Global Water Resources and Use

3

WATER DISTRIBUTION AND PROPERTIES

Over 70% of Earth's surface is covered by water. Oceans hold about 97% of all water on Earth, while freshwater constitutes about 3%. Of the freshwater that is available, most of it is trapped in glaciers and ice caps. The rest is found (in descending order) in groundwater, lakes, soil moisture, atmospheric moisture, rivers, and streams.

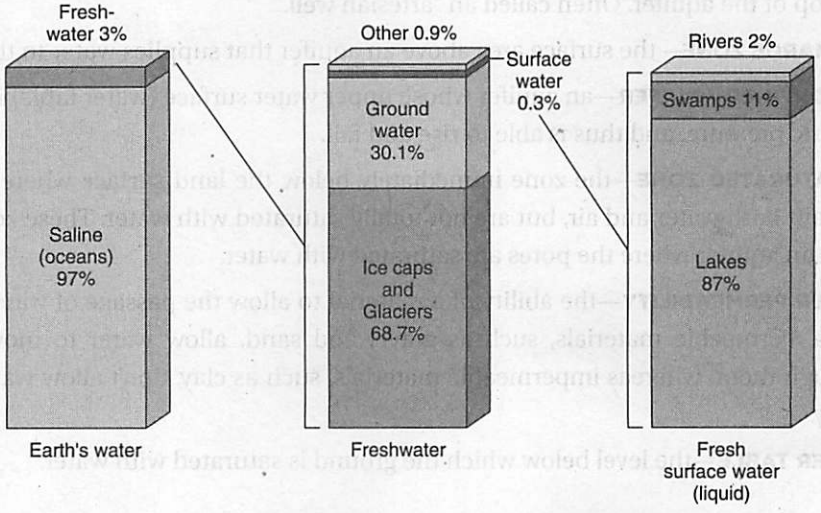


Figure 3.1 Distribution of Earth's water

Water has many unique properties:

- Strong hydrogen bonds hold water molecules to each other.
- The temperature of water changes slowly due to its high specific heat capacity.
- Water has a high boiling point.
- A lot of energy is needed to evaporate water.
- Water dissolves many compounds.
- Water filters out harmful UV radiation in aquatic ecosystems.
- Water adheres to many solid surfaces.
- Water expands when it freezes.

FRESHWATER

Most human settlements are determined by the availability of freshwater. The highest per capita supplies of freshwater are in countries with high precipitation and small populations,

e.g., Norway and Iceland. Lowest per capita freshwater supplies are in areas with low rainfall and large populations, e.g., Egypt and Israel.

The use of freshwater, a limited resource, is growing at twice the rate of population growth. In the United States, the average amount of freshwater allocated per person for all purposes is approximately 500,000 gallons (1,900,000 l) per year.

AQUIFERS

An aquifer is a geologic formation that contains water in quantities sufficient to support a well or spring. Aquifers in the United States hold 30 times more water than all U.S. lakes and rivers combined, with groundwater supplying almost 40% of all freshwater in the United States.

Important terms regarding aquifers include:

- **CONFINED AQUIFER**—an aquifer below the land surface that is saturated with water. Layers of impermeable material are both above and below the aquifer, causing it to be under pressure so that when the aquifer is penetrated by a well, the water will rise above the top of the aquifer. Often called an "artesian well."
- **RECHARGE ZONE**—the surface area above an aquifer that supplies water to the aquifer.
- **UNCONFINED AQUIFER**—an aquifer whose upper water surface (water table) is at atmospheric pressure, and thus is able to rise and fall.
- **UNSATURATED ZONE**—the zone immediately below the land surface where the pores contain both water and air, but are not totally saturated with water. These zones differ from an aquifer where the pores are saturated with water.
- **WATER PERMEABILITY**—the ability of a material to allow the passage of water through rocks. Permeable materials, such as gravel and sand, allow water to move quickly through them, whereas impermeable materials, such as clay, don't allow water to flow freely.
- **WATER TABLE**—the level below which the ground is saturated with water.

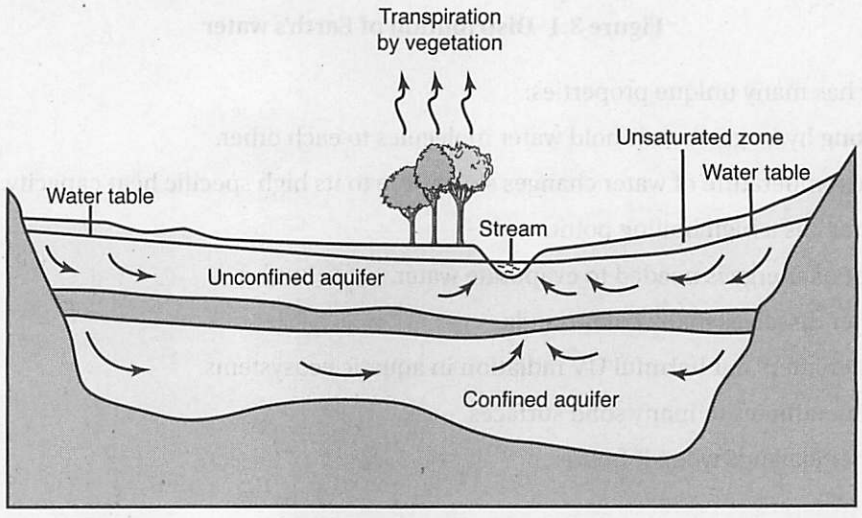


Figure 3.2 A typical aquifer

CASE STUDY

OGALLALA AQUIFER: The Ogallala Aquifer is located in the central United States. It is one of the world's largest aquifers, but it is being rapidly depleted by growing municipal and agricultural use. This huge aquifer, which underlies portions of eight states, contains water from the time of the last glaciation (12,000–1.2 million years ago). Annual recharge, in the more arid parts of the aquifer, is estimated to total only about 10% of annual withdrawals. The biggest users of water from aquifers include agricultural irrigation and oil, natural gas, and coal extraction.

