2 Ocean and Water Cycling

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As mentioned in Chapter 1, Earth is known as "the water planet." This nickname is appropriate because the surface of Earth is covered almost entirely by water. It is also probably the most important chemical on the planet. Although we may not even think about this fact, it is the presence of water that allows us and other life forms to even exist on the planet.

Water and its unique properties determine much of Earth's atmospheric conditions. It drives our global and local weather, and water vapor is a critical **greenhouse gas** that regulates temperatures on Earth. It is crucial to remember that while our planet's surface is mostly water, it also has landforms and is topped by air, and that water is found in these places as well. Water is present within soils and aquifers and provides humidity to the air. Water, land, and the air are interconnected in important ways, and the interplay between them creates what we come to experience as weather and climate. Areas where water meets land are of particular interest and are known as interfaces. Interfaces among water, land, and air play a significant role in transforming water and moving water from and into our ocean. In turn, the ocean affects life on land and makes life on our planet possible.

The Water Cycle

As water moves around our planet, it does so as part of what we call the water cycle. Most of Earth's water is present in the ocean. As the sun shines on the water, it heats the water and causes it to evaporate. As each molecule of water on the surface of the ocean evaporates into the air, it pulls another water molecule to the surface. Now this next molecule of water is exposed to the heat and drying effects of the air, and it also will evaporate. As the water molecules evaporate, the minerals or salts that they may have been carrying are left behind in the salty ocean. As evaporation occurs, the air becomes more and more humid. This water vapor

GRADE	STANDARD	EEI UNIT
Grade 3	3.1.e-h	
Grade 4	4.5.c	
Grade 5	5.3.a-e 5.4.a-c	Earth's Water Changing States: Water, Natural Systems and Human Communities Precipitation, People, and the Natural World Our Water: Sources and Uses
Grade 6	6.2.b-c 6.4.d	The Dynamic Nature of Rivers
Grade 7		
Grade 8	8.5.d	

is an invisible gas and can move quickly. As it moves about, it often travels upward or inland—carried by currents in the air (wind). As the moist air gains elevation, the molecules become colder and condense, turning into liquid. As more and more of these water molecules condense, they cluster together around particles (primarily suspended dust) in the atmosphere and form clouds. Students may think that clouds form by sucking water from the land. They may be confused whether clouds are gas or liquid. However, a cloud is comprised of liquid water droplets, which is why one can see them, as compared to the water vapor, invisible gaseous water molecules suspended in the atmosphere.

When the mass of water molecules is high enough, the clouds will dispense their contents as precipitation. This precipitation can occur as rain or snow or ice, depending on surrounding air temperature. When the precipitation falls onto land, gravity causes it to flow topographically downhill, where the individual droplets combine to form creeks or streams that, in turn, combine to form rivers. The rivers then continue the water's journey to the lowest topographical point, where they all combine and accumulate the water drops into a lake or the ocean. The process of evaporation from this body of water continues, which demonstrates the basic **water cycle.**

The more thorough water cycle recognizes that water is sometimes removed from this loop of evaporation, condensation, precipitation, and accumulation for bits of time. It can be removed by percolation, or infiltration, or used by plants and animals. Students in upper elementary and middle school may be ready to explore some of these other processes. In **percolation,** infiltration, water seeps through the soil and rock, percolating to underground pockets of water. As it infiltrates through the layers, most pollution is removed. This is why underground pockets of water, known as aquifers, are valued as an important source of clean drinking water. When people drill water wells, they are trying to reach these aquifers. Students may wonder how water

