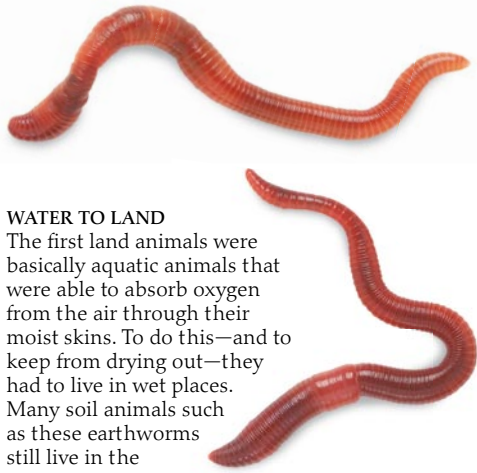


**WATER PUMP**

Trees rely on vein networks that are very like those of ferns. They work by a process called transpiration. As the Sun warms the tree, water in its leaves turns to water vapor that enters the atmosphere. That is why trees play a key role in the water cycle (see pp. 24–25). The evaporated water is replaced by more water drawn from the twigs, branches, trunk, and roots. The system pumps water to the top of the tree, which in this American redwood may be 300 ft (100 m) above the ground.



# Living on dry land



## WATER TO LAND

The first land animals were basically aquatic animals that were able to absorb oxygen from the air through their moist skins. To do this—and to keep from drying out—they had to live in wet places. Many soil animals such as these earthworms still live in the same way.

ANIMALS STARTED LIVING ON LAND about 420 million years ago. They were creatures like modern woodlice, which could lose moisture from their bodies easily because they did not have waterproof skins. This meant they were restricted to damp places where their bodies could absorb the moisture they needed to function properly. When the first land-dwelling vertebrates (animals with backbones) joined them they suffered the same problem. Most of these animals also had to breed in water, as most frogs still do. But over time animals such as insects and reptiles developed waterproof skins and ways of breeding on dry land.



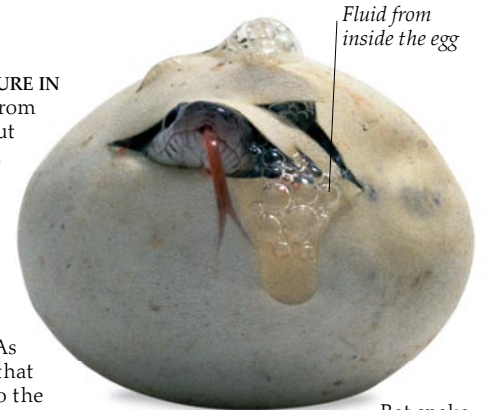
## WET AND DRY

Amphibians evolved from fish and became the first vertebrates to live on land about 400 million years ago. Although amphibians can breathe air and live on land, they return to the water to mate. Many amphibian females lay their eggs in the water, then the male swims over them and fertilizes them with his sperm. Amphibians rely on water to keep the newly hatched young from drying out and dying. This strawberry poison dart frog has placed her tadpole in water in a bromeliad plant to keep the hatchling moist. Amphibians do not drink water but soak up as much as they need through their thin skin.

## DRINKING

Aquatic animals get all the water their bodies need to function in their food, or absorb it through their skins. Some small land animals can live in the same way, but others must find water to drink. In hot, dry climates such as the African savanna grasslands, animals lose moisture easily and water is scarce. Large animals like these zebras may travel long distances every day to drink from scattered waterholes, otherwise they would not have enough water in their bodies for the life processes that keep the animals alive.

**KEEPING THE MOISTURE IN**  
The first reptiles evolved from amphibians (see left) about 340 million years ago. Reptiles can live in habitats that would be unsuitable for water-dependent amphibians because, unlike amphibians, reptiles have scaly waterproof skin and waterproof eggs. A reptile's skin keeps in essential moisture that the animal's body needs to function properly. As seen here, the egg keeps in fluid that keeps the unborn reptile moist, so the eggs do not need to be laid in water.



Rat snake hatching from its egg





**SURVIVING DROUGHT**

Unlike plants, animals are able to avoid droughts by moving to areas where the grass is still green. Some animals spend most of their lives on the move, such as these wildebeest crossing the dry African plains. Other animals go to ground, such as the desert toads that stay buried in waterproof cocoons until it rains.



**SHIPS OF THE DESERT**

Camels can travel for days without water because they do not start to sweat (see p. 49) until their body temperature rises well above the normal 98.6°F (37°C). This ability was exploited by the traders of the Sahara and Central Asia, who used camels instead of packhorses to carry their goods. This illustration from a medieval map shows the camel train of explorer Marco Polo on the Silk Road to China in the 13th century.

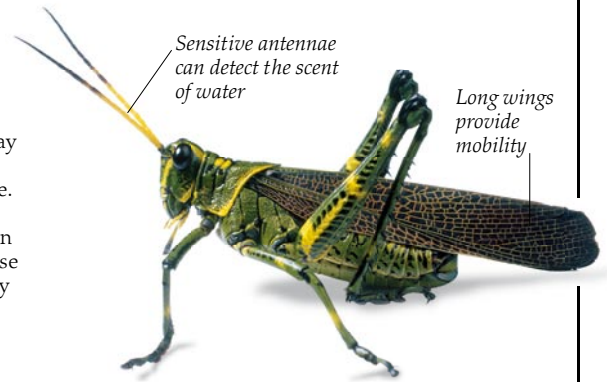
**DESPERATE MEASURES**

Most small desert animals stay in burrows all day to avoid the hot sun, and emerge at night when they are less likely to lose moisture.

In the Namib Desert of southwest Africa, beetles wait for water vapor in the cool evening air to condense on their bodies as dew. They then lift their tails so the dew drips forward into their mouths.



*Dew drops are pure water*



*Sensitive antennae can detect the scent of water*

*Long wings provide mobility*

**INSECT SWARMS**

Many desert insects have short, fast lifecycles that are triggered by rare rainstorms. They hatch, feed, mate, and lay eggs in a few weeks while the desert is still green, and their eggs then lie dormant until the next storm. Locusts live like this, sometimes forming vast swarms that contain up to 50 billion insects. If such a swarm descends on a farmer's field, the hungry locusts can destroy the entire crop within an hour





# Water in your body

**W**ATER MAKES UP AT LEAST HALF of our body weight and it is the main component of each cell in our body. Water is involved in every bodily function, and many of these functions rely on the body losing water at a steady rate. We must replace the water we lose by drinking and eating regularly to stay healthy. Losing even 10 percent of our body weight in water is enough to make us seriously ill. If we are deprived of water for too long, we can die of thirst.

## BLOOD CELLS AND PLASMA

The bloodstream is your body's transportation system. It delivers oxygen, food, and other essential substances to the tissues, and carries carbon dioxide and other waste products away. Some of these substances are carried by red blood cells. Others are dissolved in the liquid plasma, which is more than 90 percent water. The blood also carries the white blood cells that defend your body from bacteria that cause disease.



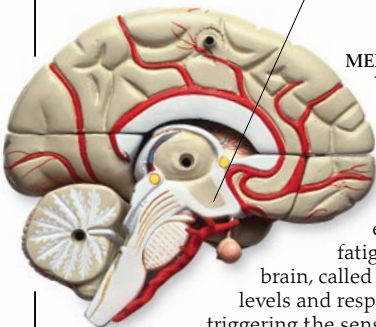
White blood cell

Red blood cell

Hypothalamus is located in the brain stem

## MENTAL POWER

Your brain is about 90 percent water. If there is not enough water in your body, the level of activity in your brain is reduced. This affects your concentration and memory, causes headaches, and may even lead to depression and chronic fatigue syndrome. Luckily, an organ in your brain, called the hypothalamus, is sensitive to water levels and responds to any shortage of water by triggering the sensation of thirst.

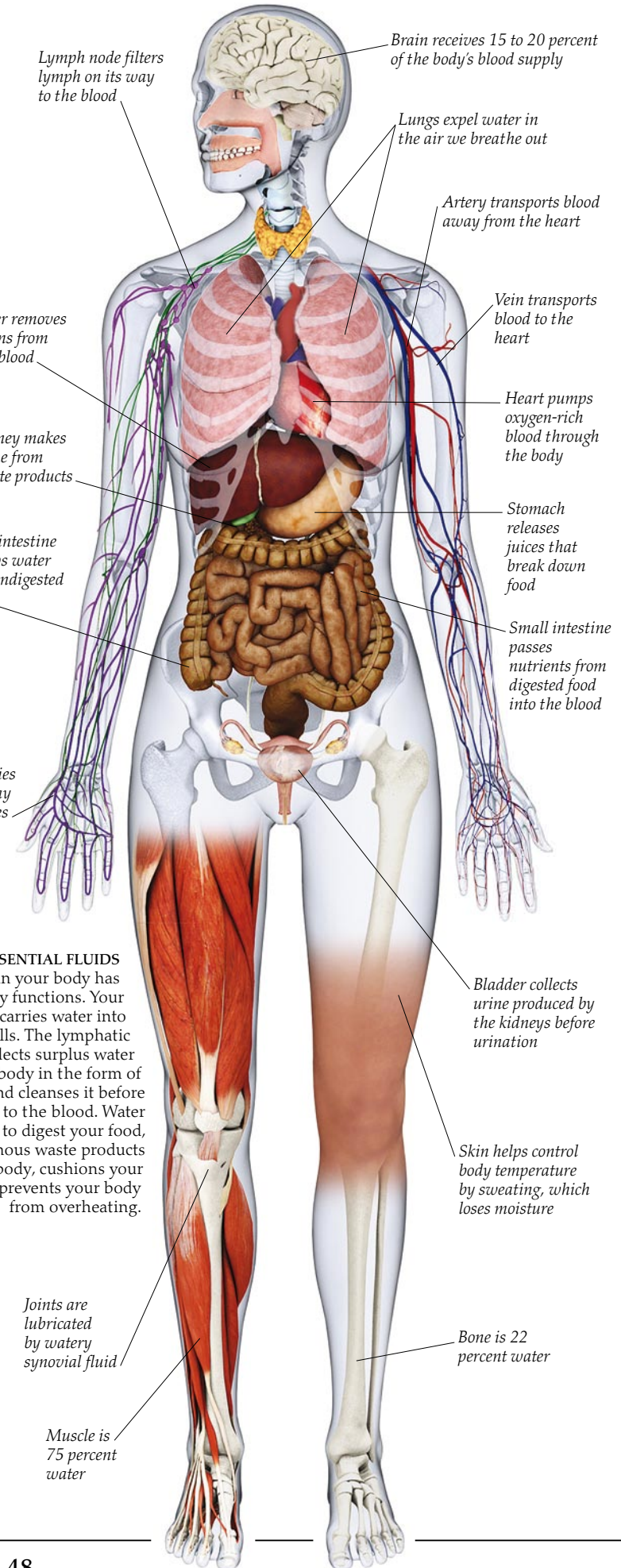


## ESSENTIAL FLUIDS

The water in your body has many functions. Your bloodstream carries water into all your cells. The lymphatic system collects surplus water from your body in the form of lymph, and cleanses it before returning it to the blood. Water helps you to digest your food, flushes poisonous waste products from your body, cushions your joints, and prevents your body from overheating.

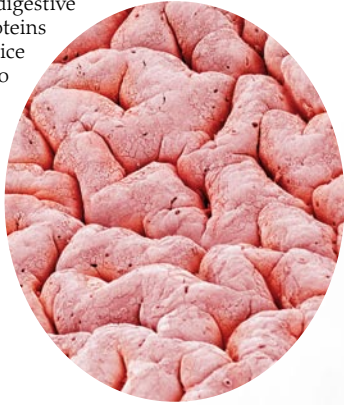
Joints are lubricated by watery synovial fluid

Muscle is 75 percent water

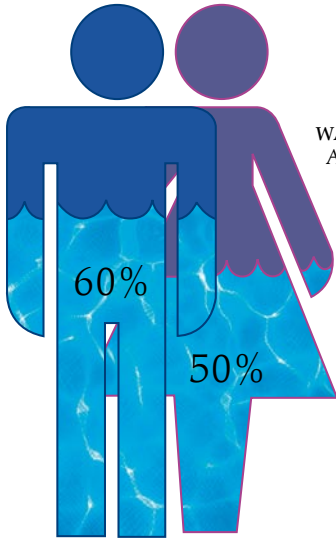


**DIGESTIVE JUICES**

During a meal, pits in the stomach lining pour about one pint (half a liter) of digestive juice onto your food. Special proteins called enzymes in the digestive juice start breaking down the food into useful nutrients. Deep in your intestines, more digestive juices continue the process. Your body absorbs the nutrients through the intestinal wall, along with most of the water.