Environmental Issues Related to Aquifers

1. **SUBSIDENCE**—the sinking of land that results from groundwater extraction. This is a major problem in the developing world as large cities swell without many alternatives for supplying freshwater to the population. Thus, the unregulated extraction of groundwater can become a Tragedy of the Commons with high economic externalities.
2. **SALTWATER INTRUSION**—the movement of saltwater into freshwater aquifers, which can lead to the contamination of drinking water sources. Groundwater pumping from coastal freshwater wells has increased saltwater intrusion in many coastal areas. Water extraction drops the level of fresh groundwater, reducing its water pressure and allowing saltwater to flow further inland. Navigational, agricultural, and drainage channels also provide ways to allow saltwater to move inland. Storm surges and hurricanes also allow saltwater to move inland, contaminating aquifers.

CASE STUDIES

SAN JOAQUIN VALLEY, CALIFORNIA: Groundwater-related subsidence is the sinking of land resulting from groundwater extraction. Land subsidence occurs when large amounts of groundwater have been withdrawn from certain types of rocks, such as fine-grained sediments. The rock compacts because the water is partly responsible for holding the ground up. When the water is withdrawn, the rocks fall in on themselves. The desert areas of the world are requiring more and more water for growing populations and agriculture. In the San Joaquin Valley of the United States, groundwater pumping for crops has gone on for generations and has resulted in the entire valley sinking up to thirty feet.

MEXICO CITY: A city of 22 million people, Mexico City is almost entirely dependent on exploiting groundwater for its needs. The water table in Mexico City is dropping almost 6 feet (2 m) per year. Such a dramatic change in land elevation causes massive impacts on buildings and infrastructure, such as cracking and tilting.

TYPES OF ICE

Glaciers

A glacier is a persistent body of dense ice that only forms on land and is constantly moving under its own weight. It forms where the accumulation of snow exceeds its rate of melting and sublimation over time. On Earth, 99% of glacial ice is contained within vast ice sheets in the polar regions. Glacial ice is also the largest reservoir of freshwater on Earth. Many glaciers from temperate, alpine, and seasonal polar climates store water as ice during the colder seasons and release it later in the form of meltwater as warmer summer temperatures

cause the glacier to melt. This creates a water source that is especially important for plants, animals, and human uses.

Ice Sheets (Continental Glaciers)

An ice sheet is a mass of glacial ice that covers the surrounding terrain and is greater than approximately 20,000 square miles in area (50,000 km^2). The only current ice sheets are in Antarctica and Greenland. About 27,000 years ago, ice sheets covered much of North America, northern Europe, and southern South America. Ice sheets are bigger than ice shelves or alpine glaciers.

Ice Shelves

An ice shelf is a thick floating platform of ice that forms where a glacier or ice sheet flows down to a coastline and onto the ocean surface. Ice shelves are only found in Antarctica, Greenland, and Canada. The thickness of ice shelves ranges from about 300 to 3,000 feet (about 100 to 1,000 m). Ocean waters melting the undersides of Antarctic ice shelves (not calving) are responsible for most of the continent's ice shelf mass loss.

Sea Ice

Sea ice is frozen seawater. Because ice is less dense than water, it floats on the ocean's surface (as does freshwater ice, which has an even lower density). Sea ice covers about 7% of Earth's surface and about 12% of the world's oceans. In the Northern Hemisphere, it is found primarily in the Arctic Ocean. In the Southern Hemisphere, it occurs in various areas around Antarctica. Icebergs are different from sea ice since icebergs are smaller floating chunks of ice shelves or glaciers that have broken off of larger pieces of ice.

OCEANS

Approximately 71% of Earth's surface is covered by the oceans. More than half of this area is below 10,000 feet (3,000 m) deep, with the average salt content of seawater being around 3.5%.

Oceans have a significant effect on the biosphere, as oceanic evaporation is the primary source for precipitation and ocean temperatures affect climate and wind patterns. Approximately 250,000 marine life-forms are currently known, with many times that number yet to be discovered.

Ocean Circulation

The Northern Hemisphere is dominated by land and the Southern Hemisphere is dominated by oceans. Temperature differences between summer and winter are more extreme in the Northern Hemisphere because the land warms and cools more quickly than water. Heat is transported from the equator to the poles mostly by atmospheric air currents but also by oceanic water currents. The warm waters near the surface and colder waters at deeper levels move by convection. Changes in ocean temperatures have a direct bearing on ocean currents. During summers, a thermocline develops in ocean waters between the warm surface water and the cooler bottom water.

Surface ocean currents are driven by wind patterns that result from the flow of high thermal energy sources generated at the tropics (higher pressure) to low-energy sources

in polar areas (lower pressure) and serve to distribute the heat generated near the tropics. Deep-water, density-driven currents are controlled primarily by differences in temperature and salt content with denser, saltier water sinking, and less-dense water rising. About 90% of the ocean volume circulates due to density differences in temperature and salinities, while the remaining 10% is involved in wind-driven surface currents. In the Northern Hemisphere, north-flowing currents are warm (originating near the equator), and south-flowing currents are colder (originating from the Arctic area).