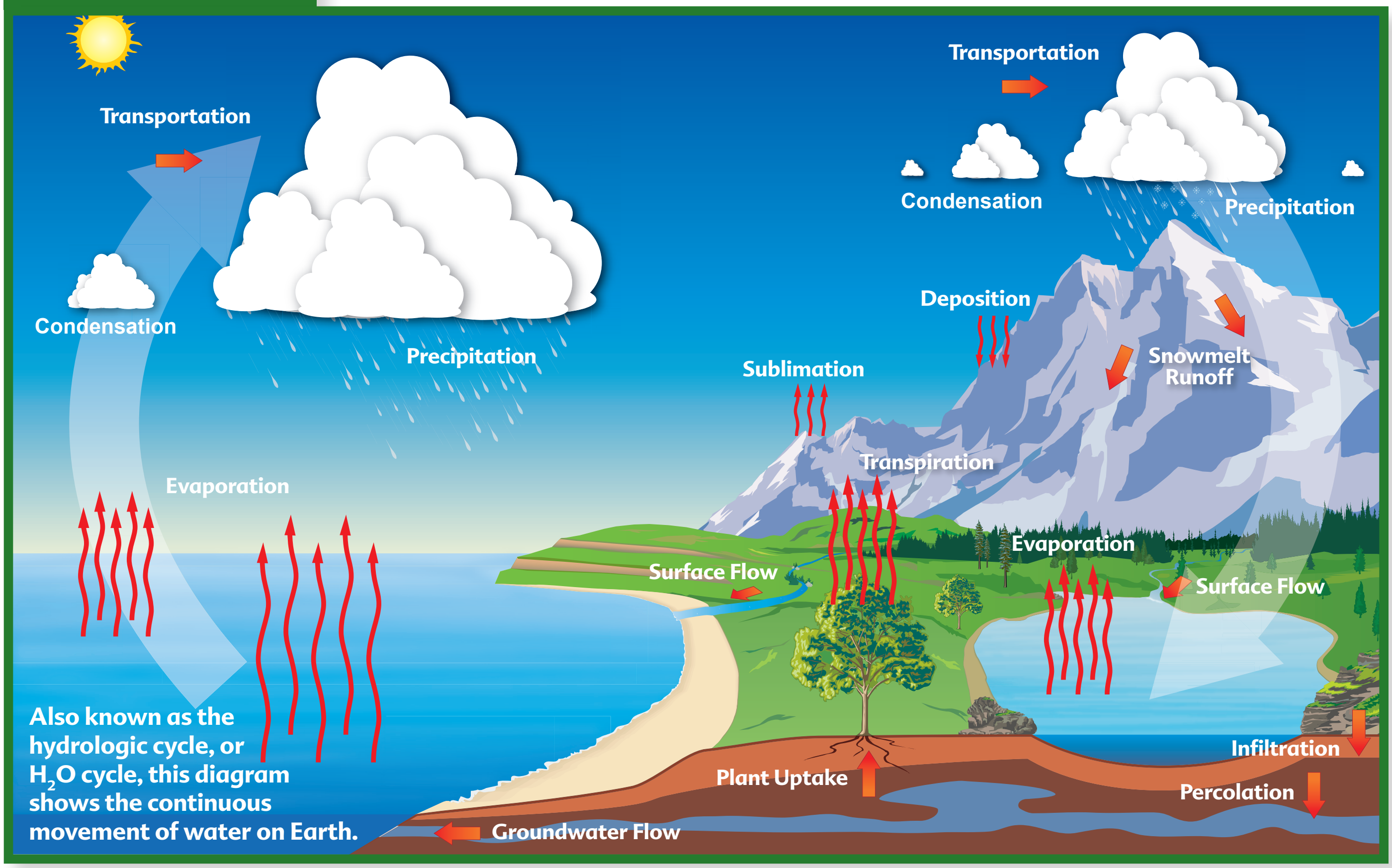
CHAPTER OVERVIEW

The ocean is an important driver of the global water cycle. Our local weather and climates are dependent upon the ocean's role in this cycle. As the surface of the ocean is heated, evaporation occurs, sending water vapor into the atmosphere. As this water vapor cools and condenses, it eventually forms clouds and will precipitate, oftentimes back into the ocean. Some of the evaporated water condenses and falls as precipitation onto land.

In addition to latitude and physical geography, proximity to the ocean or other large bodies of water is a key determinant of local weather and climate. El Niño and La Niña are examples of how precipitation patterns change in the Americas, depending on ocean conditions.

This chapter will explore the role of the ocean in the water cycle and take a closer look at properties of water, air, and land to better understand how the ocean interacts with other systems on Earth.

HYDROLOGIC CYCLE



gets into wells in the first place, so percolation is an important concept to learn. A rare step in the water cycle is when solid water, in the form of ice or snow, sublimates into a water vapor under very warm and sunny conditions. Sublimation tends to occur in snowy mountains in the spring when ice changes directly to water vapor.

Water can also be used by plants for photosynthesis and **cellular respiration.** Plants absorb most water through their roots and release it through their leaves. When water is released by plants to rejoin the water cycle, it is known as **transpiration.** The molecule of water that evaporates through the stomata on the underside of a leaf pulls the adjoining molecule of water to the surface. Students may think water only enters and exits plants through the roots. Water is also used by animals for cellular respiration and is released from the body through urination, exhalation, and sweat. As water is released from living things, it can evaporate and return to the basic water cycle. So all living things are part of the water cycle!

Watershed. As freshwater from rain or melting snow descends through a **watershed** by the force of gravity, it erodes and carries materials downstream from along the edges and bottom of the stream. These materials can include natural items such as small particles of soil and decaying plant and animal

Teaching Tip

Students tend to understand the concepts of precipitation and accumulation easily, as they are processes they can see. Evaporation can be tricky but is easily demonstrated by boiling water or leaving a cup out overnight. Condensation is the step of the water cycle that causes students the most trouble, yet most students are familiar with it without even knowing it. Ask them what happens to the outside of a cold soda can when it is removed from the refrigerator. Many will be able to tell you that it gets wet. Explain that the wetness is condensation. The soda can provides something for the molecules to condense around instead of dust which helps clouds form. This simple, real-world example helps many students conquer this confusing concept.

Pictures of Practice

Ocean and Water Cycling

Students living near a coast know their rain comes from the ocean. They grow up watching thunderstorms build offshore or along the coast. Students who live inland from a coast may not have the same wealth of experience connecting the water cycle to the ocean. However, both groups of students may have questions about how the ocean is a part of the freshwater cycle. In fact, many students at a young age still do not understand how freshwater can come from salty ocean water, and they may not realize that freshwater is an important resource we get from the ocean—even more important than seafood!

Students: Grade 5

Location: Laguna Niguel, California (a coastal community)

Goal of Video: The purpose of watching this video is to listen to students' ideas about the ocean's role in weather and water cycling.

Classroom Context

During their fifth-grade year, Ms. Reimer's students studied the ocean and water cycling. They traced a water molecule from the ocean on a path that took the molecule overland and eventually through a watershed back to the sea. Her students also studied uneven heating of the surface of the ocean and land and how this influences the movement of air (and moisture), especially in costal areas. Because students live in a costal area and the ocean determines much of their weather and climate, Ms. Reimer taught several lessons on the concepts.

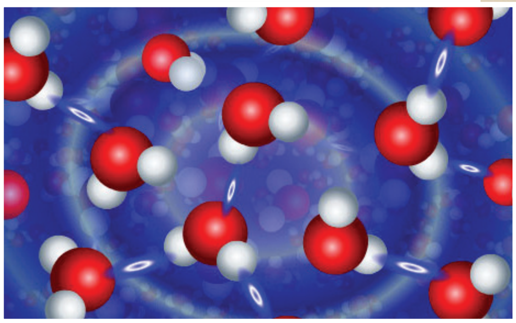
Video Analysis

In the video, you will see Ms. Reimer review these concepts with her students. She begins the review by asking her students open-ended questions about whether people could survive three days without the ocean and how the ocean impacts students' daily lives. While Ms. Reimer had hoped to hear answers about how the ocean influences weather and water cycling, her students end up focusing mostly on getting seafood from the ocean. Ms. Reimer expresses disappointment at the limited connections students make. As she moves to Leah's small group, they begin by talking about seafood, but after additional prompting from Ms. Reimer, Erol brings up the water cycle. Ms. Reimer has this group share their ideas with the whole class in order to get more students thinking beyond getting seafood from the ocean. At the end of the video, CJ still has questions about the water cycle, which indicates that he may need additional instruction to understand these concepts.