Magnified view of stomach lining



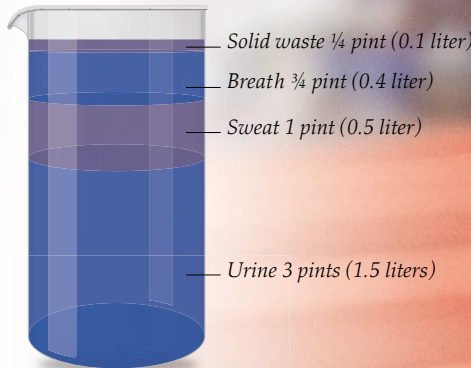
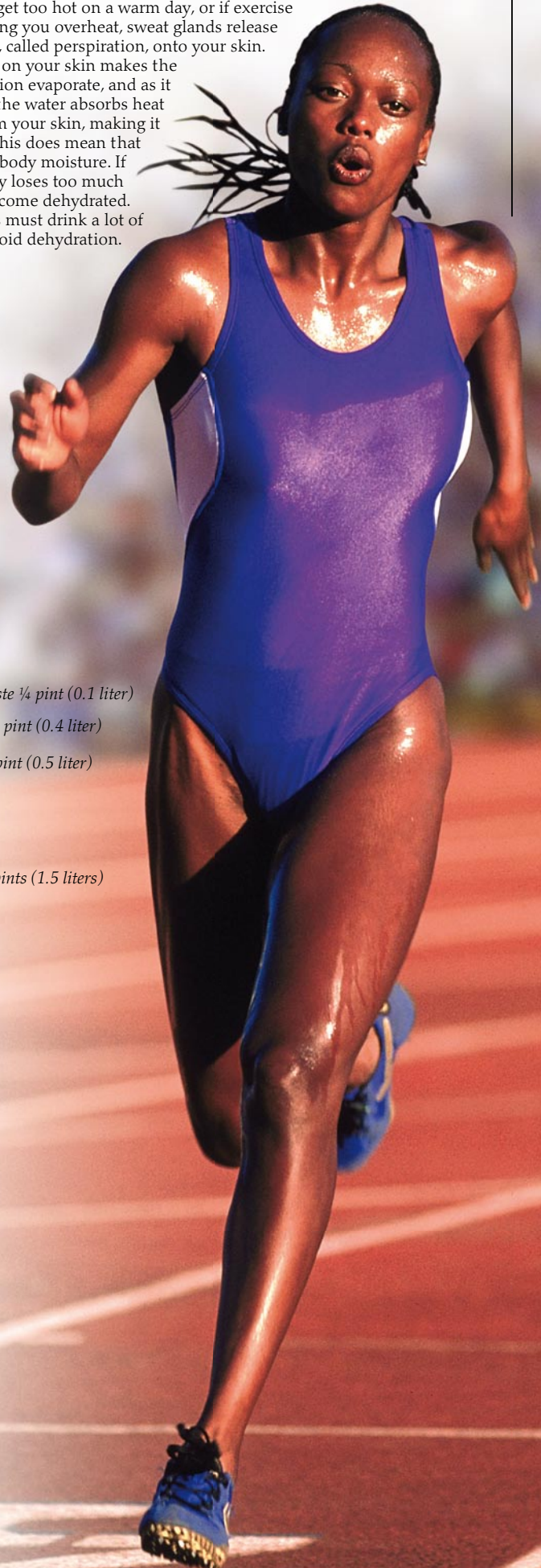
Adult man    Adult woman

**WATER AND FAT**

Although water accounts for more than 70 percent of most body tissues, fat is less than 25 percent water. So the more fat there is in your body, the smaller the percentage of water. On average, a woman's body has more fat than a man's, so her body contains a smaller proportion of water. Being dehydrated can also make you fat, because the body removes water from fat cells and this makes it harder for the fat to be turned into energy.

**WORKING UP A SWEAT**

When you get too hot on a warm day, or if exercise is making you overheat, sweat glands release moisture, called perspiration, onto your skin. The warmth on your skin makes the perspiration evaporate, and as it evaporates the water absorbs heat energy from your skin, making it cooler. But this does mean that you lose body moisture. If your body loses too much water you become dehydrated. Athletes must drink a lot of water to avoid dehydration.



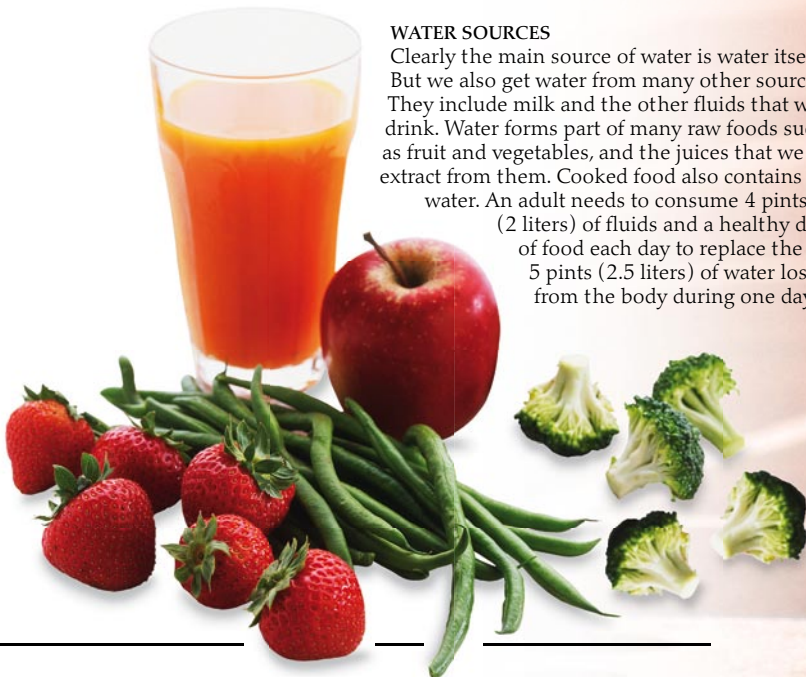
An adult's daily water loss

**LOSING WATER**

Your body is losing water all the time. The blood-cleaning function of your kidneys relies on water to carry waste products away in the form of urine. Keeping cool in warm weather relies on perspiration, which involves losing water. You also lose moisture every time you breathe out, because your breath contains water vapor. You can see this on cold days when it forms a visible mist of water droplets.

**WATER SOURCES**

Clearly the main source of water is water itself. But we also get water from many other sources. They include milk and the other fluids that we drink. Water forms part of many raw foods such as fruit and vegetables, and the juices that we can extract from them. Cooked food also contains water. An adult needs to consume 4 pints (2 liters) of fluids and a healthy diet of food each day to replace the 5 pints (2.5 liters) of water lost from the body during one day.



# Water and health

ALTHOUGH WATER IS VITAL FOR SURVIVAL, it can also be a danger to health. This is because it can carry microbes that cause disease. Some of these are parasites that live inside their host's body and sap his or her strength. Others are bacteria called pathogens that cause deadly diseases. These microbes get into the water when sewage contaminates the water supply. For most of history people had no idea that microbes existed. Yet they did realize that techniques such as boiling made water safe to drink, and some of these processes are still part of daily life.

## PRECIOUS RESOURCE

Clean, fresh water is the first and most vital requirement for health. In developed countries, where there are modern facilities and the income per person is relatively high, a reliable water supply is taken for granted. In many other parts of the world access to safe drinking water is a luxury. At least 884 million people still use sources of water that are likely to be contaminated with dangerous microbes. About 330 million of them live in Africa to the south of the Sahara. For these children in Zambia, southern Africa, the clean water flowing from this pump is a precious resource.



## DIRTY WATER

About 80 percent of disease in developing countries is caused by water contaminated with sewage. Water contamination is a constant problem in shanty towns, where poor people live in makeshift dwellings with no proper sanitation. It is also a major cause of disease when wars or natural disasters wreck drainage and water supply systems. These children in Baghdad, Iraq, may soon regret playing in this filthy water.



**PARASITE ATTACK**

Many people who live in places with poor water supplies suffer from intestinal parasites such as worms, flukes, or the microbe below, which can cause a serious illness called giardiasis. Tourists who visit these regions are also likely to pick up these dangerous parasites if they drink contaminated water, or even eat raw food that has been washed in such water.

Microscopic parasite *Giardia*



**FINDING THE LINK**

English physician John Snow discovered the link between disease and contaminated drinking water in 1854, during a cholera epidemic in Britain. With the help of clergyman Henry Whitehead, he tracked down the source of a local disease outbreak to an infected water pump in Broad Street (now Broadwick Street), London, and stopped it by getting the pump handle removed.



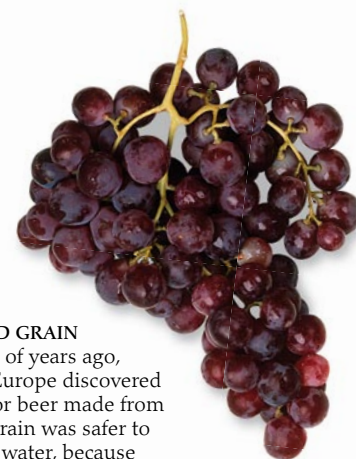
The Broad Street pump

**HEALTHY INFUSIONS**

As long ago as 350 BCE the Greek physician Hippocrates recommended boiling drinking water to rid it of bad smells and tastes, which he associated with disease. Boiling the water did remove the smells and tastes. It also removed the harmful microbes that cause diseases, although Hippocrates had never heard of microbes. Neither had the eastern peoples who also discovered that boiling their water reduced the risk of infectious disease. They found that it tasted better if poured over tea leaves, and so invented the tradition of tea drinking.



Early 19th-century Japanese woodcut print of a tea-drinking ceremony

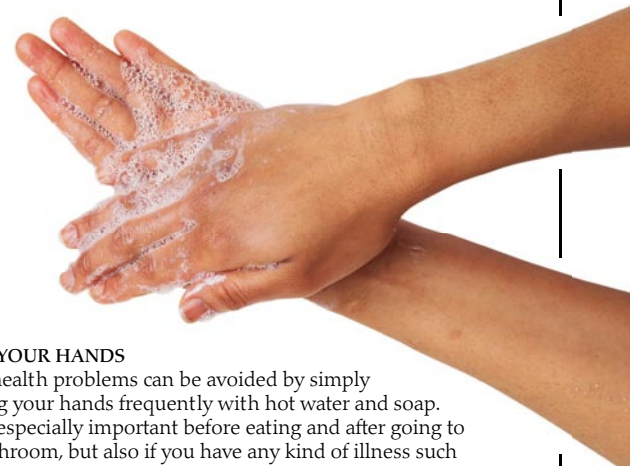


**GRAPE AND GRAIN**

Thousands of years ago, people in Europe discovered that wine or beer made from grapes or grain was safer to drink than water, because the alcohol killed any microbes, although this was not known at the time. But alcohol is poisonous to people, too, so the tradition had some unwelcome side-effects. These include diabetes, liver damage, heart disease, strokes, and throat cancer.

**WATER TREATMENT**

In most developed countries, the water supplied to homes is safe because it is filtered and treated with chlorine—the disinfectant that is also used in swimming pools. This destroys any bacteria or other organisms. Some people believe that chlorine may itself be a health hazard, but it is not nearly as dangerous as the pathogens it destroys.



**WASH YOUR HANDS**

Many health problems can be avoided by simply washing your hands frequently with hot water and soap. This is especially important before eating and after going to the bathroom, but also if you have any kind of illness such as a cold, because many infections are spread by physical contact. So although water can carry disease, it also provides one of the easiest ways of preventing it.

# Water supply

**HUMAN HEALTH** DEPENDS on a reliable supply of clean water. Long ago everyone drank the water from springs, rivers, and simple wells. But human populations are now so dense that the water from many of these sources is contaminated with human waste, which can carry parasites and pathogens. A lot of people living in developing countries risk illness by drinking the water because they have no option. But in the developed world drinking water is treated to eliminate the disease organisms, and piped directly to houses and other buildings. Wastewater is piped into drainage systems that carry it to water treatment works to be made harmless.

## RIVERS AND GLACIERS

Much of our water still comes from open sources such as streams and rivers, but it is generally treated to ensure it is safe to drink. Some countries use water that flows from glaciers, as seen here in the mountains of Chile. Glaciers act as natural reservoirs of clean water, but they are threatened by global warming.



## DAMS AND RESERVOIRS

Water is stored in reservoirs. These can be created by building river dams such as the Hoover Dam in Colorado. Reservoirs ensure a reliable supply even in times of low rainfall. But they can fill up with river sediment that settles at the dam. Often when valleys are flooded to create reservoirs, villages and farmland are lost, and the river life is devastated.

## WELLS AND BOREHOLES

These engineers in Zimbabwe are digging a traditional well—a deep hole that extends down to the water table (see p. 36). The water is collected with a bucket and windlass. Such wells are easily contaminated, but they can be made safer by sealing the well head and equipping it with a pump. The same principle is used to extract water from much deeper aquifers, using boreholes equipped with powered pumps.



Wooden dousing rod

**DOUSING**

Some people locate underground water by a traditional technique called water divining, or dousing. The douser surveys a likely area by walking slowly across it holding a forked stick or two metal rods, though the equipment varies. If carried across a hidden water source, the stick or rods react by moving, apparently of their own accord. It can work surprisingly well, but no one knows why.

Desalinated water is piped out of the filter and on to the post-treatment facility

Saltwater flows through membranes on its way to the center of the reverse osmosis filter

Intake valves draw in salt water from the sea

Outlet releases concentrated salt water into the sea

Power plant

Control center

Storage tank

Desalinated water is sent off to be added to the mains water supply

Post-treatment facility adds useful minerals to the water

Reverse osmosis filtration system removes the salt

Pipe carries concentrated saltwater out to sea

**DESALINATION**

In hot countries with few fresh water resources, drinking water can be made from seawater by removing the salt. The water is pumped through banks of very fine filters at high pressure in a process called reverse osmosis. The salt that is filtered out of the water is piped back to the sea. The process uses a lot of energy, but it can be fueled by solar power.