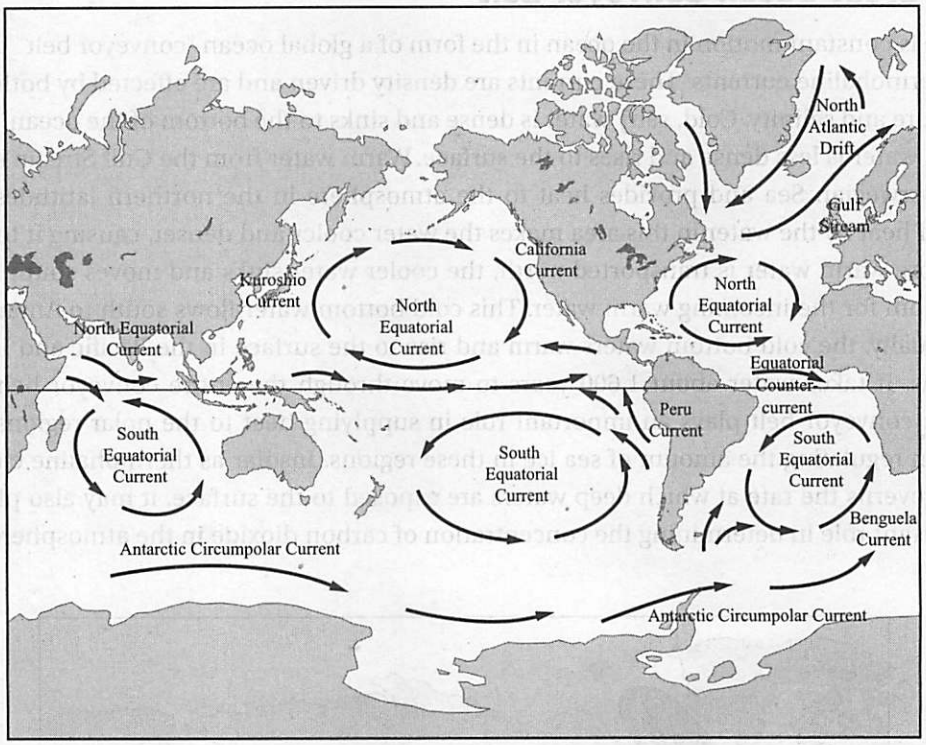


Figure 3.3 Ocean surface currents

Ocean water has warmed significantly during the past 50 years. The greatest amount of warming has occurred in the top surface layers of the ocean. The temperature of the Antarctic Southern Ocean rose by 0.31°F (0.17°C) between the 1950s and the 1980s—twice the rate for the world's oceans as a whole. Since the 1950s, the California Current that runs southward along the west coast of the United States has risen about 2.7°F (1.5°C) and has resulted in a significant decrease in plankton with resulting rippling effects within the food web. Possible reasons for dramatic increases in ocean temperatures include:

- Significant slowing of the ocean circulation that transports warm water to the North Atlantic
- Large reductions in the Greenland and West Antarctic ice sheets
- Accelerated global warming due to carbon cycle feedbacks in the terrestrial biosphere
- Decreases in upwelling
- Releases of terrestrial carbon from permafrost regions and methane from hydrates in coastal sediments

The Gulf Stream transports warm water from the Caribbean northward. A branch of the Gulf Stream known as the North Atlantic Drift is responsible for bringing warmer temperatures

to Europe. Evaporation of ocean water in the North Atlantic results in a cooling effect and a higher salt concentration, both of which increase the density of the water. As the denser water sinks, it creates a southern circulation pattern. As glaciers in Greenland melt due to the effects of global warming, the density of this ocean water decreases due to more freshwater. This, in effect, could stall the North Atlantic Drift and bring colder temperatures and flooding to Europe.

The Great Ocean Conveyor Belt

There is constant motion in the ocean in the form of a global ocean "conveyor belt" driven by thermohaline currents. These currents are density driven and are affected by both temperature and salinity. Cold, salty water is dense and sinks to the bottom of the ocean, while warm water is less dense and rises to the surface. Warm water from the Gulf Stream enters the Norwegian Sea and provides heat to the atmosphere in the northern latitudes. The loss of heat by the water in this area makes the water cooler and denser, causing it to sink. As more warm water is transported north, the cooler water sinks and moves south, making room for the incoming warm water. This cold bottom water flows south to Antarctica. Eventually, the cold bottom waters warm and rise to the surface in the Pacific and Indian oceans. It takes water about 1,600 years to move through the entire conveyor belt. The ocean conveyor belt plays an important role in supplying heat to the polar regions, and thus in regulating the amount of sea ice in these regions. Insofar as thermohaline circulation governs the rate at which deep waters are exposed to the surface, it may also play an important role in determining the concentration of carbon dioxide in the atmosphere.

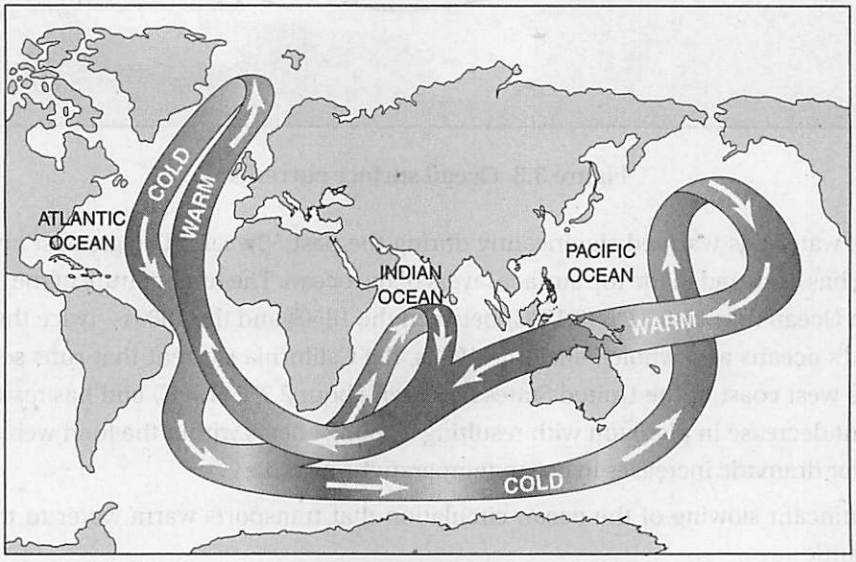
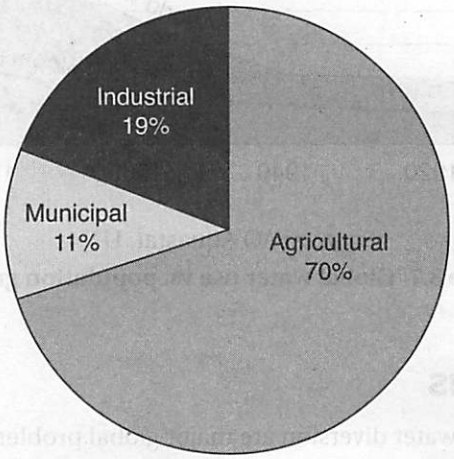


Figure 3.4 The great ocean conveyor belt

AGRICULTURAL, INDUSTRIAL, AND MUNICIPAL USE

About half of the precipitation that falls on Earth either evaporates or returns to the atmosphere through transpiration from plants. The remainder, known as renewable freshwater resources, is converted to surface runoff, which feeds rivers, lakes, and groundwater aquifers.