Reflect

How would you teach ocean and water cycling?

Ms. Reimer still has doubts that her students retained information about how the ocean influences their local weather and climate—as well as global water cycling—despite that students had previously had a substantial unit on the topic. If you ask your students how the ocean influences our daily lives, how would you expect them to respond? How would you plan instruction so that students have a good understanding of the ocean's role in water cycling?



The dynamic interactions of water molecules include the forming of links that vary in strength and span.

materials or unnatural pollution such as chemicals and trash. During a storm, when the volume and force of the water are much greater, the swiftly moving water can carry large rocks, branches, and even fallen trees. A watershed is the land area drained by water into a particular feature, usually a river or stream. For example, in central North America, you have the Arkansas River watershed, which consists of all the rivers, creeks, streams, and land surfaces that drain into the Arkansas River as it travels from Colorado to Arkansas, where it spills into the Mississippi River. Many watersheds are made up of smaller watersheds. The Mississippi River watershed is made up of the Arkansas, Ohio, Red, Tennessee, and Missouri rivers watersheds, just to name a few! The Mississippi River watershed drains more than a million square miles, carrying with it the pollution and minerals from all its tributary watersheds, to the Gulf of Mexico. Have your students explore their own watershed and learn more about the area that contributes to water flowing in their backyards.

As water picks up rocks and soil, the minerals they contain are dissolved and washed downstream through the watershed, eventually reaching the ocean. This contributes to the ocean's salinity, or saltiness, which your students may wonder about.

The ocean is an important driver of weather and climate, but before we explore this further, let us take a closer look at the properties of water, land, and air.

Water

Some of the special properties of water can be better understood by taking a closer look at the structure of the molecule itself. Water is comprised of one atom of oxygen and two atoms of hydrogen. Each of the hydrogen atoms is bonded at an angle to the oxygen atom, in a Y configuration. The shape of the molecule resembles Mickey Mouse's head, with the hydrogen atoms representing the character's ears. Chemists sometimes jokingly refer to it as the Mickey Mouse Molecule. Because of this architectural skew of the hydrogen bonds, the more positively charged hydrogen atoms form a slightly positive side to the molecule, while the more negatively charged oxygen atom forms a slightly negative side; the molecule overall is a stable one that is ionically balanced, meaning it does not easily bond with other molecules or elements. This **polarity,** or positive/negative charge distribution, allows the water molecule to behave like a magnet, with the negative (oxygen) side attracting positively-charged atoms and molecules, and the positive (hydrogen) side attracting negative atoms or molecules. This attraction means that it can act as a powerful solvent. Solvents are substances that are good at dissolving or dispersing other chemicals and particles. For example, common table salt, NaCl, is an ionic compound, comprised of a positively-charged Na^+ (sodium) atom and a negatively charged Cl^- (chloride) atom. In water, this solid salt can dissolve. The Na is attracted to the oxygen side of the water molecule, and the Cl is pulled toward the positively-charged hydrogen side. The result is that the salt molecule is pulled apart; it dissolves into the powerful solvent of water. It is water's polarity

Teaching Tip

A quick classroom demo or student exploration for surface tension: Fill a glass to the very top with water. Have students estimate how many more drops can be added to the glass before it will spill over. Gently add additional drops, one by one. The water will form a dome—the molecules of water are holding onto each other because of their polarity. Students may be surprised by how many additional drops of water can be added. Ask students what force eventually is too much for the polarity. The answer is gravity, of which many students may already have a basic understanding. If students need more exposure to surface tension to really grasp the subject, lessons or activities related to bubbles can help them to better grasp this concept.

that allows for salinity in our ocean. Common food items, such as Jell-O and Tang, take advantage of water's solvent powers to deliver the other ingredients to us in a tasty form.

The negative (oxygen) side of the water molecule can also lightly bond with the positive (hydrogen) side of other water molecules, a phenomenon known as hydrogen bonding. In this case, the water molecule's polarity leads to properties known as cohesion and surface tension. Cohesion is the attraction of water molecules to one another. Because of this property, water molecules tend to stick together, forming clumps. Cohesion allows for water to flow through plant tissues and blood vessels by capillary action. At the surface of a container or puddle, water will appear to take on a domed shape. This **surface tension** is due to the cohesion of water molecules.

Water is a very heavy substance. One experiences the weight when lifting a bucket of water or by feeling the difference between wet and dry beach towels. Water is constantly acted upon by the force of gravity pushing the water downhill. The more water available and the faster it is moving, such as during floods and storms, the greater its power. This power is ubiquitous and obvious on our planet, if you know where to look for it. Seaside cliffs are worn down by the constant surges of water. River rocks that have been tumbled smooth by water's action are often used in decorating. One of the most amazing natural wonders of our planet, the Grand Canyon, which is so huge it can be seen from space, was created over millennia largely by the power of river water. After breaking away rock and sediment from landforms such as inland mountains and seaside dunes, the river carries these substances. Due to water's nature as a solvent, many substances, such as salts and gases, are dissolved into the water, forming a solution. Other substances, from huge tree limbs to tiny bits of clay, float in the water, either at or below its surface. This mixture of water and other solids is known as a suspension.