Engineer uses windlass to lower inspector



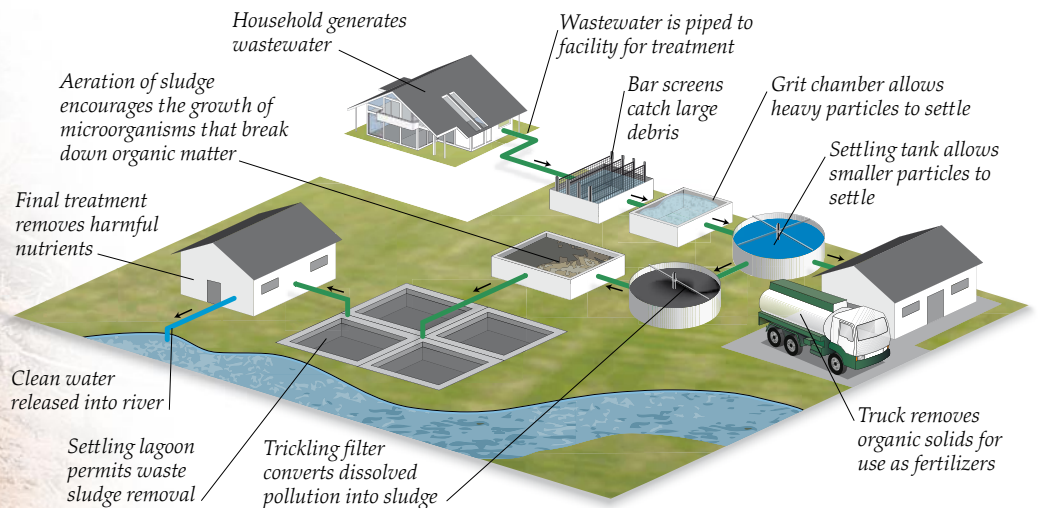
**SUPPLY PIPES AND SEWERS**

Most people in the world have to use a shared water supply, such as a village well. But in all developed countries water is delivered to individual homes and workplaces through a system of supply pipes. A similar network collects wastewater from houses, feeding it into big sewers like this that carry it to wastewater treatment plants.



**ANCIENT TECHNOLOGY**

The ancient Romans built magnificent aqueducts such as the Pont du Gard in southern France to supply water to cities. These were linked to long channels running over the ground or through tunnels. Engineers planned the course precisely so that the water would flow at a steady rate downhill.



**TREATING WASTEWATER**

Wastewater is delivered through the sewers to a treatment plant. Here it is filtered and passed through settlement tanks to remove most of the solids, before being treated to destroy any harmful microbes. The treated water is released in rivers or seas where it will be naturally purified long before there is any chance that it will be extracted for use again.

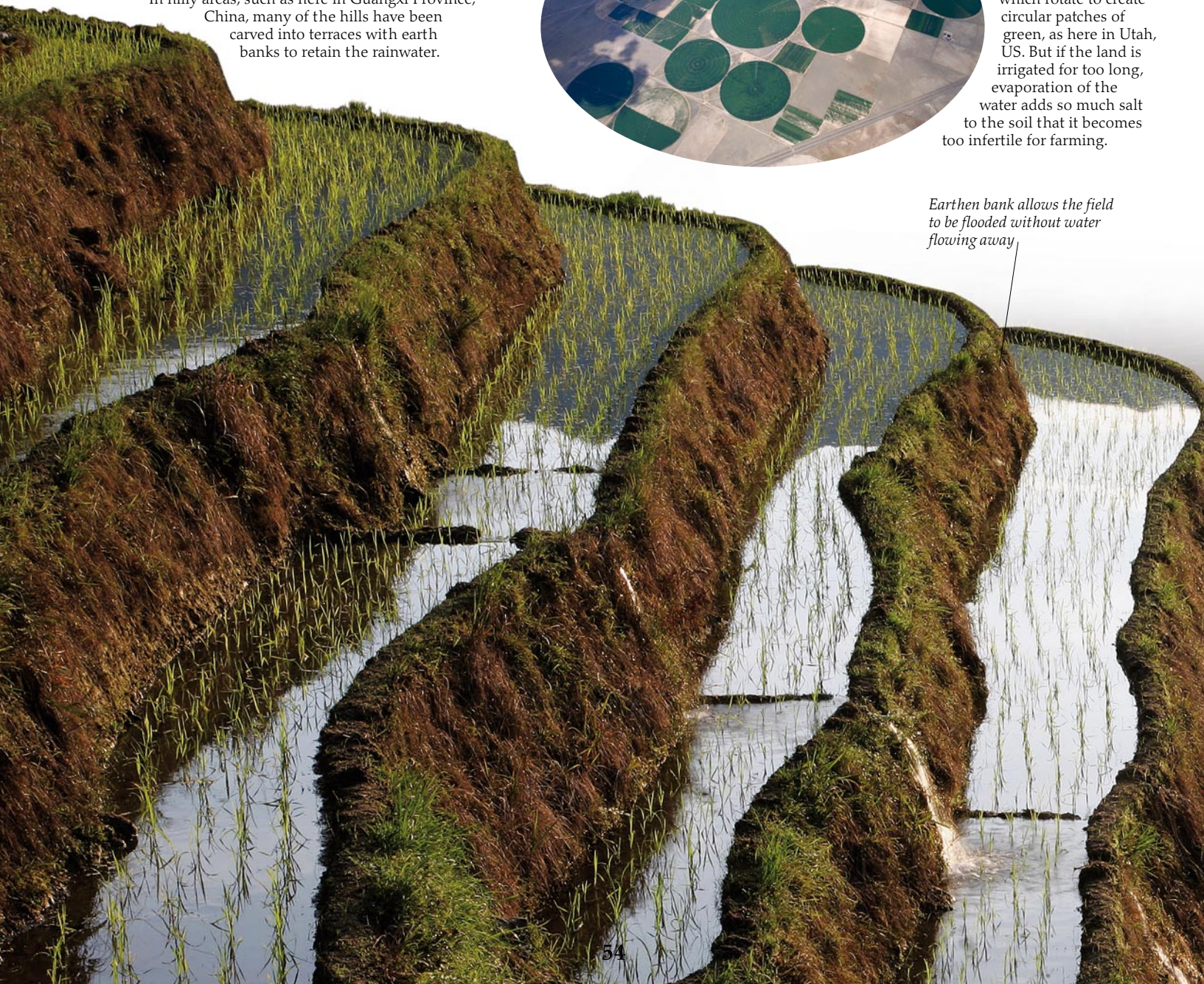
# Farms and factories

WE USE HUGE QUANTITIES OF WATER IN THE HOME, but at eight percent of the total water used, domestic use is tiny when compared to the massive 69 percent used to keep farm animals and to irrigate, or artificially water, crops. Industrial processes, including mining and papermaking, use the remainder. Using water on a large scale can seriously reduce supplies, especially in times of low rainfall, and this can cause problems for other water users. Some forms of agriculture and industry also introduce pollutants into waste water that is deliberately or accidentally released into the environment.

## RICE FARMING

Rice grows best in paddy fields, which are like broad, but shallow pools. In the Asian tropics, where rice has been a staple food for centuries, rice paddies cover much of the farming landscape.

In hilly areas, such as here in Guangxi Province, China, many of the hills have been carved into terraces with earth banks to retain the rainwater.



## ANCIENT IRRIGATION

In rice-growing regions that do not get daily tropical rain, paddy fields have to be irrigated—water is supplied to them artificially. In the past farmers used simple irrigation machines, such as the Archimedes screw in this 19th-century watercolor, to raise water from nearby rivers.



## GREENING THE DESERT

Irrigation can be used to turn barren deserts into farmland. Water is piped to long sprinkler arms, which rotate to create circular patches of green, as here in Utah, US. But if the land is irrigated for too long, evaporation of the water adds so much salt to the soil that it becomes too infertile for farming.

*Earthen bank allows the field to be flooded without water flowing away*



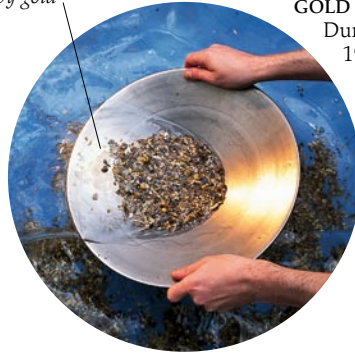
#### FARM ANIMALS

It takes a lot of water to keep a farm animal. A dairy cow drinks more than 40 gal (150 liters) on a hot day. Even more water is used to clean that cow's milking equipment and housing, and for growing food for the animal.

**HEAVY INDUSTRY**  
Water is used in huge quantities by industries such as papermaking—it took up to 2 pints (1 liter) of water to make this single sheet of paper. Metalworks such as this steel rod factory also use a lot of water for cooling both the product and the machines that make it. However, the water is not necessarily used up by these processes. It can be recycled in the factory or, if properly treated, returned to the environment.



*Water carries away sand and stones to leave heavy gold*



#### GOLD PANNING

During the US and Australian gold rushes of the 19th century, thousands of prospectors used water to separate gold from river sediments. Initially they would pan for gold by swirling sand and gravel in a pan of water. The heavier gold particles sank to the bottom of the pan and were separated out by gently swirling the lighter stony material over the rim.



#### HYDROPONICS

In some regions with little fertile farmland, crops are often grown under glass without soil. The system, known as hydroponics, uses just water containing dissolved nutrients, as seen in this glass jar. The method is often used in laboratories, and has even been proposed as a way of growing food in space.

*Pools polluted with copper from a copper mine in Michigan*



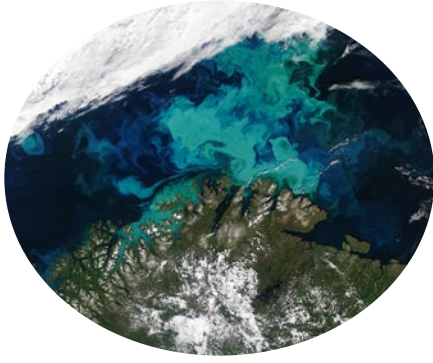
#### POLLUTION

Agriculture and industry can sometimes cause serious pollution of streams, rivers, and shallow seas. Fertilizer dissolved in water runs off agricultural land into bodies of water, which can become so fertile that certain algal species thrive. When they die the process of decay uses up the oxygen in the water, killing other wildlife. Toxic metals released by industry, such as lead and mercury, poison aquatic wildlife and make the water undrinkable. Some watercourses have even been known to contain radioactive waste.

*Water nourishes the rice and prevents weeds from growing*







#### RICH FISHERIES

Most of the richest fishing waters are shallow coastal seas where currents can scour nutrients from the seabed and bring them to the surface. Here they nourish swarms of plankton that feed big shoals of fish. The pale blue-green area in this satellite image of the Arctic is a plankton bloom.

# Fishing and fish farming

FISHING HAS BEEN A WAY OF LIFE for coastal, riverside, and lakeside communities for thousands of years. Some fish are caught by rod, or hand-thrown nets and traps in local waters. Far more fish are caught at sea by modern fishing vessels using the latest technology. Walls of nets and long lines of hooks, which are designed to catch fish in large numbers, often bring up by-catch, or species that are trapped unintentionally. Overfishing has reduced fish populations in many fishing grounds, so some seafood, such as salmon and shrimp, is now grown in fish farms to help meet demand.

#### SUSTAINABLE METHODS

For most of history fishing techniques were not efficient enough to have a serious impact on fish populations. Fish could breed fast enough to replace the numbers caught. Human populations were also much smaller. These lake fishermen in Burma (Myanmar) still use simple nets, watching for fish while paddling their boats with one oar. They do not catch more than they need and never run out of fish.



#### ANCIENT ART

Historical evidence of fishing, such as discarded fish bones and cave paintings, dates back 40,000 years. But people were probably fishing long before then. Many artists and authors have shown the importance of fishing to the people of their time in their work. This medieval painting illustrates a poem by the Greek author Oppian.





Reel releases and winds in fishing line

Trout rod (disassembled)

**ROD AND LINE**

For some people, fishing is just for fun. Most of these fishing enthusiasts fish with rods and lines and are known as anglers. They use bait and lures such as these imitation flies, which are designed to attract fish such as trout and salmon. Some anglers take away the fish for food, others return the fish alive to the water to sustain fish populations.



Hooks with fly lures

**BIG BUSINESS**

Sea fishing is now an industry, carried out by big boats such as these. They are equipped with electronic fish-finder equipment, great expanses of nets or immensely long multihooked longlines. They also have facilities for cleaning and freezing the catch on board. Often the boats must work in remote, stormy seas for months at a time because local fishing grounds have been overfished.



Conical net trap is dropped over freshwater carp, which is then speared.



**OVERFISHING AND BY-CATCH**

Commercial fishing has become so efficient that many of the world's richest fishing grounds have been virtually fished out. At the same time many other species, such as albatrosses and sea turtles, are threatened with extinction because they are being trapped and drowned by fishing nets and hooks.