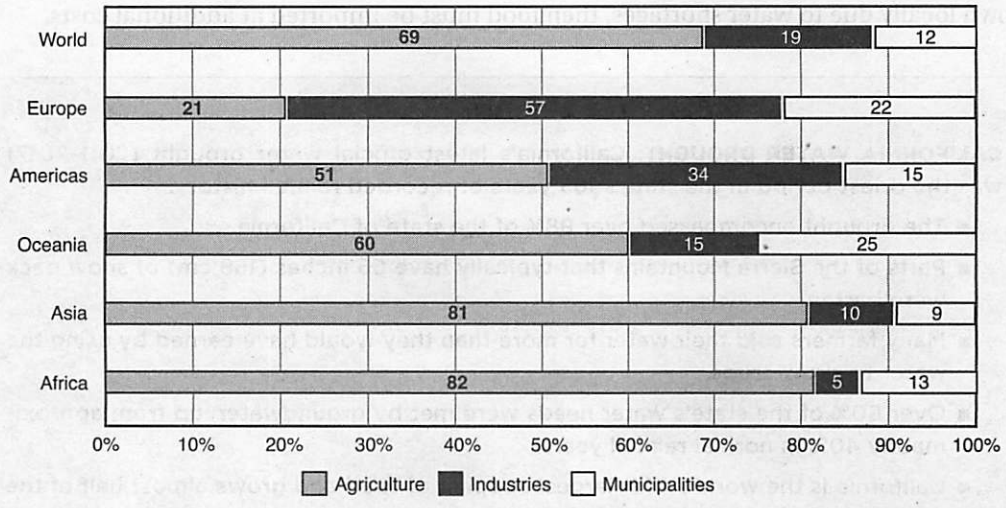
The three types of water withdrawal are agricultural (e.g., irrigation, livestock, and aquaculture), industrial (e.g., steel, chemical, manufacturing, paper, mining, and petroleum refining), and municipal (e.g., drinking water, bathing, and laundry). Figure 3.6 below shows the relative withdrawal ratios of these three types of water withdrawal.



Source: Food and Agricultural Organization of the United Nations

Figure 3.5 Global sources of water withdrawal

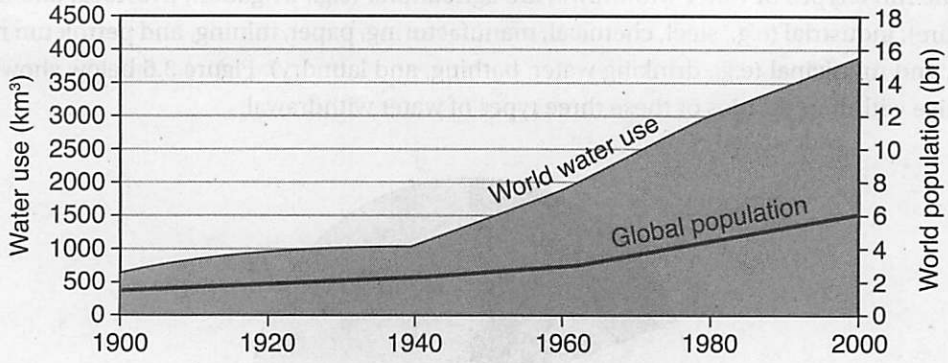
Africa leads the world in water withdrawal for agricultural purposes while Europe leads the world in water withdrawal for industrial purposes. Oceania (Australia and nearby islands) leads the world in water withdrawal for municipal purposes.



Source: Food and Agricultural Organization of the United Nations

Figure 3.6 Water withdrawal ratios by continent

During the 20th century, the world population increased 4.4 times while water withdrawal increased 7.3 times over the same period. Thus, global water withdrawal increased 1.7 times faster than the world population.



Source: FAO Aquastat, UN

Figure 3.7 Global water use vs. population growth

GLOBAL PROBLEMS

Freshwater shortages and water diversion are major global problems.

Water Shortages

The rate of water consumption is growing twice as fast as the population growth rate. Freshwater shortages that result from this demand can be due to natural weather patterns that reduce rainfall, rivers changing course, flooding that contaminates existing supplies, competition for available water, overgrazing and the resulting erosion, pollution of existing supplies, and competing interests that reduce water conservation programs. Water is a limiting factor as it limits the amount of food that can be produced in a region. If food cannot be grown locally due to water shortages, then food must be imported at additional costs.

CASE STUDY

CALIFORNIA WATER DROUGHT: California's latest official water drought (2011–2017) was the driest period in the state's 163 years of recorded rainfall history.

- The drought encompassed over 98% of the state of California.
- Parts of the Sierra Mountains that typically have 66 inches (168 cm) of snow pack were barren.
- Many farmers sold their water for more than they would have earned by using the water to grow crops.
- Over 60% of the state's water needs were met by groundwater, up from approximately 40% in normal rainfall years.
- California is the world's fifth-largest supplier of food and grows almost half of the nation's fruits, nuts, and vegetables.
- In some areas of California, the land subsidence (sinking) was over one foot per year.
- The shortage of water dramatically reduced the state's hydropower capacity.

Water Diversion

Groundwater is the largest source of freshwater on Earth. However, with ever-increasing demands for freshwater, surface water from rivers, lakes, streams, and natural springs is also being diverted for agricultural irrigation, hydropower, nuclear power plant cooling, industrial, recreational, residential, and municipal purposes. The following environmental consequences can result from water diversion:

- Flow changes as stream banks are modified and realigned, which can lead to changes in the bottom structure of streams and river beds (e.g., coarse substrates, such as gravels and boulders, are replaced and covered by sand and silt, altering the conditions for the plants and animals that live there).
- With a decrease in freshwater volume, the concentration of salts and other minerals and pollutants (e.g., arsenic) in the water may increase.
- A decrease in water levels reduces the habitat for fish and can impact feeding and spawning success.
- Turbidity, temperature, and oxygen levels can increase with reduced flows in rivers.
- Less water lowers the water table and may result in saltwater intrusion and/or land subsidence (sinking).
- A reduction in the population of migratory birds that depend upon wetlands for survival (e.g., feeding, reproductive cycles, nesting).
- A reduction in the native populations of animals and plants that inhabited the area before water diversion, possibly resulting in an increase in the number of invasive species.

Mitigation steps include:

- Facilitate an upstream and downstream passage for fish migration, where these areas may be blocked by a diversion, using ramps, ladders, and spillways.
- Create natural meanders, low flow channels, and "rest" areas.
- Maintain, restore, and enhance riparian vegetation and wetland areas.

Methods to Increase the Amount of Available Freshwater

Freshwater is a renewable resource (water cycle); the ultimate source is rain and snow. However, it is the rate of the renewal process versus the rate of demand that determines its availability. Listed below are several methods that can increase the amount of available freshwater.