Like all compounds, the water molecule is able to exist as a solid (ice), liquid, and a gas (water vapor). Something unique about water is that it is the only substance that is naturally found in all three phases at normal Earth temperatures. Your students may not realize this fact, but it is actually quite amazing. Changes in temperature and pressure affect how closely the molecules are packed and how quickly or actively they can move around. At low temperatures and high pressures, water exists as ice. Medium temperatures and pressures, which are found on much of the Earth's surface, allow water to exist as a liquid. While at high temperatures and low pressures, water usually exists as a gas, or water vapor. (At extreme temperatures and pressures, water can also exist as a plasma, but those are very rare on Earth.) As water circulates about our planet, it is able to change its phase.

Teaching Tip

Students may be challenged to understand that soil and water have different capacities for holding heat. A simple demonstration can help them witness this with their own eyes. Take two similar containers and fill one with water and one with soil, approximately equal volumes. Place them both in a sunny spot and put a thermometer into each container. Take daily temperature readings for a few days—first thing in the morning and just before leaving in the afternoon. Compare the fluctuations in each. Which substance had the greatest fluctuation in temperature? Which substance changed the least? If you have a classroom thermometer, record and then compare the changing air temperatures. This helps to complete the picture of the different ways that water, land, and air react to changes in temperature.

The Colorado River carves out Horseshoe Bend in the Grand Canyon of northern Arizona.

Land

Land has different properties from water, and, therefore, it behaves differently. Land is not made of one

As the sun reaches the ocean, it warms the surface and increases the water temperature.

uniform molecule, like water. Land is made of different minerals and elements, depending upon where it's found. Some land is made of loose soils, while other land is made of solid rock. Land also responds to heat differently from water. As most beachgoers know, the sandy distance to the cool water can be uncomfortably hot in the daytime, but icy cold at night. Soil, sand, and rock do not hold onto heat the way water does. As a general rule, the land heats up quickly and loses its heat quickly. Moisture also evaporates more easily and quickly from the land than it does from the ocean.

Air

Finally, there is air. Air is made of gases and so is technically considered a fluid. Students may think fluids only include liquids. The molecules of fluids vibrate rapidly and are constantly in motion. Because of this, molecules are easily influenced by changes in temperature or altitude. Heat causes the molecules to speed up, while cold causes them to slow down. We witness this when boiling water. When a kettle or pan of water with a loose lid is brought to a boil, the lid rattles as the heated water molecules become water vapor and begin to move faster and vibrate. The movement and rattling stop when the heat is turned off, causing the molecules to slow down.

Air also has a tremendous range in its ability to hold water vapor. In deserts, the water content of the air is fairly low. Even though it can be very hot, people usually describe the heat as dry heat or a low humidity—like a sauna. In coastal areas, or during a storm, the water content is much higher, and so the heat is experienced as wet heat, with a high humidity—more like a steam bath if it's hot enough. Remembering the water cycle, many water molecules have evaporated (from the ocean, rivers, and lakes) and are present in the adjacent air, and it's these evaporated molecules that determine the air's humidity.

The Ocean, Weather, and Climate

Weather, at its most basic, is water moving among the air/atmosphere, the land, and the ocean. Weather takes place in the lower atmosphere, known as the troposphere, because this is the area in which water vapor is found. In the water cycle, the sun heats the ocean (or any other body of water) causing water molecules to evaporate and flow into the atmosphere. Water molecules, in the form of liquid (such as in clouds) or as vapor are carried great distances, both vertically and horizontally within the atmosphere. Factors on land, in the ocean, or in the atmosphere can all lead to the right conditions for precipitation. For example, in the tropics, the sun's energy is strong and direct, leading to a good deal of evaporation and water vapor in the air, which is why the air often feels so humid. If the water evaporates quickly enough, it will travel upward within the atmosphere where it is cooled and condenses into clouds. Due to water's high **heat capacity,** the top layers of the ocean absorb and retain much more energy than does the atmosphere. The solar energy leads to evaporation, driving predictable vertical and horizontal movements of air molecules (including water vapor) in the atmosphere. The horizontal movements are prevailing winds that drive the movements of air masses and weather patterns.

Landmasses can also affect airflow and, therefore, weather. As clouds that have formed over the evaporating ocean travel inland, they often encounter mountains. As the moist air approaches the mountains, it tends to travel upward in elevation, cooling as it goes. The air then reaches that critical point of cooling (known as the dew point) when the water molecules become too cool and condensed to remain as water vapor and they precipitate out. This is why the Pacific Northwest tends to be so moist. The humid ocean air is quickly cooled as it hits the Cascade Mountains, and it precipitates out—leading to lush rain forests and other wet habitats of this region. If there are no mountains and the land below retains its warmth at night, the clouds can carry their watery load for very long distances before precipitation may occur. Prevailing winds in the atmosphere, driven by differential heating and the water cycle, carry clouds and storms, resulting in weather. The energy and water vapor from the tropical ocean lead to the development of storm systems. In fact, most of the rain that falls on land was evaporated in the tropical ocean. Because so much of our weather is driven by the evaporation occurring over the ocean, the ocean is said to control the planet's weather and climate.

El Niño is one ocean phenomenon that demonstrates how tightly the ocean and atmosphere are tied. Your students may have heard of El Niño but not understand exactly what it means.