Young hawksbill turtle caught in a fishing net

Fishermen protesting against fishing controls, Scotland, UK



**QUOTAS AND RESERVES**

Governments control fisheries with quotas that limit the number of fish caught. The fish must also be big enough to have had a chance to breed and increase fish stocks. The measures are unpopular with fishermen, who are forced to throw back part of their catch. These British fishermen are protesting against the rules by dumping young fish on a city street.

**FISH FARMING**

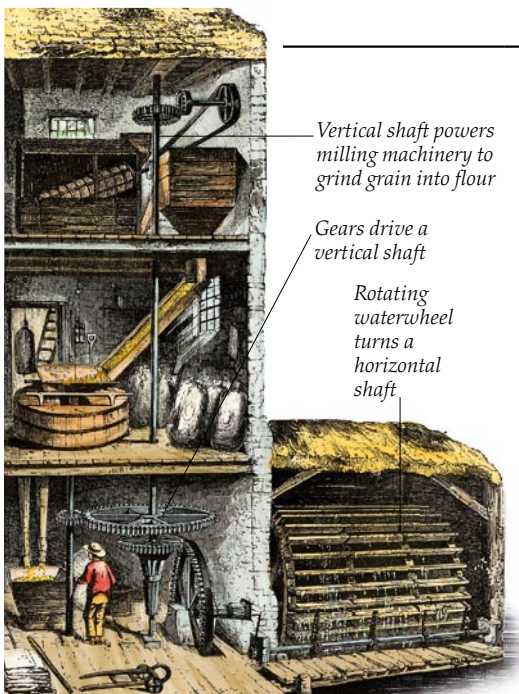
These shrimp have been raised in coastal pools in the Far East, rather than caught from the wild. Such fish farming might seem an ideal solution to overfishing, but creating the pools damages coastal ecosystems, especially the mangroves that resist oceanic storms. Rearing fish in submerged, densely-stocked cages can pollute the water with excess fish food, droppings, parasites, and chemicals used to control disease. Also, some fish are fed on seafood caught in the wild.



Farmed shrimp

# Water power

WATER CAN BE TURNED INTO ENERGY in several ways, either directly through the power of flowing water, or indirectly by turning it into high-pressure steam. Steam can be used to drive engines—including the steam turbines that generate a lot of our electricity. Turning water into steam requires heat. This has to be produced by using other forms of energy such as burning fuel, so the water is just part of the process rather than the source of the energy. But flowing water has a power of its own, making burning fuel unnecessary, and modern techniques for harnessing this power can be efficient.



Vertical shaft powers milling machinery to grind grain into flour

Gears drive a vertical shaft

Rotating waterwheel turns a horizontal shaft

## MILLWHEEL

Waterwheels have been used to extract power from running water for more than 2,000 years. The force of the water moved blades, paddles, or buckets on the wheel to turn it. The turning wheel rotated gears and shafts, which in turn drove machinery, often turning the grinding stones in flour mills such as this one. Simple wheels varied in speed according to the water flow rate. More sophisticated waterwheels provided consistent power because they were driven by the weight of water stored in a reservoir.



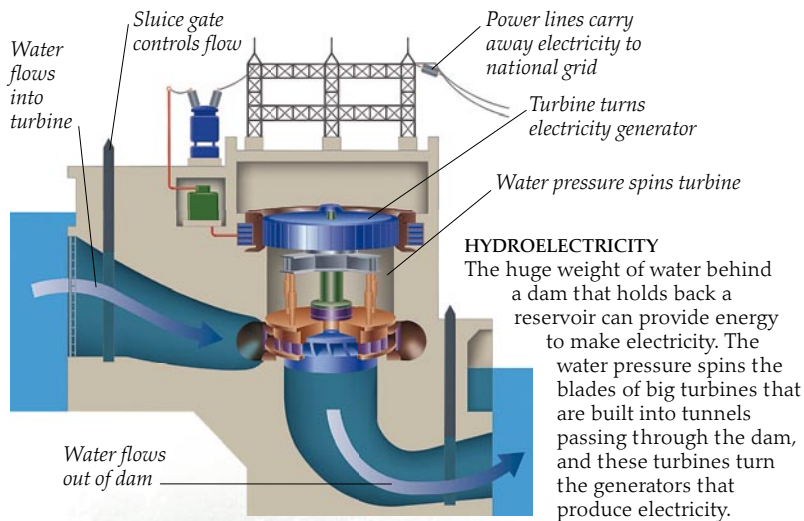
## JAMES WATT

The first steam engines were clumsy devices with pistons that moved in and out with a slow, jerky action. They were fine for pumping water, but they could not turn a rotating shaft. In 1765 the Scottish engineer James Watt invented a new type of steam engine with a smooth, continuous action that could be used as a power source for heavy industry. It was also ideal for driving steam railroad locomotives.

## STEAM PRESSURE

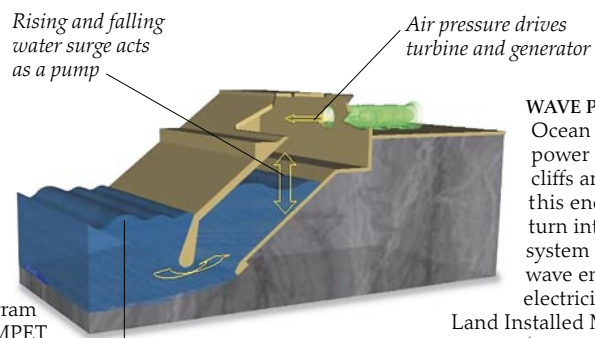
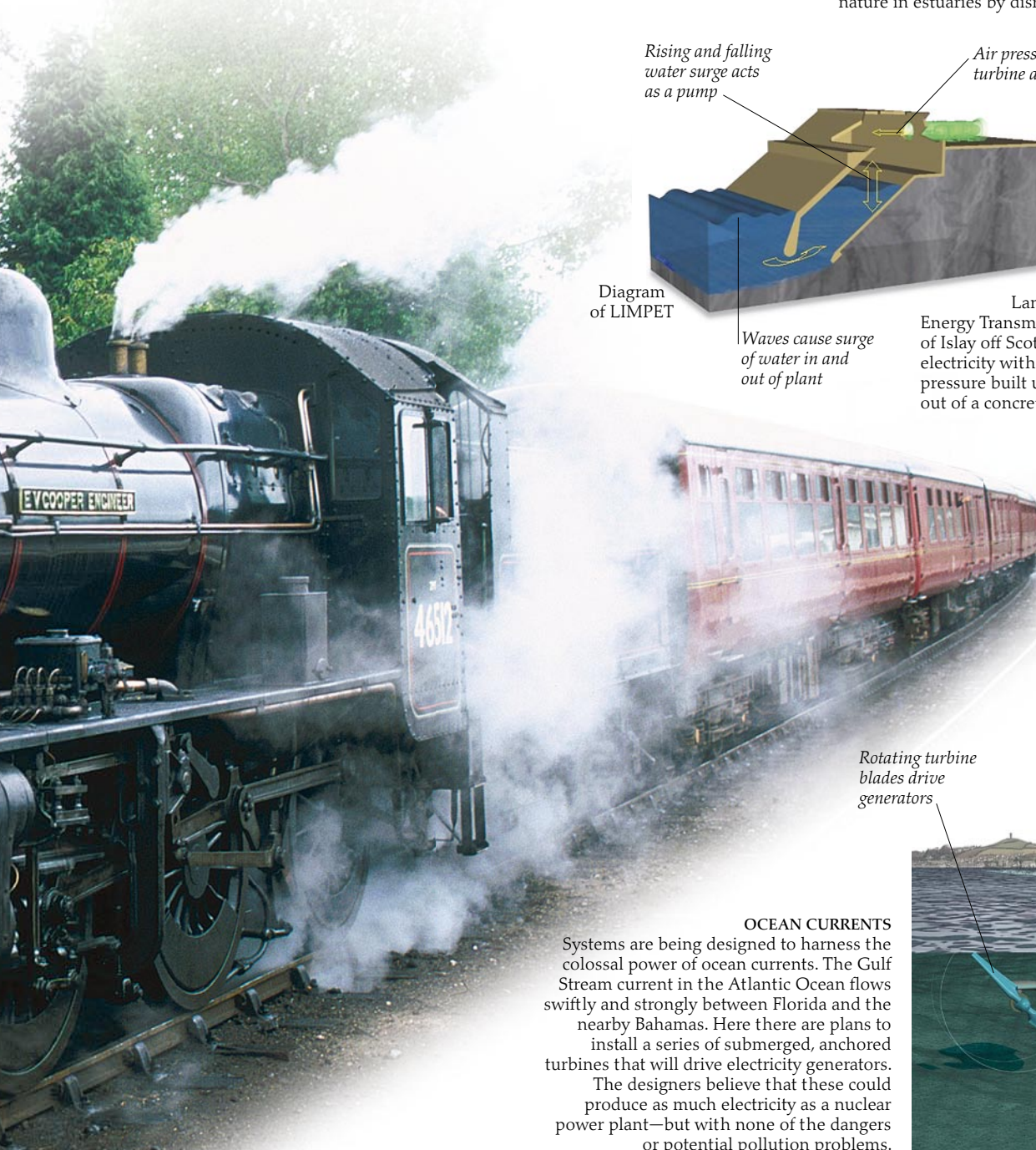
Old railroad engines such as this are driven by steam pressure that builds up when burning coal heats water in an enclosed boiler. The same principle is used to drive fanlike turbines in power plants to generate electricity. The heat that turns the water to steam can be produced by a furnace that burns fuel such as coal or gas, or by a nuclear reactor. Some turbines even run on steam that is generated by solar energy.





**TIDAL SURGE**

Barrages built across tidal river estuaries generate electricity in a similar way to hydroelectric plants. As the tide rises and falls it flows through turbines built into the barrage, and these drive electricity generators. The system can work well, but such barrages can upset the balance of nature in estuaries by disrupting the rhythm of the tides.



**WAVE POWER**

Ocean waves have the power to bring down cliffs and sink ships, but this energy is difficult to turn into electricity. One system that can harness wave energy and generate electricity from it is the

Land Installed Marine Power Energy Transmitter (LIMPET) on the island of Islay off Scotland, UK. The system creates electricity with turbines powered by the air pressure built up by waves surging in and out of a concrete chamber.



**OCEAN CURRENTS**

Systems are being designed to harness the colossal power of ocean currents. The Gulf Stream current in the Atlantic Ocean flows swiftly and strongly between Florida and the nearby Bahamas. Here there are plans to install a series of submerged, anchored turbines that will drive electricity generators. The designers believe that these could produce as much electricity as a nuclear power plant—but with none of the dangers or potential pollution problems.



# Water conflict

WE TAKE CLEAN WATER for granted. But in many parts of the world, fresh water is a luxury. It is so scarce and so valuable that people regularly risk their lives to gain access to it. In these regions extracting water from rivers for farming and city use can cause serious problems for people living downstream, as can damming rivers to provide power. The pollution of streams and rivers can have disastrous impacts on wildlife. All these problems can lead to political conflict and, if they are serious enough, can even trigger wars.

## VITAL SOURCE

Only 10 percent of the world's population have tap water in their homes. The rest must carry their water from communal sources. For these people, every drop of water is precious. They would never dream of wasting water, because they have barely enough for their needs.



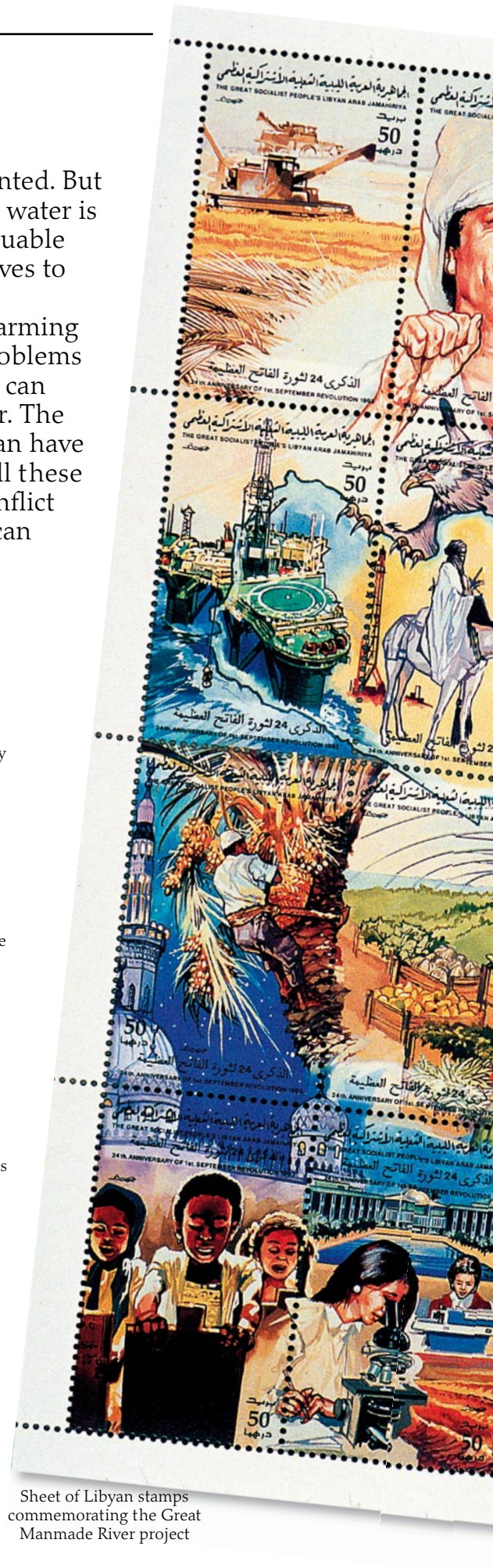
## WATER WARS

Disputes over water supply can lead to bitter conflict. In the early 1960s, Syria tried to divert water draining off the Golan Heights toward neighboring Israel by building a canal, shown as a blue dashed line on this map. The Israelis forced the Syrians to abandon the project, but tensions over water resources escalated into the Six-Day War in 1967, when Israel invaded Syria. Israel went on to occupy the entire Golan Heights region up to the dotted purple line, controlling all the water draining off the high land. Israel continues to occupy the Golan Heights and this is still an issue in Middle-Eastern politics today.