- **COVER SOIL SURFACES WITH MULCH:** Mulch (a material such as decaying leaves, bark, or compost) reduces evaporation from the soil.
- **DESALINATION OF SEAWATER:** Due to its energy consumption, desalinating seawater is generally more costly than freshwater from rivers or groundwater, water recycling, and water conservation. Approximately 1% of the world's population is currently dependent on desalinated water to meet their daily needs.
- **PLANT CROPS THAT DO NOT REQUIRE AS MUCH WATER:** Match the water demands of crops to the water availability and supply in the area. Replace nonnative plants and lawns that require frequent watering with native plants that require substantially less water. Government subsidies or other incentives may be available.

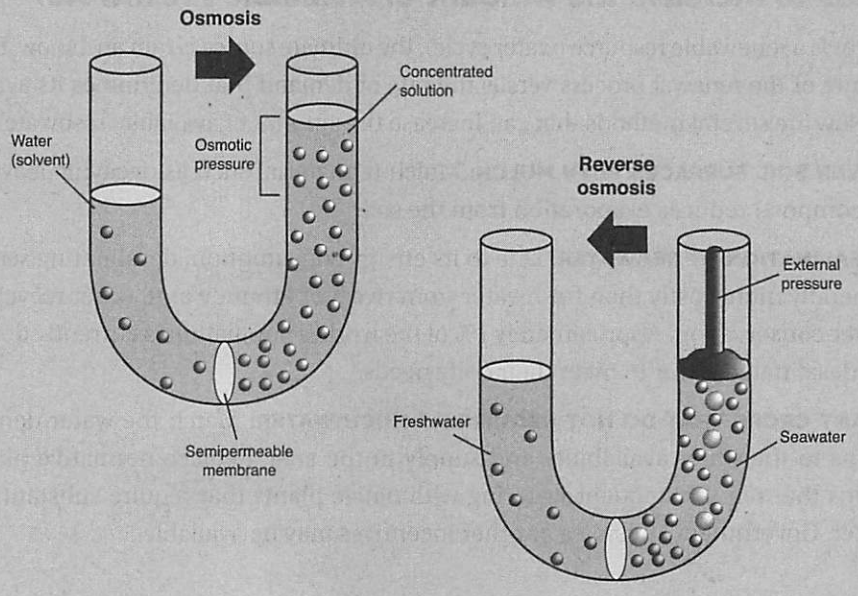
- **TIERED PRICE SCALE:** This method would reduce the effective family income for larger families. This effect could be remedied through exemptions or the allocated share of water per family member.
- **USE AND ENFORCEMENT OF WATER SCHEDULES:** Watering can only occur on certain days, only for so long, and only at certain times based on a schedule. For example, even home addresses can only water on Mondays, Wednesdays, and Fridays between 8 P.M. and 5 A.M.
- **USE AUTOMATIC WATERING SYSTEMS THAT USE SOIL MOISTURE AND WEATHER REPORT DATA:** Systems are currently available that only automatically water when the soil moisture falls below a certain level.

CASE STUDIES

ASWAN HIGH DAM, EGYPT: Completed in the 1970s, the Aswan High Dam in Egypt was built to supply irrigation water. The water that is available is only half of what was expected due to evaporation and seepage losses in unlined canals. Several other problems were encountered: First, the elimination of nutrients onto farmlands now requires the use of expensive fertilizers. Second, the depletion of nutrients into the Mediterranean caused a decline in certain fish catches. Third, large amounts of standing water caused the proliferation of snails and ultimately resulted in a debilitating disease known as schistosomiasis, with some areas having infection rates of 80%.

BANGLADESH: In the 1960s, thousands of wells were dug in Bangladesh by foreign governments and humanitarian organizations in an effort to supply freshwater to the population. Shortly thereafter, arsenic compounds from the soil began to leach into the groundwater. Arsenic poisoning began to appear among the population, with millions of people showing symptoms.

CATALINA ISLAND, CA: Catalina Island is one of only a handful of sites that use the process of reverse osmosis to obtain drinking water from seawater. Reverse osmosis is a water purification technology that uses a semipermeable membrane to remove ions, molecules, and larger particles from drinking water. Ocean water is pumped through seawater wells to a desalination plant, located in the city of Avalon. The plant's maximum daily output is about 325,000 gallons.



CASE STUDIES

COLORADO RIVER BASIN: Diversion of water from the Colorado River has led to water right disputes between California, Arizona, and Mexico. Dams on the Colorado River trap large quantities of silt (over 10 million metric tons per year) and reduce nutrient levels in farmlands below the dam. As a result, more fertilizer is required. Farm irrigation has resulted in high levels of salts in the alkaline soils becoming incorporated in agricultural runoff. Millions of acres of once-valuable farmland are now useless due to the salt buildup in soil, a process known as salinization.

JAMES BAY, CANADA: Diversion of rivers into Hudson Bay to generate electrical power has resulted in massive flooding. During one flood, up to 10,000 caribou drowned. In addition, mercury has leached out of rocks and into water, with nearby residents showing signs of mercury poisoning. The project also created expensive legal battles and many issues with indigenous people whose land was flooded.

THREE GORGES DAM, CHINA: In 1949, China had no large reservoirs and only 40 small hydroelectric stations. By 1985, there were 80,000 reservoirs and 70,000 hydroelectric stations. The Three Gorges Dam required relocation of 1.2 million people.

Case Studies can be brought into your FRQ responses to bring a historical connection into your answer. Try to bring at least one Case Study into your FRQ responses—your score will go higher!

MULTIPLE-CHOICE QUESTIONS

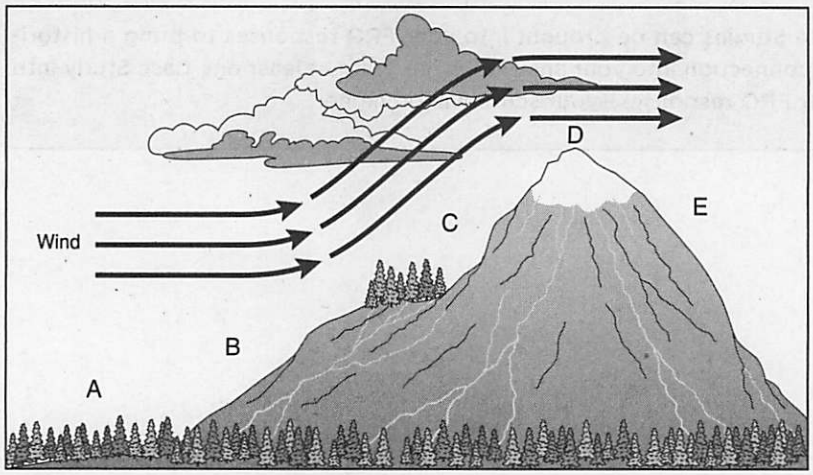
1. Which of the following is/are NOT a property of water?