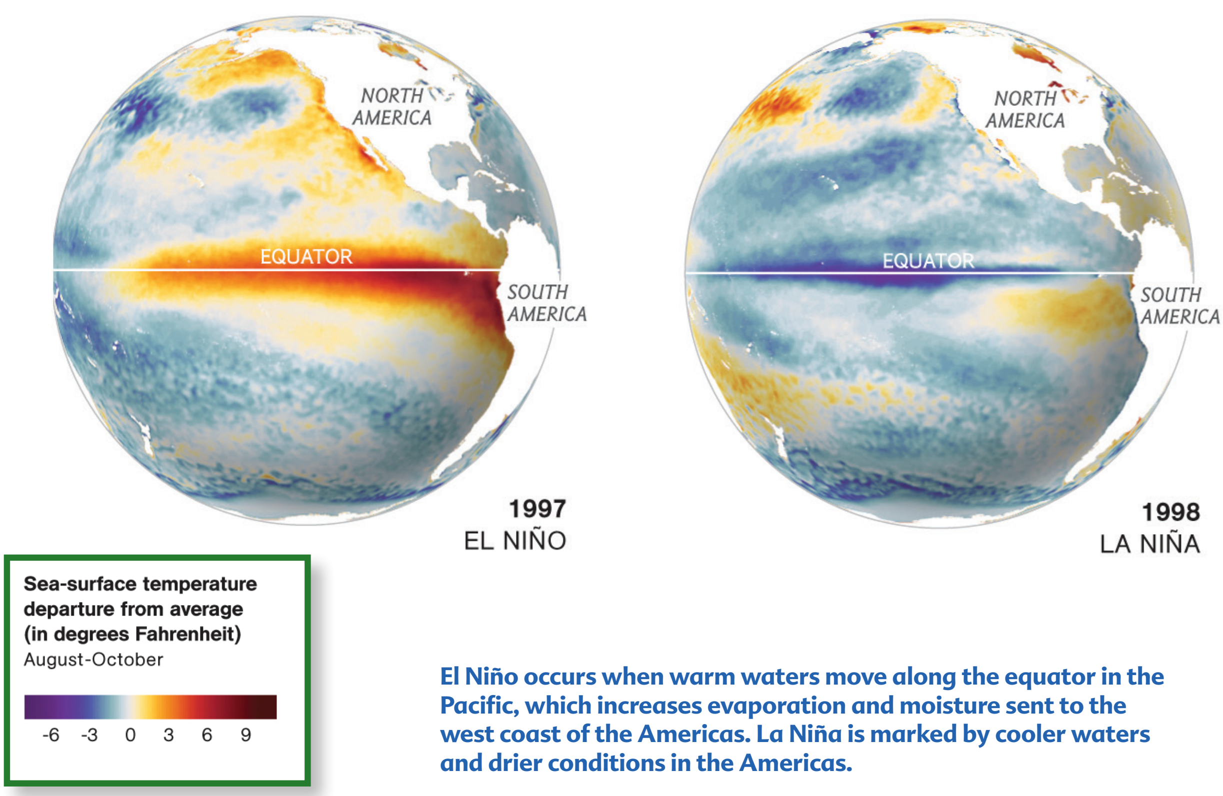
El Niño is also known as ENSO (El Niño-Southern Oscillation). It gets its name from the Spanish term for Christ child, or the little boy, because it often starts to occur near Christmastime when people celebrate the birth of Jesus. These events are characterized by warm Pacific waters, which usually stay in the western Pacific, slowly making their way across the Pacific to remain in the eastern Pacific for a while. The warmer waters are more prone to evaporation and, therefore, tend to bring more rain to the western coasts of North, Central, and South America. In California, El Niño years tend to be very wet. It should also be noted that, during an El Niño, the thermocline is depressed due to the influx of warmer water from the western Pacific. As a result, the water that is upwelled is from above the thermocline and, thus, is nutrient-poor. Therefore, El Niño not only affects weather but also influences the food web.

El Niños, however, are not permanent. Cold upwelling along the west coast of South America and along the Equator may strengthen, along with the easterly trade winds. The tropical Pacific's subsurface water temperatures become cooler than normal as well. This phenomenon is referred to as **La Niña.** With cooler waters off the western coasts of North, Central, and South America, there is less evaporation to help fuel rain and the coasts once again return to their drier climate.

This brings us to an important point of clarification. Climate is the average weather conditions over wide areas and long periods, such as decades and centuries. Weather, in contrast, is the moment-to-moment conditions of temperature, wind, barometric pressure, and precipitation at a particular location. The difference between the two can be confusing, especially for your students. While El Niño brings conditions that influence the weather over months or sometimes even a few years, it does not change the overall climate. El Niño is a change in the ocean that influences a change in the atmosphere over the short term, not a permanent condition. If it were to be a permanent condition, or at least one that existed for decades, it could be said to influence climate as well.

Climate is influenced by the atmosphere, land, and ocean. The interaction between the ocean and atmosphere greatly affects climate. For example, San Francisco and Kansas City, Missouri, are located at nearly the same latitude. One would expect, therefore, a similar climate in these two cities. In actuality, San Francisco enjoys a much more moderate climate, with cooler summers and warmer winters than Kansas City, largely due to the California city's proximity to the ocean and its high heat capacity. Other climatic patterns, such as seasonal

EL NIÑO AND LA NIÑA



El Niño occurs when warm waters move along the equator in the Pacific, which increases evaporation and moisture sent to the west coast of the Americas. La Niña is marked by cooler waters and drier conditions in the Americas.

In the Classroom

Splish, Splash: Water's Journey to My Glass

Critical to our existence, water sustains all life on Earth. Water moves continuously through the stages of the hydrologic cycle (evaporation, condensation, and precipitation). How does our drinking water fit into the hydrologic cycle? Where does the water we drink come from? This lesson will explore the hydrologic cycle, and students will map the path of drinking water from the origin of precipitation to the tap.