## WASTING WATER

We waste water without thinking about it. Some 30 percent of the water we use in the home is flushed down the toilet. We use even more to wash cars and sprinkle lawns to keep them green in summer. We even waste water in semideserts such as the one surrounding Las Vegas, where vast quantities of water are used to create golf courses like this one.



Sheet of Libyan stamps commemorating the Great Manmade River project

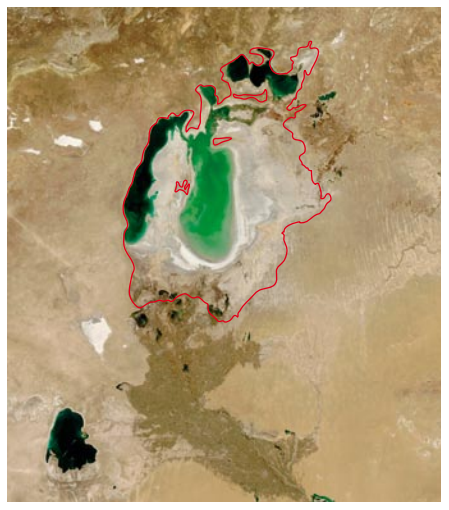
Colonel Gadaffi, Libya's leader



Huge concrete pipes for the Great Manmade River are hoisted into place by cranes

Stamps show how water will be used to grow crops in the desert

**DIVERTING RIVERS**  
Channelling water into irrigation programs can have disastrous effects. In the 1960s, 90 percent of the water that had been flowing into the Aral Sea in northwestern Asia was redirected into irrigation for growing cotton. As a result the Aral Sea shrunk from its original extent, marked by the red line on this satellite image, to one-tenth of its former size, and the lake's water became intensely salty and polluted.



**DRAINING THE DESERT**  
The Great Manmade River project in Libya, north Africa, draws water from a natural reservoir beneath the Sahara that accumulated during the last glacial period, which ended about 20,000 years ago. The program is supplying vast amounts of water each day to the major cities of Libya and has won Libyan politicians short-term prestige. But the water is not being replaced, so it will eventually run out. This could lead to many oases and towns in the desert losing their vital water supplies.

**WATER POLLUTION**  
Mining and industrial waste dumped in rivers can poison the river or restrict its flow, killing the wildlife and destroying the livelihoods of people living downstream. Pollution also affects the oceans. Some is deliberate, such as dumping at sea, but accidents such as oil spills can be just as devastating to animals such as this penguin. The coastal communities affected by these environmental disasters are often not properly compensated.



**THINK BEFORE YOU DRINK!**

Every year manufacturers use about 2.7 million tons of plastic to bottle water. Most of those bottles are produced from crude oil, a nonrenewable resource. Almost 90 percent of the plastic bottles end up in landfill sites, where they can take up to 1,000 years to break down. Despite these environmental concerns, in parts of the world where clean drinking water is not available, bottled water is often the only safe option.



**CLIMATE CHANGE**  
We are facing the probability of dramatic climate change. This is likely to cause more intense storms and local flooding in some areas, while others will suffer prolonged droughts that create deserts and trigger catastrophic fires like this. Such events, caused entirely by too much or too little water, will have big political impacts as national economies suffer and people migrate to regions that are not so badly affected.



#### THE VALUE OF WATER

In the past, life-giving fresh water was often seen as an almost sacred substance, and was frequently used to enhance temples and other places of deep spiritual significance, such as the Taj Mahal in India. Today many people have lost that sense of the value of water, but we must get it back if we are to use water wisely in the future.

# Water in the future

**W**ATER IS GOING TO PLAY an increasingly important part in the future of humanity. As human populations grow, and some areas become affected by droughts caused by climate change, water supplies may become stretched to the limit. We are already finding new sources of water, however, and finding ways to avoid waste and make the best of the water resources we already have. Before long, water conservation and recycling systems will be built into every new home, office, school, and factory, and efficient ways of using water will become part of everyday life.



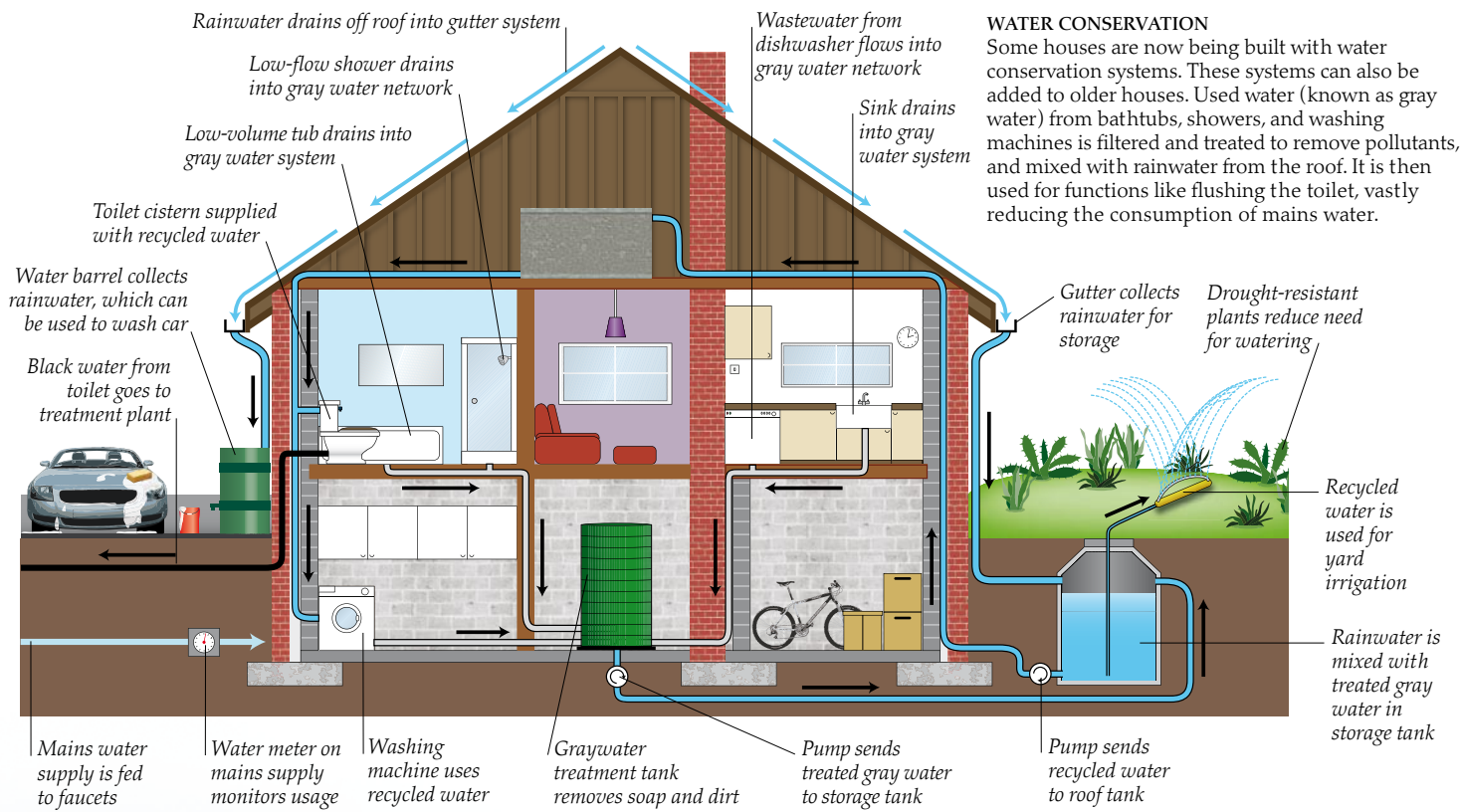
#### SECURING SUPPLIES

As rainfall patterns change, many countries may find that their water resources are inadequate and will need to search for others. One option is harvesting rain water or recycling some wastewater. Another option is removing salt from seawater, here being directed from the control room of a desalination plant in southern Spain.

#### SIMPLE SOLUTIONS

Many organizations are working hard to improve water supplies in places where clean drinking water is a scarce resource. The Hitosa gravity flow project in central Ethiopia has involved tapping the water from two springs, and using these pipes to carry it downhill to 31 villages and towns. It now supplies some 60,000 people with safe water.





**WATER CONSERVATION**  
Some houses are now being built with water conservation systems. These systems can also be added to older houses. Used water (known as gray water) from bathtubs, showers, and washing machines is filtered and treated to remove pollutants, and mixed with rainwater from the roof. It is then used for functions like flushing the toilet, vastly reducing the consumption of mains water.

**WATER AND WILDLIFE**

Droughts in the future could have dramatic effects on wildlife, especially the plants and animals of wild wetlands. Many wetlands are now protected wildlife reserves, where water levels are kept high to keep the ground wet. This ensures the survival of marshland and bog species such as these trumpet pitcher plants being examined by a biologist in the southeastern United States.



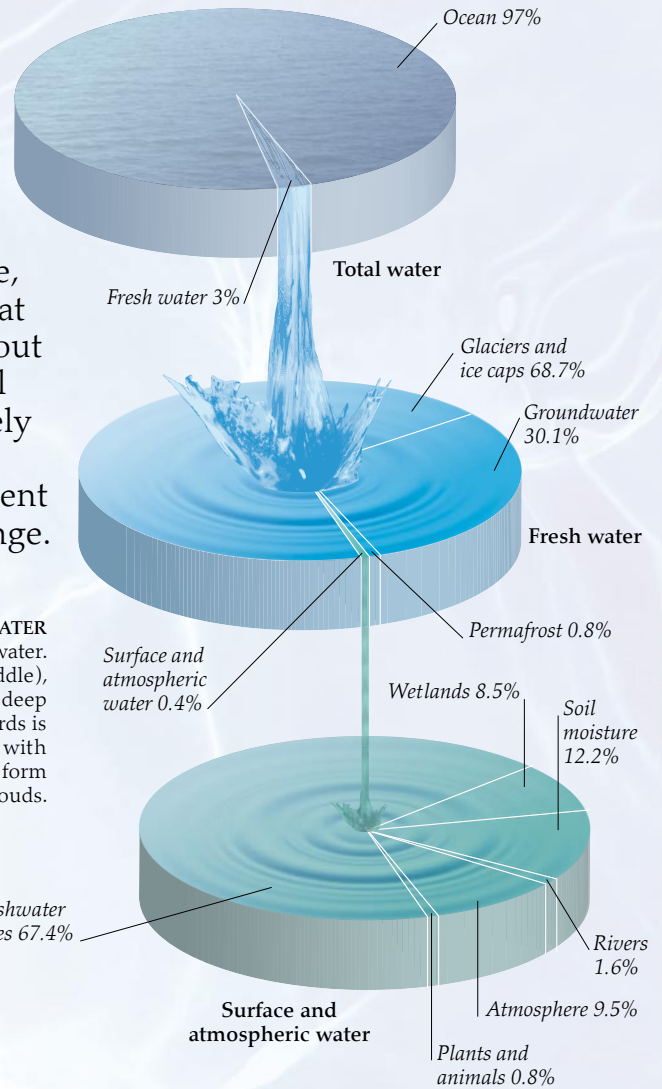
Amaranth plant      Amaranth grain

**CROPS FOR ARID LANDS**  
Regions that become more arid in the future will need crops that can survive with less water. These include amaranth, a high-yielding grain crop that is far more tolerant of drought than most crop plants. The grain can be used instead of rice or wheat, and because of its high protein content it is very nutritious.