   (A) Water forms strong hydrogen bonds.
   (B) Water dissolves many compounds.
   (C) Water takes up less space when it freezes.
   (D) Water filters out harmful UV radiation in aquatic ecosystems.
   (E) All are properties of water.

2. What type of relationship exists between the legislation that proposes to subsidize farmers for growing water-thirsty crops and water demand?

   (A) A positive feedback loop
   (B) A negative feedback loop
   (C) A synergistic relationship
   (D) An inverse relationship
   (E) A mutualistic relationship

Questions 3 and 4 refer to the following illustration.



3. The area that would receive the most precipitation would be

   (A) A
   (B) B
   (C) C
   (D) D
   (E) E

4. The rain shadow effect would be located at point

   (A) A
   (B) B
   (C) C
   (D) D
   (E) E

5. Of the freshwater on Earth that is not trapped in snow packs or glaciers, most of it (95%) is trapped in

   (A) lakes
   (B) rivers
   (C) aquifers
   (D) dams
   (E) estuaries, marshes, and bogs

6. Freshwater is primarily used for

   (A) industry
   (B) domestic use
   (C) fishing
   (D) agriculture
   (E) landscaping

7. A mixture of freshwater and saltwater is known as

   (A) brackish water
   (B) gray water
   (C) black water
   (D) connate water
   (E) lentic water

8. Which of the following household activities in the United States uses the most water in a year?

   (A) Showering
   (B) Bathing
   (C) Washing clothes
   (D) Landscape watering
   (E) Washing dishes

9. Of the following methods of irrigation, the one that currently conserves the most water is .

   (A) flooding fields
   (B) irrigation channels
   (C) sprinklers
   (D) drip irrigation
   (E) misters

10. Which of the following uses the most water?

    (A) Cooling electrical power plants
    (B) Automobile manufacturing
    (C) Mining
    (D) The food and beverage industry
    (E) Aquaculture

11. A country that would represent large per capita water use would be

    (A) China
    (B) India
    (C) Israel
    (D) United States
    (E) Iceland

12. When compared with the rate of population growth, the worldwide demand rate for water is

    (A) about half
    (B) about the same
    (C) about two times
    (D) about ten times
    (E) about twenty times

13. The U.S. per capita use of water on a daily basis is closest to

    (A) 50 gallons
    (B) 100 gallons
    (C) 1,500 gallons
    (D) 5,000 gallons
    (E) 10,000 gallons

14. Countries that are more likely to suffer from water stress would be located in

    (A) North America
    (B) South America
    (C) western Europe
    (D) the Middle East
    (E) Asia

15. What fraction of the world's population does not have access to adequate amounts of safe drinking water?

    (A) 1/2
    (B) 1/3
    (C) 1/4
    (D) 1/6
    (E) 1/10

16. The boundary between the saturated zone and the unsaturated zone in an unconfined aquifier is called the _____.

(A) water table
(B) artesian well
(C) confined zone
(D) mid-saturated zone
(E) porous zone

17. "Hard" water contains large amounts of _____.

(A) lead
(B) iron
(C) calcium
(D) soil particles
(E) sulfur

18. What percentage of Earth's water is freshwater?

(A) Less than 1%
(B) About 3%
(C) About 10%
(D) About 25%
(E) 52%

19. Which of the following ocean currents flows without obstruction or barriers around Earth?

(A) Gulf Stream
(B) California Current
(C) Antarctic Circumpolar Current
(D) Aghulas Current
(E) They all flow unimpeded.

20. Saltwater intrusion into groundwater occurs most often when

(A) the water table near the coast drops due to the over-pumping of groundwater
(B) surface salts from irrigation water seep into the ground
(C) storms at sea create unusually low tides
(D) less surface water reaches the water table
(E) saltwater is pumped into aquifers to replenish water tables

FREE-RESPONSE QUESTION

An APES class visited a local freshwater stream near their high school and performed several tests to determine the water quality of the stream.

(a) Choose ONE test of water quality. For that test, provide

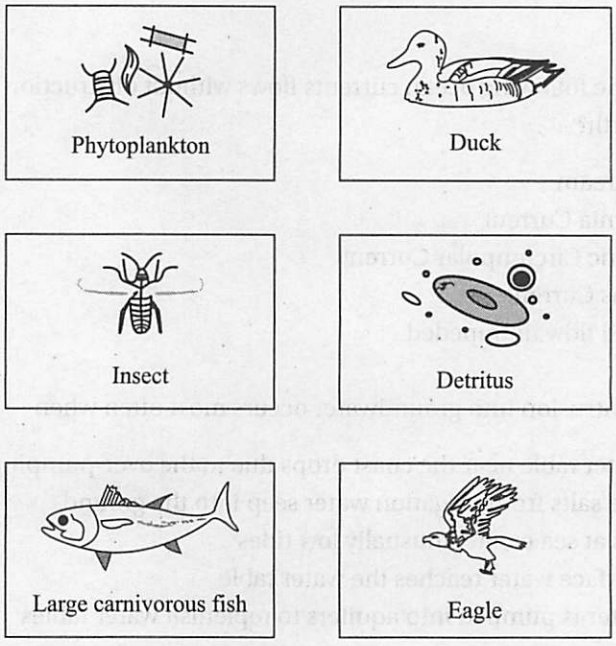
- (i) A description of exactly what that water quality test measures
- (ii) A brief explanation of how that test is performed
- (iii) How the results of that test are interpreted and how they relate to overall water quality

(b) Assume that the results of the water quality test that you chose in (a) are such that they are negatively impacting stream water quality. Describe ONE remediation technique that could be used to reduce the environmental impact.

(c) What are indicator species and how are they used to assess environmental quality?