Materials

- Topographic map of your region
- Blank map of your region
- Information from your local water provider (location of aquifer, reservoir, or well from which the school tap water comes)
- Paper, pencils/pens

Directions

1. Review the basic principles of the water cycle.
2. Brainstorm and list the various types of water sources found on Earth.
3. Explain that the water they drink probably traveled a great distance to end up in their drinking glass. Identify the aquifer, reservoir, or well from which the school tap water comes. Tell students they will work back from this point to trace the water source origin.
4. Ask students to predict where the headwater, or source of origin, for their drinking water might be.
5. Using the topographic map of your region, challenge students to explore the path the water travels. Encourage students to consider the role of the water cycle in this journey.
6. Working from the immediate source of your drinking water (a reservoir, for instance), students will follow rivers and streams back to their headwaters. Students may want to work in groups for this. Be sure to discuss water flow, such as elevation changes that might send a stream flowing in another direction!
7. Students will finish by using the blank regional map to highlight boundaries that define the drainage basin or watershed from which their drinking water comes. Students will also label the paths and names of the waterways within this area.
8. Reinforce the idea that precipitation that falls within the boundaries might also wind up in their drinking glass or water fountain, without following the elaborate path from the headwaters.

Discuss

1. How did your prediction compare to the actual water-source origin?
2. What path does local water follow in order to get to your tap?
3. Name something you learned about water that you did not know before.

Explore more National Geographic Freshwater activities at http://environment.nationalgeographic.com/environment/freshwater/.

Student Thinking

Ocean and Water Cycling

Students may take a land-centered view of weather, seeing it as more a phenomenon on land rather than ocean-driven. Evaporation of water from the ocean can sometimes be a tricky concept to learn. Students may believe that water molecules themselves expand during evaporation, rather than understanding the molecules move apart from one another. (Henriques 2002; Tytler 200). Students may also wonder why rain clouds from the ocean move onshore, which relates to how the sun heats the ocean and land. They may not realize that land and ocean heat differently.

Scenario

A student teacher has asked to do research in your class about student knowledge of the water cycle. The student teacher designs an interview assessment that she uses with a few of your students as practice. The interview is about what students know about the water cycle, but one question in particular asks students to explain how the land and ocean heat and cool. The transcripts of student responses to this question follow.

Question

Describe what happens to the ocean when sunlight heats the ocean? Is this different from what happens on land?

Scientific Answer

Land and water behave differently when exposed to heat. Land heats and loses heat more quickly than water, which means moisture evaporates more easily and quickly from land than it does from water. Water evaporates when heat from the sun warms land or ocean surfaces. In the ocean, as more water evaporates, the air becomes humid and it travels upward or inland (see **The Water Cycle,** page 28). The differential heating and cooling of land and ocean also influence the movement of air and moisture, leading to weather and climate patterns we experience all the time.

Student Answers

Marian: The ocean's temperature is different from the land's temperature. And the oxygen and air atoms pick up the same temperature. I think the land can heat up faster and cool down faster than the ocean. So if it's summer, it's really hot on the land. But in the ocean, it's still pretty cold. It's harder for the ocean to take in the heat.

Jessie: The ocean cools off faster than the land, so I think the air closest to the surface of the ocean will become cooler, faster than the air on land. The ground absorbs the heat faster than the water, and I think it lets it off faster as well. And so winds come off the ocean so it kind of pushes the warm air away and keeps it cooler than the air on land.

Kevin: If it's hotter in summertime, then more water is evaporating from the ocean. The ocean is gathering more salt when the water evaporates because the water leaves behind all this salt when it evaporates. So the surface of the ocean could get a lot saltier. I know the ocean heats up different from land, but I'm not really sure why.

What Would You Do?

1. What do the students' answers show they understand about ocean/land heating and cooling? What do they misunderstand?
2. How could you use information from this interview to plan your teaching? What concepts would you address?

monsoons in South Asia, result from air/sea interactions.

The Other End of the Cycle: Where Freshwater Meets the Sea

Land, sea, and freshwater interface at areas around the globe known as **estuaries.** Estuaries, often simply described as "where rivers meet the sea," are characterized by the interface of two types of water—freshwater from rain and snowmelt and salt water from the ocean. The semi-salty water that forms by their mixing is called **brackish water.** Your students may wonder if estuaries are freshwater or salt water, or they may wonder what *brackish water* means. The freshwater has carried organic (plant and animal) and inorganic (rocks, minerals, chemicals) materials downstream to the estuary. The ocean waves, tides, and surges have encroached upon the otherwise freshwater habitat. It is in estuaries that water is transformed.

Estuaries are shaped by the size and flow of the river joining the ocean, the local sediment or rock type, and how exposed the area is to the open ocean. These differing physical profiles greatly determine the dynamics within each estuary. If an estuary is around steep cliffs, there will be little opportunity for the river to pick up sediment and other items enroute to the ocean, as well as a dramatically shortened area of ocean-freshwater mixing. If the estuary is in gently rolling hills, then the freshwater has more opportunity to pick up and carry sediments and other natural materials along the way, and the incoming ocean waters will extend deeper into the estuary. Because of the differences in the physical structure of the surrounding land, an estuary can exist in myriad forms, such as a bay (San Francisco), a salt marsh (Bolsa Chica), a delta (Sacramento), a mudflat (Morro Bay), a wetland (Elkhorn Slough), or a lagoon (Malibu). If the estuary has a deep bottom, then there will actually be stratification zones—with the less dense freshwater floating on top of the denser salt water and perhaps a middle layer of mixed waters if the tidal movement is sufficient to cause turbulence and blending (similar to the layering in the open ocean discussed in Chapter 1). If the estuary is shallow, these stratification zones may be absent.