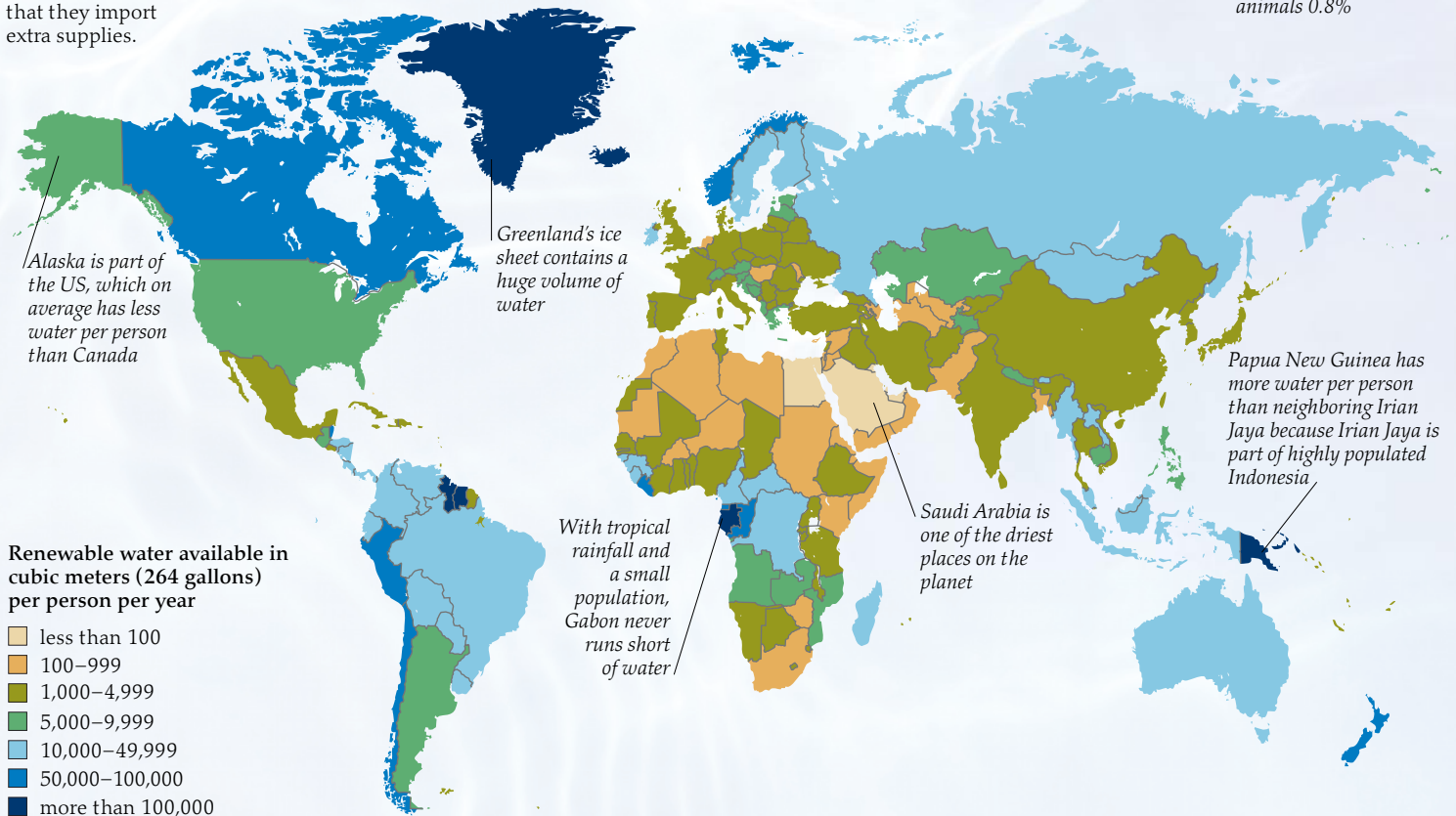
# Access and consumption

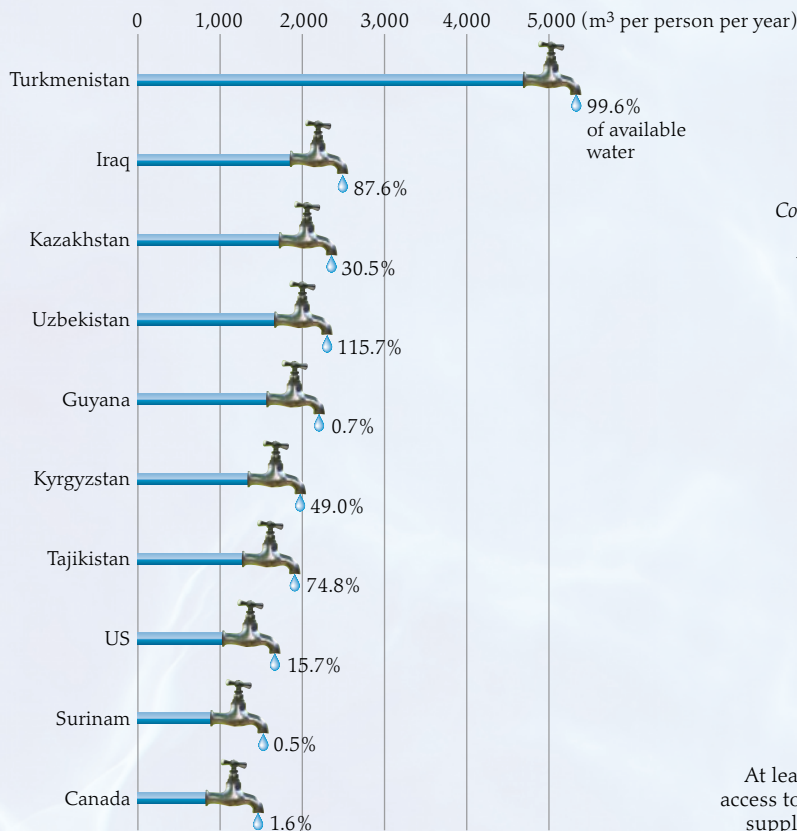
**W**ATER IS VERY UNEVENLY DISTRIBUTED across Earth, with some areas getting regular torrential rain while others suffer years of drought. In general, people live in regions where water supplies are reliable, but rising populations and changing climates mean that many now have difficulty getting enough water. Nine out of ten people have to fetch their water from communal sources, and of these, about 15 percent are forced to rely on sources that may be unsafe. Better water-supply systems may improve these figures, but the improvement could be offset by population growth and climate change.



## WATER AVAILABILITY

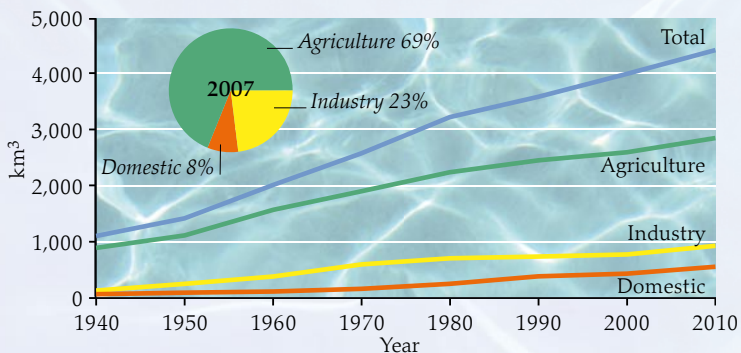
The availability of renewable water to people in different nations depends on how much water there is in water sources, such as in streams or aquifers that refill from rain and snow, runoff, or groundwater. The availability of water also depends on how many people there are. Australia, for example, has vast areas of desert but a small population, so it has more water available per person than India, which has far more water but a much bigger population. Some desert states have so little water that they import extra supplies.





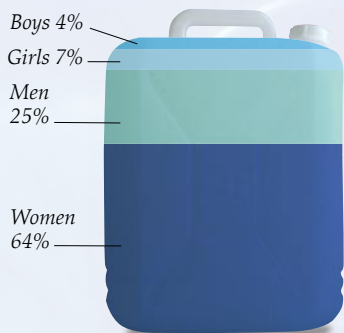
#### TOP TEN WATER CONSUMERS

The yearly water usage per person often depends on the climate. Turkmenistan is a very dry area of central Asia where crops have to be irrigated, so it uses most of its water resources. Canada has a lot more rainfall, less need for irrigation, and a lot more water to spare. (One cubic meter / m<sup>3</sup> is 264 gallons.)



#### HOW WATER IS USED

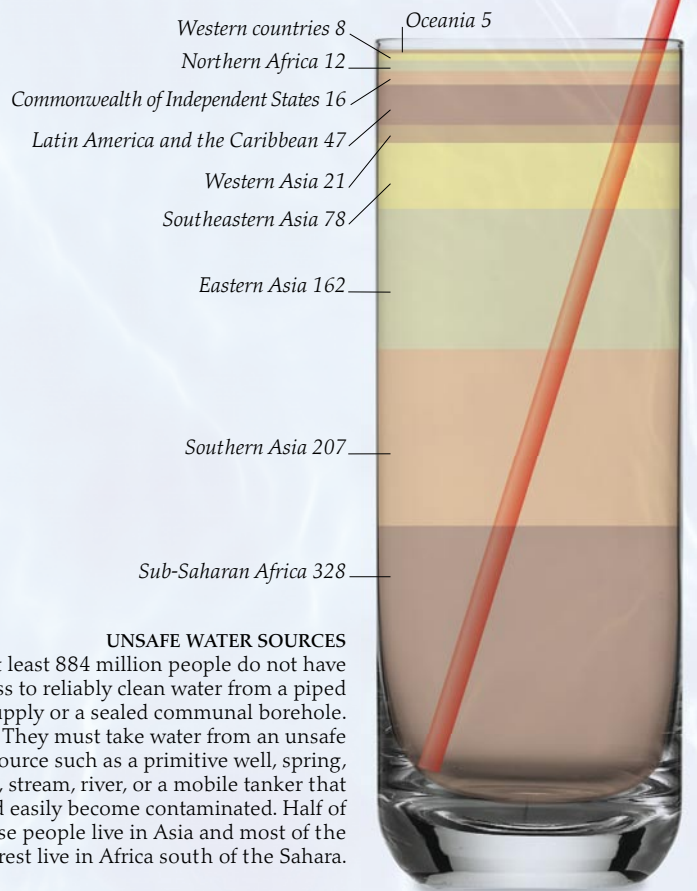
Since 1940 the world's water use has risen steadily, mainly due to the increase in the population, greater industrialization, and more widespread intensive farming. Industrial use of water has increased more than domestic use, but the main consumer of water is agriculture. The inset chart shows how water was used in 2007—agriculture accounts for more than two-thirds of the total. (One cubic kilometer / km<sup>3</sup> is 264 billion gallons.)



#### WHO COLLECTS THE WATER?

About 90 percent of the world's population must get its water from communal sources. Despite its weight, water is generally collected by women as part of their traditional domestic role. This can be a sociable task, offering the chance to meet and talk. Many women walk 10 miles (16 km) or more every day to fetch water.

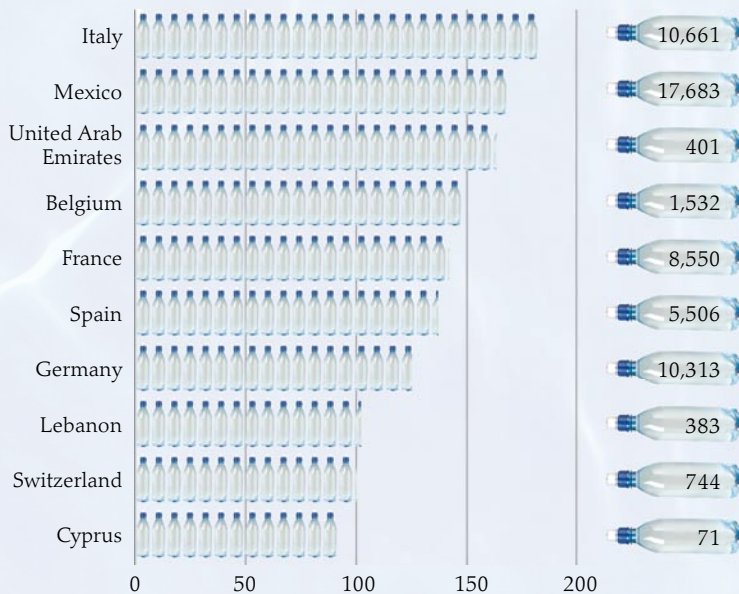
#### Region (millions of people)



#### UNSAFE WATER SOURCES

At least 884 million people do not have access to reliably clean water from a piped supply or a sealed communal borehole. They must take water from an unsafe source such as a primitive well, spring, lake, stream, river, or a mobile tanker that could easily become contaminated. Half of these people live in Asia and most of the rest live in Africa south of the Sahara.

#### Liters per person per year (1 liter is 2.1 pints)




#### BOTTLED WATER CONSUMPTION

The biggest consumers of bottled water, per person, are the Italians. But Mexico uses more in total because it has a bigger population, while the total consumption of the UAE is relatively small. Some of these countries use a lot of bottled water because they do not have reliably safe piped supplies. The US uses the most bottled water in total, consuming 26,000 million liters.

# Timeline

**W**ATER HAS PLAYED A MAJOR ROLE IN HISTORY, in agriculture and technology, and in travel, exploration and trade. In the 17th century scientists began investigating the nature of water itself, and later discoveries helped explain the role of water in the weather, climate, life, and even global geology. Meanwhile advances in water treatment and supply have helped combat water-borne disease and pollution.



Grain grown by first farmers c. 9000 BCE

**c. 4 BILLION YEARS AGO**  
The first oceans form.

**c. 3.8 BILLION YEARS AGO**  
The first life forms develop in the oceans.

**c. 400 MILLION YEARS AGO**  
Amphibians evolve from fish.

**c. 2 MILLION YEARS AGO**  
The current ice age begins. Sheets of ice cover North America and the northern parts of Europe and Asia.