(d) Provide a specific example of an indicator species that lives in a freshwater or riparian ecosystem and how it functions in its role as an indicator species.

(e) Freshwater wetlands are highly productive ecosystems with complex food webs. Complete the diagram of the freshwater food web below by drawing arrows that show a possible direction of energy flow.



MULTIPLE-CHOICE ANSWERS AND EXPLANATIONS

1. **(C)** When liquid water is cooled, it contracts like one would expect until a temperature of approximately 39°F (4°C) is reached. After that, it expands slightly until it reaches the freezing point, and then when it freezes, it expands by approximately 9%.

2. **(A)** Positive feedback loops enhance or amplify changes, tending to move a system away from its equilibrium state and make it more unstable. Negative feedback loops tend to dampen or buffer changes, which tends to hold a system to some equilibrium state, making it more stable. In this case, legislation that makes it easier or more cost-effective to use water for thirsty crops would increase the demand for water.

3. **(C)** As the air lifts (orographic lifting), it becomes cooler. Cooler air holds less water vapor. At location C, the air is holding the maximum amount of water vapor. Given the fact that the temperature has decreased, it would receive the maximum amount of rain. At the top of the mountain at location D, much of the water vapor has been depleted from the air.

4. **(E)** Point E is on the leeward side of the mountain. This side receives little precipitation because most of the rain has been deposited on the windward side. The leeward side is experiencing the rain shadow effect.

5. **(C)** The oceans hold 97% of all water on Earth. Freshwater only makes up 3%. Of that 3%, 90% of it is trapped in ice and snow, which is rapidly melting due to global warming. Of the freshwater left, the majority is found in groundwater, with the remaining 3% of freshwater found in lakes, rivers, and streams. Of the total amount of water on Earth, only 0.01% is located in lakes, rivers, and streams.

6. **(D)** Agriculture uses about 70% of all freshwater. Use for agriculture depends upon national wealth, climate, and degree of industrialization. Industry uses about 25% of all freshwater, with Europe using the most and developing countries using the least. Water used for cooling of power plants is the largest sector.

7. **(A)** Gray water is sewage water that does not contain toilet wastes. Black water is sewage that does contain toilet wastes. Connate water is also known as fossil water and is water that has been trapped within sediment or rock structures at the time the rock was formed. Lentic water is the standing water of lakes, marshes, ponds, and swamps.

8. **(D)** Up to 50% of household water is used for landscaping purposes and 50% of that water is lost to water runoff and evaporation. Awareness of freshwater resource shortages brought on by recent droughts, which have resulted in higher water bills in many areas of the United States, has resulted in greater use of water-conservation steps such as low-flow toilets, water flow restrictors, xeriscaping, drip irrigation, and odd-even landscape watering requirements.

9. **(D)** Drip irrigation can increase yields and decrease water requirements and labor. It provides the plant with continuous, near-optimal soil moisture by conducting water directly to the plant. It saves water because only the plant's root zone receives moisture.

10. **(A)** Industry used about 25% of all freshwater, ranging from 75% in Europe to less than 5% in developing countries.

11. **(D)** Highest per capita supplies of freshwater are in countries with high rainfall and small populations, e.g., Iceland and Norway. These water-rich countries have low water withdrawals. Remember, *per capita* means "per person."

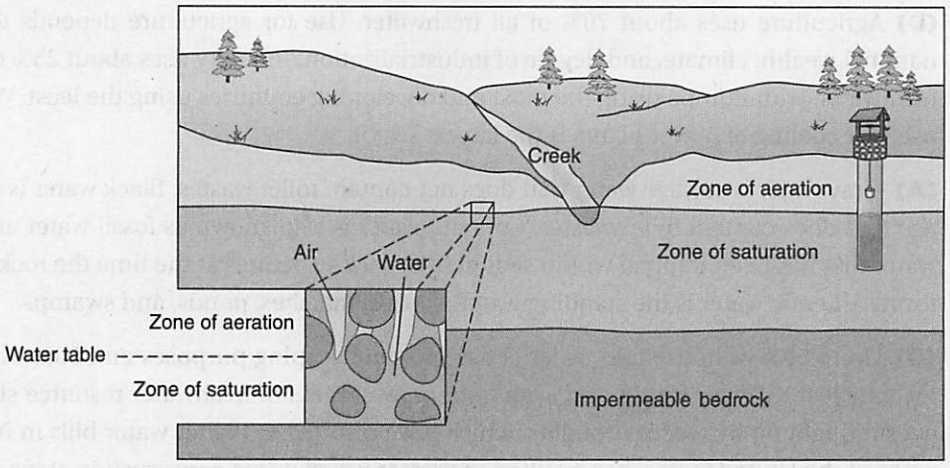
12. **(C)** Since populations are increasing and increased populations result in higher levels of pollution and since freshwater sources are finite, the amount of freshwater per person is decreasing each year.

13. **(C)** In the United States, renewable or replacement water averages 2.4 million gallons (9 million L) per person per year. The average amount withdrawn from water supplies in the United States is about 500,000 gallons (1.9 million L) per person per year (1,500 gallons [5,700 L] per day).

14. **(D)** Areas that do not receive as much precipitation include polar regions (cold air cannot hold as much water as warmer air), mid-continental areas (they are too far from oceans and the clouds have released much of their moisture before they reach inland), subtropical deserts (air masses are subsiding), and the leeward sides of mountains near coastal regions (rain shadow effect).

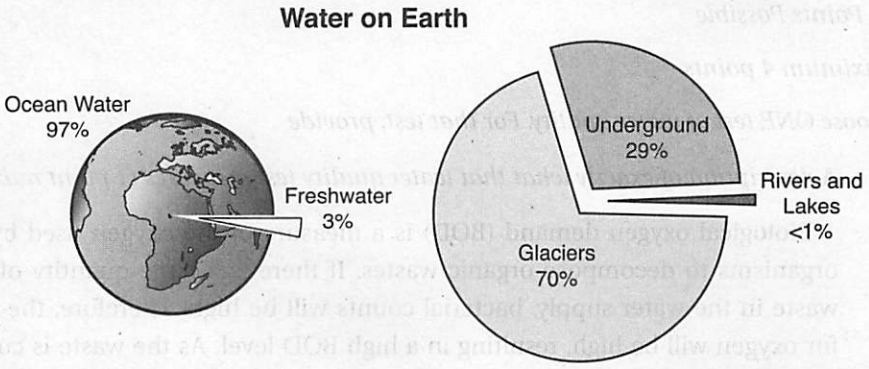
15. **(D)** It is estimated that over 1 billion people lack access to safe drinking water. A child dies every 8 seconds worldwide from contaminated water sources (over 5 million children each year).