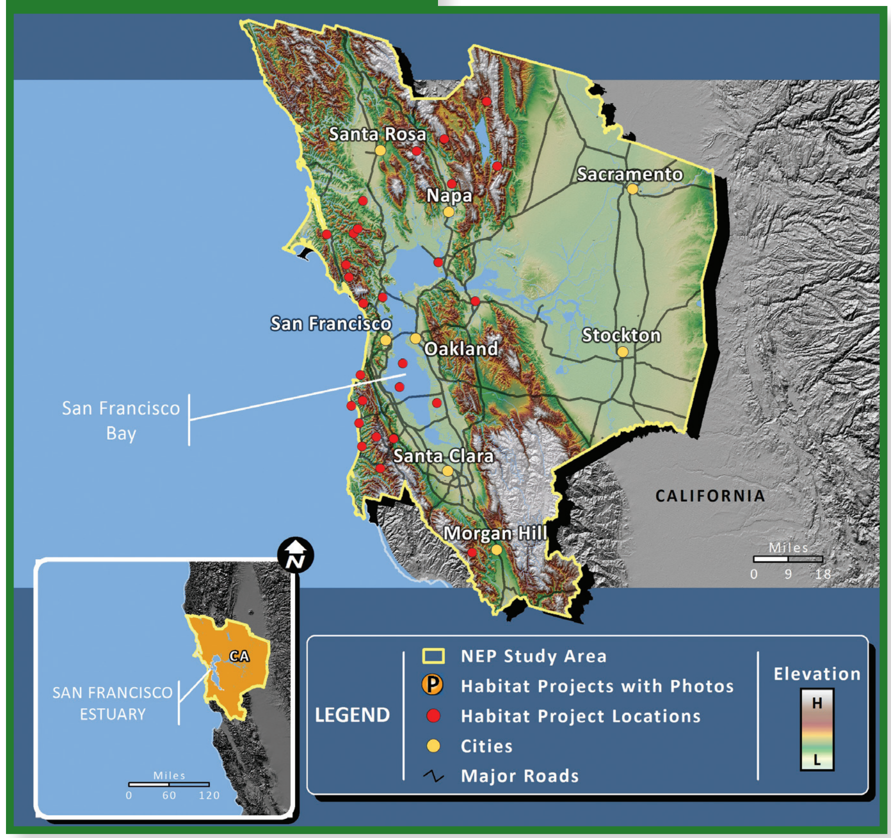
There are normal tidal and seasonal fluctuations in a healthy estuary. Along most of the West Coast, there are two high tides and two low tides each day. During times of a high tide, the salty ocean waters will move upstream into the estuary. Again, the physical configuration of the particular estuary will determine how far upstream it moves. If there are inlets or islets that form barriers, the salty water will not travel as far as it might in an estuary that is unimpeded and shaped like a long river with little change in elevation. During high tides, the waters are naturally saltier as higher salinity ocean water creeps upstream. During low tides, the ocean recedes and it is common to see large areas of the estuary bottom exposed. Particularly in mud flats and salt marshes, low tide is prime feeding time for the many birds that hunt in the estuary because they have increased access to the animals living in the mud. As one would expect, during the rainy season and spring's melting of snow, the estuaries have a greater influx of freshwater than they do in the dry months. During drier periods, especially if there's a drought, estuaries can have very little freshwater. Lack of circulation within an estuary can occur when outlying sand bars build up (in the absence of freshwater outflow) and block water movement or due to human activities such as the construction of jetties.

Besides the mixing of the two types of waters, estuaries are distinctive in that they provide a remarkable service to the planet. This can seem surprising to both students and teachers because estuaries often look like a wasteland. Viewed quickly and superficially, one sees the changing water level, scrub vegetation, and often litter floating in the water and might make the judgment that an estuary is worthless. Ironically, these scrubby plant species enable estuaries to make such a huge contribution to the health of our planet.

Estuaries provide a buffer zone between freshwater and the ocean. This buffer zone provides an area of refuge from direct wave action which impacts the topography of the local beach, the water quality, and the **biodiversity** of the habitat. During storms, estuaries can accommodate extra water and keep neighboring regions from flooding. This buffer zone also allows the upstream water to circulate and percolate within the estuary before moving out to sea. While the water is in the estuary, it seeps down between the pores in the sediment, through pebbles and decaying organic material. As the water percolates through the sediment, the process acts as a natural filter, removing chemicals and impurities in the water. Additionally, many estuarine plant species are able to absorb chemicals, including toxic metals, and transform them into harmless compounds. The longer water stays in the estuary, the more it is filtered by the local species and geological processes.

The water in an estuary is greatly impacted by its surroundings—upstream and adjacent. Run-off from industrial plants and agriculture, as well as oil, soaps, sewage discharge, pesticides, and herbicides that are used by the people living upstream, increase the demands placed on the filtering capacity of an estuary. The pesticides and herbicides that are used to protect gardens also kill plants and animals in the estuaries. Chemicals, such as the phosphorus in

RESTORING OUR ESTUARIES



the detergents we use to wash our cars and the oil that drips onto our driveways and streets, also add to the chemical mix found in estuaries. **Eutrophication,** or nutrient loading, can overwhelm estuaries. All the extra nutrients, including the added phosphorous, can promote rapid growth of algae (algal blooms). When the algae die off, the oxygen levels in the water greatly decrease, imperiling the other organisms living in the estuary. Higher levels of carbon dioxide resulting from increased emissions from cars and industry has made our waters increasingly acidic. Many of the organisms that live in and by the water have calcium carbonate shells (similar to chalk) that dissolve in acidic waters. Many estuaries also have been beset by invasions of nonnative species of plants and animals, which can be introduced through the **ballast** water and hulls of ships. Because they have no local natural predators, these nonnatives out compete the native species, and the balanced food web becomes unbalanced.

The perception of estuaries as wastelands has put them in peril. California has lost about 90 percent of its wetlands due to urbanization and agricultural development. As demand for land grew, these undeveloped areas were purchased and developed. The natural ability of estuaries to filter impurities out of the water before it reaches the ocean has been seriously overloaded by the decrease in acreage and the increasing level of toxins that are flowing in the water. This means more pollutants are entering the ocean. The decrease in wetlands has also impacted wildlife that rely on estuaries as feeding, nesting, and nursery areas.