**c. 50,000 BCE**  
First people migrate over open sea to colonize Australia.

**c. 15,000 BCE**  
The last interglacial, or cold phase, of the current ice age ends.

**c. 9000 BCE**  
Mesopotamians use irrigation to become the first farmers.

**c. 1500 BCE**  
Polynesians start to colonize islands in the Pacific Ocean, crossing the ocean in large double-hulled sailing canoes. They reach Hawaii and New Zealand by 1000 CE.

**c. 600 BCE**  
The Romans install the first large-scale underground sewer networks.

**c. 312 BCE**  
The Romans begin to supply their cities with fresh water via aqueducts.

**c. 985 CE**  
Vikings discover the coast of North America.

**1492**  
Genovese navigator Christopher Columbus crosses the Atlantic and discovers the West Indies.

**1519–21**  
Portuguese navigator Ferdinand Magellan undertakes the first voyage around the world.

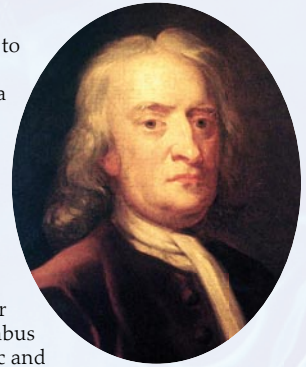
**1611**  
German astronomer Johannes Kepler is first to describe the six-sided shape of snowflakes.

**1662**  
British scientist and architect Christopher Wren invents the first modern rain gauge.

**1697**  
British scientist Isaac Newton explains how the gravity of the Moon causes the tides.

**1735**  
British physicist George Hadley explains how water vapour circulates in the atmosphere.

**1742**  
Swedish scientist Anders Celsius devises his temperature scale based on the freezing and boiling points of water.



Isaac Newton explains tides, 1697



Romans build aqueducts, such as this one in Segovia, Spain, from about 312 BCE

1770

American inventor and statesman Benjamin Franklin publishes the first description and map of the Gulf Stream ocean current.

1768-79

British explorer Captain James Cook undertakes three voyages of exploration, mainly in the Pacific and Southern Ocean, where he charts many of the islands and the eastern coast of Australia.

1783

French scientist Antoine Lavoisier shows that water is composed of hydrogen and oxygen.

1800

British scientists William Nicholson and Anthony Carlisle use electricity to split water into hydrogen and oxygen gas.

1803

British amateur meteorologist Luke Howard devises a naming scheme for clouds.

1804

The first citywide, municipal water treatment plant is installed in Paisley, Scotland.

1805

French scientist Joseph-Louis Gay-Lussac shows that water consists of two parts hydrogen to one part oxygen by volume.

1819

Swiss chemist Alexander Marcet discovers that the basic chemistry of seawater is the same throughout the world.

1829

Scot James Simpson develops a water purification system based on sand filtration.

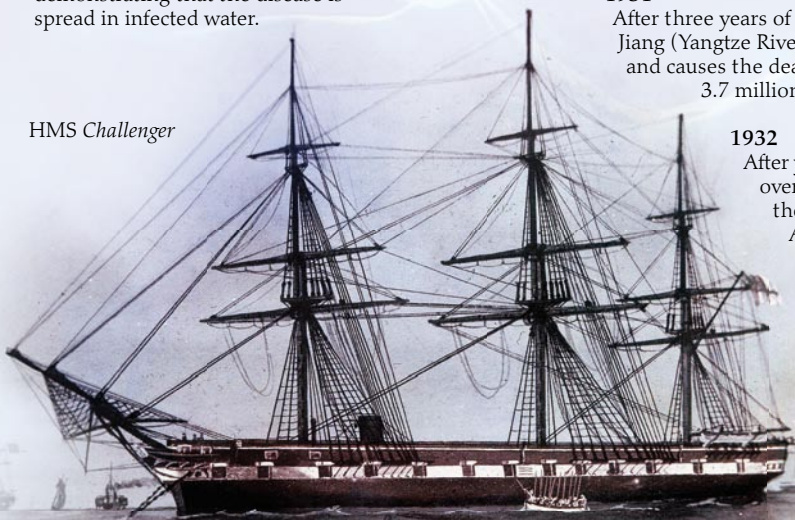
1831-36

British naturalist Charles Darwin conducts some of the earliest oceanographic research during the voyage of the *Beagle*.

1854

English doctor John Snow contains a cholera outbreak by sealing a contaminated well, demonstrating that the disease is spread in infected water.

HMS Challenger



Newspaper reporting the Chang Jiang (Yangtze River) flood in 1931

1872-76

HMS *Challenger* makes the first thorough scientific exploration of the oceans. The ship travels 110,900 km (68,900 miles) on its four-year voyage around the world.

1882

The first commercial hydroelectric generator is built on the Fox River, Wisconsin, USA.

1920

Serbian scientist Milutin Milankovitch discovers that regular variations in Earth's orbit around the Sun cause cycles of changing global temperature, which are responsible for ice ages.

1924

Russian biochemist Aleksandr Oparin suggests that life on Earth could have originated in the oceans. He says that simple substances linked up to form the first complex molecules essential to life.

1931

After three years of drought, the Chang Jiang (Yangtze River) in China floods and causes the death of more than 3.7 million people.

1932

After years of drought and overcropping, the soil of the "Dust Bowl" in the American Midwest starts to blow away. The dust storms continue until 1939.

1934

US naturalist Charles Beebe and engineer Otis Barton make a world-record descent of 923 m (3,028 ft) in a submersible called the *Bathysphere*, pioneering deep-sea exploration.

1936

The first gravity arch hydroelectric dam, the Hoover Dam on the Colorado River in southwestern US, is completed.

1943

French diver Jacques Cousteau and engineer Emile Gagnan invent the aqualung – an underwater breathing apparatus based on an air supply carried on the diver's back.



Jacques Cousteau (right) and a diver test the aqualung in 1943

1944

The world's longest water supply tunnel is opened, supplying New York City from the Rondout Reservoir 169 km (105 miles) away.

1948

US oceanographer Henry Melson Stommel publishes a paper explaining the workings of the Gulf Stream and the ocean circulation that redistributes heat around the world.

1951

Scientists find the deepest point of the oceans, the Challenger Deep of the Mariana Trench in the western Pacific. At nearly 11 km (6.8 miles) deep, it is the deepest chasm on Earth.

1960

Jacques Piccard and Don Walsh descend to the deepest part of the Mariana Trench in the submersible *Trieste*, and discover marine life even at this depth.

1962

US geologist Harry Hess proposes his theory of ocean-floor spreading from mid-ocean ridges.

1967

La Rance hydroelectric tidal barrage begins operating near St Malo, France, generating 240,000 kilowatts of electricity.

**1968-69**

British sailor Robin Knox-Johnston sails around the world to complete the first single-handed, nonstop circumnavigation.

**1972**

The US legislature passes the Clean Water Act to restore the chemical, biological, and physical nature of waterways damaged by pollution.

**1977**

US scientists in the submersible *Alvin* discover hot springs, known as hydrothermal vents, on the floor of the Pacific Ocean.



Robin Knox-Johnston on *Suhaili*, 1968-69.

**1981**

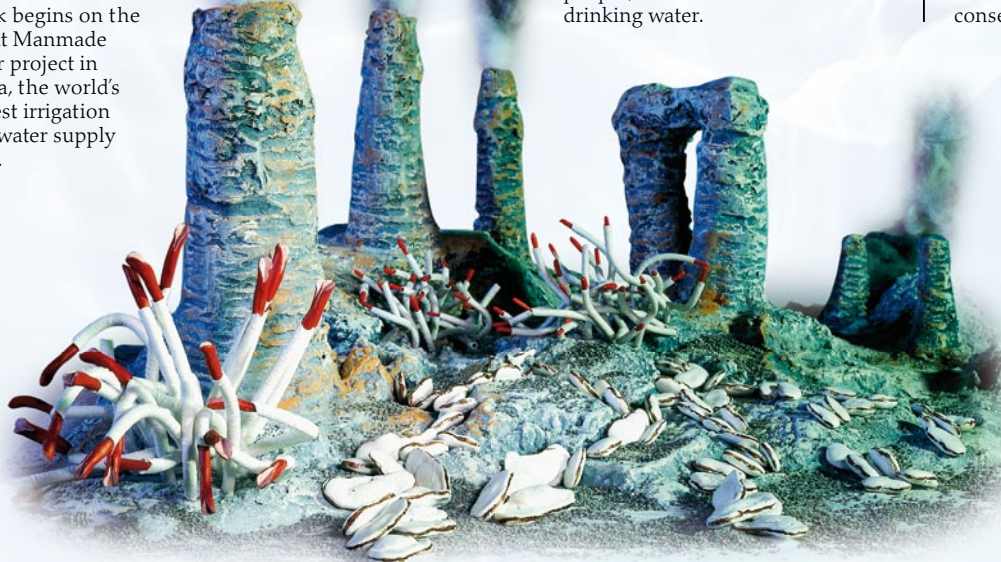
WaterAid, an international non-profitmaking organization, is set up with the goal of helping people escape the poverty and disease caused by living without safe water and sanitation.

**1984**

A long drought causes famine in Ethiopia and Sudan, killing 450,000 people.

**1984-85**

Work begins on the Great Manmade River project in Libya, the world's largest irrigation and water supply plan.



Hydrothermal vents are discovered in 1977

**1985**

Live Aid, an international rock music event, is held to fund famine relief in Ethiopia.

**1985**

The Dead Zone, a lifeless region in the Gulf of Mexico, caused by pollution carried into the sea by the Mississippi, is systematically surveyed for the first time.

**1986**

The world's longest barrier across a tidal river, the 5½-mile (9-km) Oosterschelddedam, is completed in the Netherlands. It is designed to defend the coast against very high tides and storms.

**1991-92**

Africa suffers its worst dry spell of the 20th century when 2.6 million sq miles (6.7 million sq km) are affected by drought.

**1994**

The UN Law of the Sea comes into force, governing how nations should safeguard the oceans. The law replaces conventions defining national rights over the seas that had existed since the 17th century.

**1995**

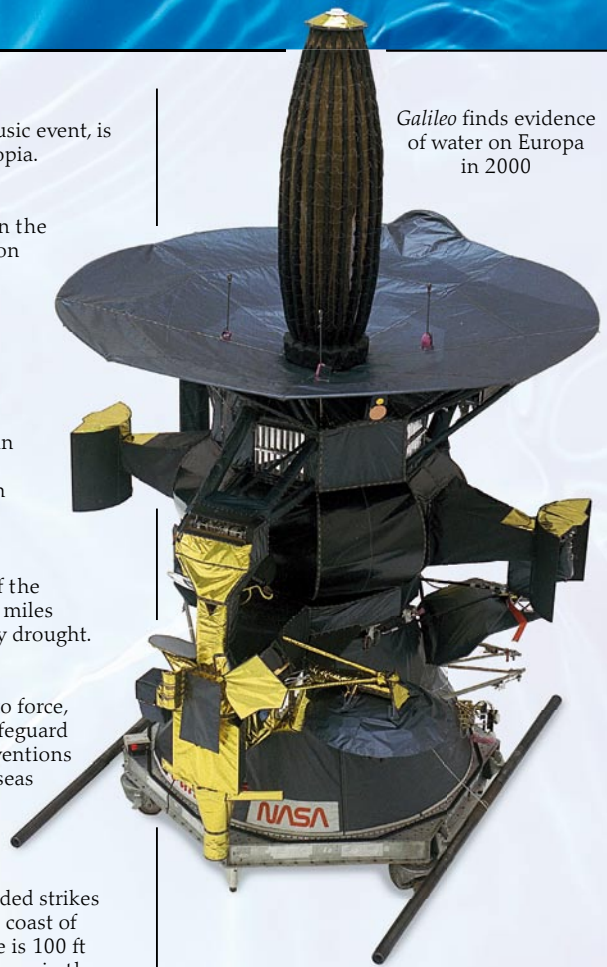
The largest ocean wave ever recorded strikes the liner *Queen Elizabeth II* off the coast of Newfoundland, Canada. The wave is 100 ft (30 m) high. Higher waves may occur in the Southern Ocean, but have not been measured.

**2000**

NASA's *Galileo* mission provides evidence that Europa, one of the moons of Jupiter, may have oceans of liquid water beneath its icy surface. If so, this would be the only other body in the solar system that has oceans—and it is just possible that these could contain forms of life.

**2000**

Research shows that, in less developed countries, 27 percent of the population (nearly 900 million people) do not have access to safe drinking water.



*Galileo* finds evidence of water on Europa in 2000

**2002**

A huge block of Antarctic ice that projects out to sea, called the Larsen-B ice shelf, disintegrates and 1,254 sq miles (3,250 sq km) of ice drift away in the sea.

**2003**

The world's first open-sea tidal power generator is installed off the coast of north Devon in southern England.

**2005**

An international team of oceanographers reports that the oceans are becoming dangerously acidified by carbon dioxide absorbed from the air. This could have severe consequences for marine life.

**2005**

A series of tsunamis, triggered by an earthquake in the Indian Ocean, kills about 300,000 people in Asia.

**2005**

The world's largest desalination plant for turning seawater into drinking water opens at Ashkelon in Israel.

**2006**

A scientific study finds that fish stocks have collapsed in nearly one-third of sea fisheries, and the rate of decline is accelerating. If the trend continues, many of the fish we eat will be too scarce to be caught by 2050.