16. **(A)** The saturated zone is the area in an aquifer, below the water table, in which relatively all pores and fractures are saturated with water. The unsaturated zone is the part of the subsurface between the land surface and the groundwater table. The boundary between these two zones is known as the water table.



17. **(C)** Hard water is formed when water percolates through deposits of limestone and chalk, which are largely made up of calcium and magnesium carbonates.

18. **(B)**



19. **(C)** The Antarctic Circumpolar Current is the most powerful ocean current system on Earth and exerts a strong influence on climate. It circles Earth in the Southern Hemisphere and connects the three great ocean basins—Atlantic, Indian, and Pacific. Unlike in the Northern Hemisphere, there are no landmasses to break up this large, continuous stretch of water.

20. **(A)** Normally, the groundwater underlying coastal regions has an upper layer of freshwater with saltwater beneath it. The layering occurs because rain, falling as freshwater, is less dense than saltwater. When freshwater is withdrawn at a faster rate than it can be replenished, a drawdown of the water table occurs, with a resulting decrease in the overall hydrostatic pressure. When this happens near an ocean coastal area, saltwater from the ocean intrudes into the freshwater aquifer.

FREE-RESPONSE ANSWER

10 Total Points Possible

(a) Maximum 4 points

Choose ONE test of water quality. For that test, provide

(i) *A description of exactly what that water quality test measures (1 point maximum)*

Biological oxygen demand (BOD) is a measure of the oxygen used by microorganisms to decompose organic wastes. If there is a large quantity of organic waste in the water supply, bacterial counts will be high. Therefore, the demand for oxygen will be high, resulting in a high BOD level. As the waste is consumed or dispersed through the water, BOD levels will begin to decline. Nitrates and phosphates in a body of water can also contribute to high BOD levels. Nitrates and phosphates are plant nutrients and can cause plant life and algae to grow quickly. When plants grow quickly, they also die quickly. This contributes to the organic waste in the water, which is then decomposed by bacteria—resulting in a high BOD level. When BOD levels are high, dissolved oxygen (DO) levels decrease because the oxygen that is available in the water is being consumed by the bacteria. Because less dissolved oxygen is available in the water, fish and other aquatic organisms may not survive.

(ii) *A brief explanation of how that test is performed (1 point maximum)*

The BOD test takes five days to complete and is performed using a dissolved oxygen test kit. The BOD level is determined by comparing the DO level of a water sample taken immediately with the DO level of a water sample that has been incubated in the dark for five days. The difference between the two DO levels represents the amount of oxygen required for the decomposition of any organic material in the sample and is a good approximation of the BOD level.

(iii) *Explain how the results of that test are interpreted (1 point maximum) and explain how the test results relate to overall water quality (1 point maximum)*

BOD levels of 1–2 ppm are indicative of good water quality without much organic waste present in the water supply. A water supply with a BOD level of 3–5 ppm is considered moderately clean. In water with a BOD level of 6–9 ppm, the water is considered somewhat polluted because there is usually organic matter present, and bacteria are decomposing this waste. At BOD levels of 10 ppm or greater, the water supply is considered very polluted with organic wastes. At these BOD levels, organisms that are more tolerant of lower dissolved oxygen may appear and become numerous (such as leeches and sludge worms). Organisms that need higher oxygen levels (like caddis fly larvae and mayfly nymphs) will not survive.

(b) *Maximum 1 point.*

Describe ONE remediation technique that could be used to reduce the environmental impact. (1 point maximum)

High BOD usually indicates the presence of organic waste(s) in the water. The first step in reducing the environmental impact of low dissolved oxygen content in the water is to identify the source of the waste. By carefully testing various sites along the stream, it may be possible to identify exactly the source of the organic pollution, i.e., leaking sewer line, leaking septic tank, discharge from a factory, runoff from a cattle feedlot, etc. Once the source has been identified, some options are available: (1) contact the polluter and let them know your results and/or (2) contact local, state, or national authorities. If the source of pollution is a point-source such as a leak in a sewer line, this can generally be easily corrected. However, non-point pollution sources such as agricultural runoff may be more difficult to locate and identify. However, remediation techniques could involve changes in: the type of fertilizer being used and its application; erosion and sediment control techniques; changes in animal feeding operations; changes in cattle grazing management; and/or changes in irrigation water management.

(c) *Maximum 2 points total*

Describe what indicator species are (1 point maximum) and describe how they are used to assess environmental quality in a freshwater ecosystem. (1 point maximum)

Indicator species are species whose presence, absence, or relative well-being in a given environment is a sign of the overall health of the ecosystem. By monitoring the condition and behavior of an indicator species, scientists can determine how changes in the environment are likely to affect other species that are more difficult to study.

Human activities that alter a watershed and interfere with the natural processes of a stream have immediate as well as long-lasting effects on the animals that live in that stream. Freshwater macroinvertebrates in a stream provide the best indicators of that stream's overall health and ecological condition.

Freshwater macroinvertebrates represent an enormous diversity of body shapes, survival strategies, and adaptations. Many of them require clear, cool water, adequate oxygen, stable water flows, and a steady source of food in order to complete their life cycles. In turn, they provide food for trout, salmon, herons, kingfishers, and higher trophic levels in the food chain. High biodiversity (or taxa richness) indicates a healthy site with low human influence.

(d) *Maximum 2 points*

Provide a specific example of an indicator species that lives in a freshwater or riparian ecosystem (1 point maximum) and how it functions in its role as an indicator species. (1 point maximum)

Freshwater macroinvertebrates such as stoneflies, mayflies, and caddisflies are some examples of indicator species that live in freshwater or riparian ecosystems and are good indicators of a stream's overall health and ecological condition. Stoneflies spend the majority of their lives as nymphs. Many species require a high concentration of

dissolved oxygen and are found in clean swift streams with gravel or stone bottoms and their presence indicates relatively high oxygen content in the water.

(e) *Maximum 1 point*

ALL boxes must have at least one connecting arrow and no points are earned if ANY arrows are incorrect. (1 point maximum)