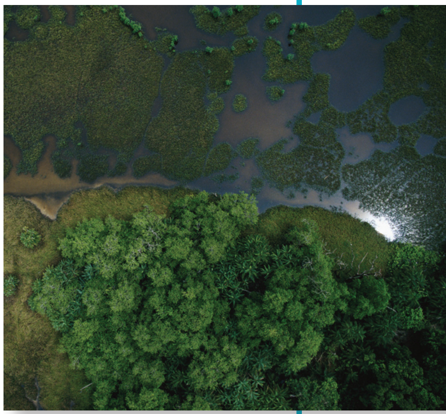
The good news is that in recent years, we have become more aware of the importance of estuaries in the filtering and health of our water. Several laws have been passed to protect our ocean and estuaries. National and state agencies have been funded and are endowing local groups to monitor and reclaim estuaries. Volunteers, partnering with scientists, are now able to use modern monitoring tools, such as aerial photography and more user-friendly chemical testing kits to help monitor the health of the estuaries. Concerned locals can research and share available resources and data banks in their efforts to reclaim our oceans and estuaries (e.g., The National Estuarine Research Reserve System—NERRS). Restoration projects are currently underway in California's San Francisco Bay, Santa Monica Bay, Bolinas Lagoon, Goleta Slough, and Long Beach's Colorado Lagoon (http://www.era.noaa.gov/). Each restoration project faces special challenges unique to its location. Some sites have to dredge toxic chemicals, while others are getting rid of asphalt parking lots that seep oil. A common thread is concern for the water quality and the preservation of native plant species to reestablish the natural balance in the habitat. The projects discussed here and those that are similar strive to assure the health of estuarine ecosystems and the natural filtration structure in these systems.

The active exchange of fresh and salt waters in estuaries provides a significant service to our planet. The fresh rain and snowmelt that have journeyed downstream—collecting minerals, organic materials, chemicals, and debris along the way—gets filtered. This filtered water is returned to the ocean where it will evaporate and start its journey through the water cycle once again. This constant cycling of liquid, gas (vapor), and solid (snow /ice) water is fueled by the energy and heat of the sun. The differences in heat retention of water and land create changes in winds and air patterns. These winds move both water and air currents that come ashore and distribute rain across the continents. The ocean drives our weather and has a profound effect on our climatic zones.

Student Thinking

Estuary Interfaces

While students may be familiar with some marine ecosystems, such as coral reefs, few are familiar with estuaries. These important ecosystems can be home to many unique species. Unless you enjoy birding or paddling, estuaries are not a common place to choose for outdoor recreation. Some may think estuaries are "swampy," "buggy," or that they smell funny. Yet, estuaries are an important ecosystem teeming with life, and as you teach about estuaries, you may find students have incorrect ideas or simply lack a general understanding of these ecosystems.



Loango National Park, in Gabon, was established to protect diverse coastal habitats.

Scenario

You are going to start teaching about marine ecosystems to your students. In order to determine what your students already know, you decide to give them a quiz. One question on this quiz asks about estuaries. As you read answers to the following question, think about your plans for teaching estuaries to students.

Question

Why are estuaries important to the ocean?

Scientific Answer

Estuaries act as a barrier between land and ocean, and fresh and salt water. They act as a basin for extra water, often accommodating excess water during storms, preventing flooding in nearby areas. They also act as a filtering system, allowing for percolation of freshwater in the sediment and filtration through vegetation before it enters the ocean. Lastly, estuaries are important nurseries for many marine species.

Student Answers

Leah: Estuaries might be important for the ocean because they are filters almost, for other animals that probably shouldn't go in the ocean, they can live there.

CJ: They might be important because the water from the estuaries flows to the ocean, and during that process, it gathers salt and creates salt water.

Allison: Estuaries may be important for the ocean because it can be a safe place for other living things to stay away from harmful creatures to them.

Jacob: An estuary is good for the ocean because a lot of things that migrate from the ocean into freshwater, or from freshwater into the ocean, like salmon. They need the estuaries because that's almost like a gate to get into the ocean or out from the ocean.

Tony: Wetlands are important to the ocean because wetlands take water from the ocean, then they renew it and they give it back. And sometimes the wetland purifies the water and turns it to freshwater so animals can live in it.

What Would You Do?

1. What misconceptions do you observe? Which ones do you think should be addressed and why?
2. How would you use the students' prior knowledge to plan your lessons so that students' ideas about estuaries become more sophisticated?

References

Henriques, L. "Children's ideas about weather: A review of the literature." *School Science and Mathematics* 102.5: (2002) 202–215.

Tytler, R. "A comparison of year 1 and year 6 students conceptions of evaporation and condensation: dimensions of conceptual progression." *International Journal of Science Education* 22.5: (2000) 447–467.

Teaching Resources

California Education and Environmental Initiative resources: http://www.calepa.ca.gov/Education/EEI/default.htm

EPA's Estuary Kids resources: http://water.epa.gov/learn/kids/estuaries/index.cfm

EPA's videos on estuaries: http://water.epa.gov/type/oceb/nep/nepvideos.cfm

Estuary Protection Act: http://www.fws.gov/laws/lawsdigest/estuary.html

Heal the Bay watershed resources: http://www.healthebay.org/about-bay/current-policy-issues/keeping-ocean-healthy#openspace

Marine Life Protection Act: http://www.dfg.ca.gov/mlpa/

NASA Lesson on El Niño: http://mynasadata.larc.nasa.gov/preview_lesson.php?&passid=57

National Coastal Condition and NEP State of the Estuary Reports: http://water.epa.gov/type/oceb/nep/bay.cfm#sob

NOAA Activities on El Niño: http://www.oar.noaa.gov/k12/html/elnino2.html

NOAA Water Cycle Game: http://response.restoration.noaa.gov/watercyclegame

NOAA Ocean Role in Climate and Weather: http://oceanservice.noaa.gov/education/pd/oceans_weather_climate/welcome.html