**2007**

UNESCO declares 2008 International Year of Sanitation.



# Find out more

**W**ATER IS AN AMAZING SUBSTANCE, and there are many ways of exploring its different aspects. One of the most enjoyable is just to experience it in all its force and majesty on rivers, lakes, and the ocean. You can also visit nature reserves and aquariums to see how wildlife interacts with water. Museum exhibitions and displays at water engineering sites show how we use water in different ways. You can also think about how you use water yourself, and whether you might use too much in a world where water is precious.



Children bird-watching from a boat, Estrella River, Costa Rica

**EXPLORE THE NATURAL WORLD**  
Rivers, wetlands, and seashores are wonderful places to discover aquatic plants and animals and find out how important water is to the natural world. Guided trips are best, because the guides know what to look for and can identify most of the wildlife. A well organized trip is also the safest way of getting close to wildlife on the water.

**AQUARIUMS**  
A modern aquarium can provide a dramatic insight into what life is like underwater. Many, like this one, have glass tunnels that allow you to walk through the aquarium itself, and watch sharks and other fish swim over your head. Since water covers two-thirds of the planet, this is like seeing how most of life on Earth exists. It can be a memorable, magical experience.



## WATER ENGINEERING

Some of the most awe-inspiring of all engineering works are designed to harness the power of water, or defend against it. Many hydroelectric plants run regular tours, and big dams can often be visited at any time. This one even has a public viewing platform overlooking the spectacular outfall.

## USEFUL WEBSITES

- These four sites all offer good overviews of water:  
<http://ga.water.usgs.gov/edu/>  
<http://library.thinkquest.org/C0115522/>  
[http://www.ec.gc.ca/water/en/nature/e\\_nature.htm](http://www.ec.gc.ca/water/en/nature/e_nature.htm)  
<http://www.allaboutwater.org>
- This website, run by the United States Geological Survey (USGS), is all about the water cycle:  
<http://ga.water.usgs.gov/edu/followdrip.html>
- The Franklin Institute has an excellent website giving information about water in cities:  
<http://www.fi.edu/city/water>
- The US government's Energy Information Administration tells you all you need to know about hydropower on this site:  
<http://www.eia.doe.gov/kids/energyfacts/sources/renewable/water.html>
- WaterAid has a useful site covering access to clean water, sanitation, and hygiene education:  
[http://www.wateraid.org/uk/learn\\_zone/](http://www.wateraid.org/uk/learn_zone/)
- The United Nations Food and Agriculture Organization provides water access and consumption data by country and by region on this useful site:  
<http://www.fao.org/nr/water/aquastat/main/index.stm>
- The National Maritime Museum of the United Kingdom has a site containing information on everything from maritime maps and charts to navigation instruments and sea-going vessels:  
<http://www.nmm.ac.uk>



# Glossary

## ACID

A chemical, usually liquid, that contains hydrogen and is able to eat away alkaline substances such as limestone.

## ALGAE

Plantlike organisms, often microscopic, that are able to make food using the energy of sunlight.

## ALKALINE

The opposite of acid. When acids and alkalis are mixed, they neutralize each other.

## ANTICYCLONE

A type of weather system in which cool air is sinking and swirling outward at ground or sea level, creating high atmospheric pressure.

## AQUATIC

Describes plants or animals that live in water.

## AQUIFER

A layer of rock that holds water.

## ATMOSPHERE

The layers of gas that surround Earth, held by gravity.

## ATOM

The smallest particle of a substance. Elements such as oxygen contain just one kind of atom. Compounds such as water contain more than one kind of atom.

## BACTERIA

Microscopic organisms with a simple single-celled structure.

## BOILING POINT

The temperature at which a liquid turns to a vapor.

## BOREHOLE

A type of well drilled deep into the ground and equipped with a pump for drawing up water.

## CARBOHYDRATES

Energy-rich substances, such as sugars and starch, made by some living things and used as food.

## CARBONATE

A mineral containing carbon and oxygen.

## CARBON DIOXIDE

A colorless gas formed when carbon combines with oxygen. Living things such as plants and algae combine it with water to make food.

## CELL

The smallest unit of a living thing, with a cell membrane enclosing liquids, nutrients, and organic molecules such as proteins.

## CLIMATE

The average weather in a region.

## CLIMATE CHANGE

When Earth's climate is significantly altered because of natural causes or human activities.

## CONDENSE

To turn from a gas to a liquid.

## CONTAMINATED

Containing impurities and/or pathogens (disease organisms).

## CONVECTION

The movement and circulation of gases and liquids in response to heat.

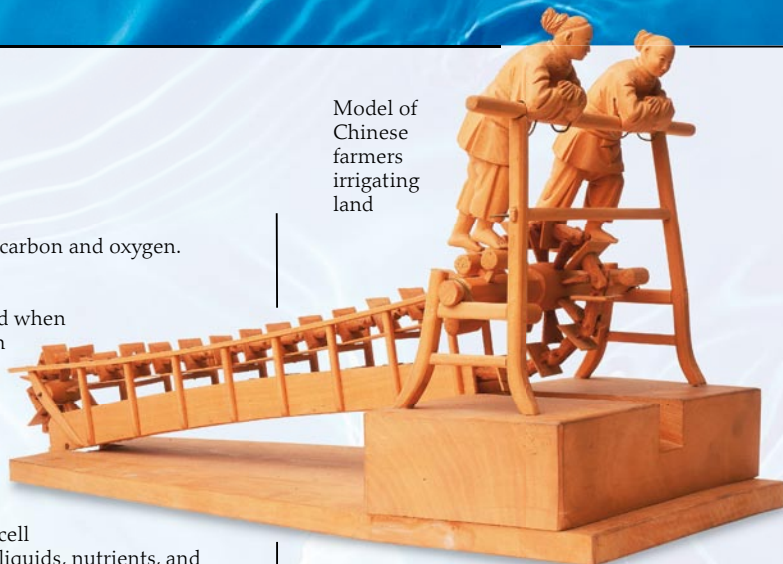
## CURRENT

A flow of ocean water, driven by the wind or by differences in water density caused by temperature and/or salt content.

## CYCLONE

A weather system with clouds, rain, and strong winds caused by air swirling into a region of rising warm, moist air.

Model of Chinese farmers irrigating land



Model of a cell

## DENSITY

The compactness of the molecules in a substance. Density gives the substance its heaviness. Icebergs float on water because the ice is less dense than the water.

## DESALINATION

Removing the salt from seawater so it can be used for drinking or crop irrigation.

## DEVELOPED COUNTRY

An industrialized and modernized country with a high level of income per person.

## DEVELOPING COUNTRY

A nonindustrialized country with a low level of income per person.

## DISSOLVE

Disperse a substance in a liquid so completely that all its molecules are separated.

## DROUGHT

A long period with no rain.

## ECOSYSTEM

An interacting community of living things in their environment.

## EROSION

Wearing away, usually by natural forces such as wind, rain, or waves on the shore.

## EVAPORATE

To turn from a liquid to a gas.

## EVAPORITE

The substance left behind, such as salt crystals, when the water in a solution evaporates.

## FLASH FLOOD

A flood that rises very quickly after a rainstorm, and may form a strong torrent.

## FREEZING POINT

The temperature at which a liquid freezes to become a solid.

## FRESHWATER

Water containing low concentrations of dissolved salts, such as rain, rivers, ponds, and most lakes.

## GLACIER

A riverlike mass of ice that is flowing very slowly downhill.

Iceberg



**GYRE**  
A circular system of ocean currents.

**HYDRATED**  
Having had water added.

**HYDRAULIC**  
Using water as a pumping fluid, but also systems that use oil instead of water.

**HYDROGEN**  
The lightest gas in the universe, and a component of water.

**ICE AGE**  
One of several periods in Earth's history when much of the planet was covered by vast sheets of ice. Each ice age had cold phases and warmer phases.

**ICEBERG**  
Part of a glacier or ice sheet that has broken off and floated out to sea.

**ICE SHEET**  
A thick layer of ice that covers a very large area, such as Antarctica.

**IMPERMEABLE**  
Describes a substance that forms a barrier against liquids and gases.

**IRRIGATION**  
The regular watering of crops.

**LAVA**  
Molten rock that erupts from volcanoes.

**MANTLE**  
The thick layer of very hot, but not molten, rock beneath Earth's crust.

**MICROBE**  
A microscopic living thing.

**MICROSCOPIC**  
Visible only under a microscope.

**MOLECULE**  
A group of atoms held together by chemical bonds. A water molecule (H<sub>2</sub>O) is composed of two hydrogen atoms and one oxygen atom.

**MONSOON**  
A seasonal change of wind that affects the weather, especially in tropical regions where it causes wet and dry seasons.

**NUTRIENTS**  
Substances that living things need to build their tissues or fuel and maintain their bodies.

**OASIS**  
A small area in the desert that is made fertile by water that comes up from the ground, or underground water that has been exposed by wind erosion.

**OXYGEN**  
An odorless and colorless gas with the molecular formula of O<sub>2</sub>. Oxygen makes up 20 percent of the atmosphere and is a component of water.

**PACK ICE**  
Thick floating ice that forms when the ocean surface freezes.

**PATHOGEN**  
A microbe that causes disease.

**PERMAFROST**  
Frozen groundwater that never thaws out.

**PERMEABLE**  
Describes a substance that allows fluids and gases to pass through or into it.

**PHOTOSYNTHESIS**  
The process by which green plants, algae, and some other organisms use the energy of light to make carbohydrate food (sugar) from carbon dioxide and water.

**PLANKTON**  
Living things that mainly drift in the water, rather than swimming actively.

**POLLUTION**  
Anything added to the natural environment, usually by people, that upsets the balance of nature.

**PROTEIN**  
A type of large molecule made up of smaller units called amino acids. Proteins are the building blocks of cells. They are involved in all life functions.

**RESERVOIR**  
A water store.

**SALTWATER**  
Water containing high concentrations of dissolved salt, such as seawater.

**SANITATION**  
Facilities for dealing safely with sewage and wastewater.

**SEDIMENT**  
Solid particles such as sand, silt, or mud, that have settled on the seabed or elsewhere.

**SEDIMENTARY ROCKS**  
Rocks formed from compressed sediments.

**SOLUTION**  
A fluid consisting of a substance fully dissolved in a liquid such as water.



Tundra in bloom

Model of a stalactite

**STALACTITE**  
A suspended pinnacle of rock in a cave, created by the dripping of water containing dissolved limestone. Formations created when the dripping water deposits minerals on the cave floor are called stalagmites.

**STEAM**  
Very small but visible water droplets suspended in the air, caused by the condensation of water vapor.

**STORM SURGE**  
A local, temporary rise in sea level caused by storm winds and low air pressure.

**SUBDUCTION ZONE**  
A boundary between two plates of Earth's crust, where one plate plunges beneath the other and is destroyed.

**SUBMERSIBLE**  
A craft designed to dive to the ocean depths.

**SUBTROPICS**  
The regions of Earth that lie immediately north of the Tropic of Cancer, and immediately south of the Tropic of Capricorn.

**SUPERHEAT**  
To heat a liquid such as water under pressure, so it gets hotter than its normal boiling point.

**SUSPENSION**  
A fluid containing suspended particles of another substance that has not dissolved.

**THERMOCLINE**  
The boundary between deep, cold, dense water and a layer of warmer, less dense water that floats at the surface.

**TROPICS**  
The hot regions to the north and south of the Equator, between the Tropic of Cancer and the Tropic of Capricorn.

**TSUNAMI**  
A huge wave generated by an earthquake on or near the ocean floor, or by the collapse of an oceanic volcano.

**TUNDRA**  
The cold, treeless landscape that lies on the fringes of the polar ice sheets.

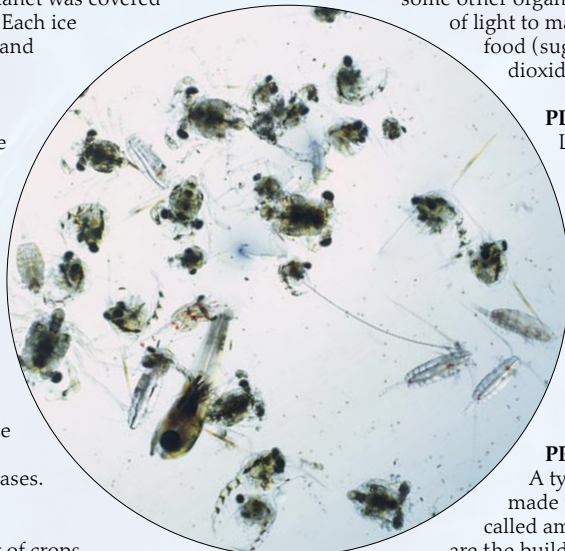
**UPWELLING ZONE**  
A part of the ocean where deep water that is rich in nutrients is drawn to the surface.

**VASCULAR**  
Living things having veins or similar systems of tubes for fluid transportation.

**WATER TABLE**  
The upper surface of groundwater.

**WATER VAPOR**  
The invisible gas formed when liquid water is warmed and evaporates.

**WEATHER**  
The short-term conditions of the atmosphere at a given time and place. The weather is determined by such things as temperature, wind, rain and snow, and air pressure.



Plankton

They are involved in all life functions.



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