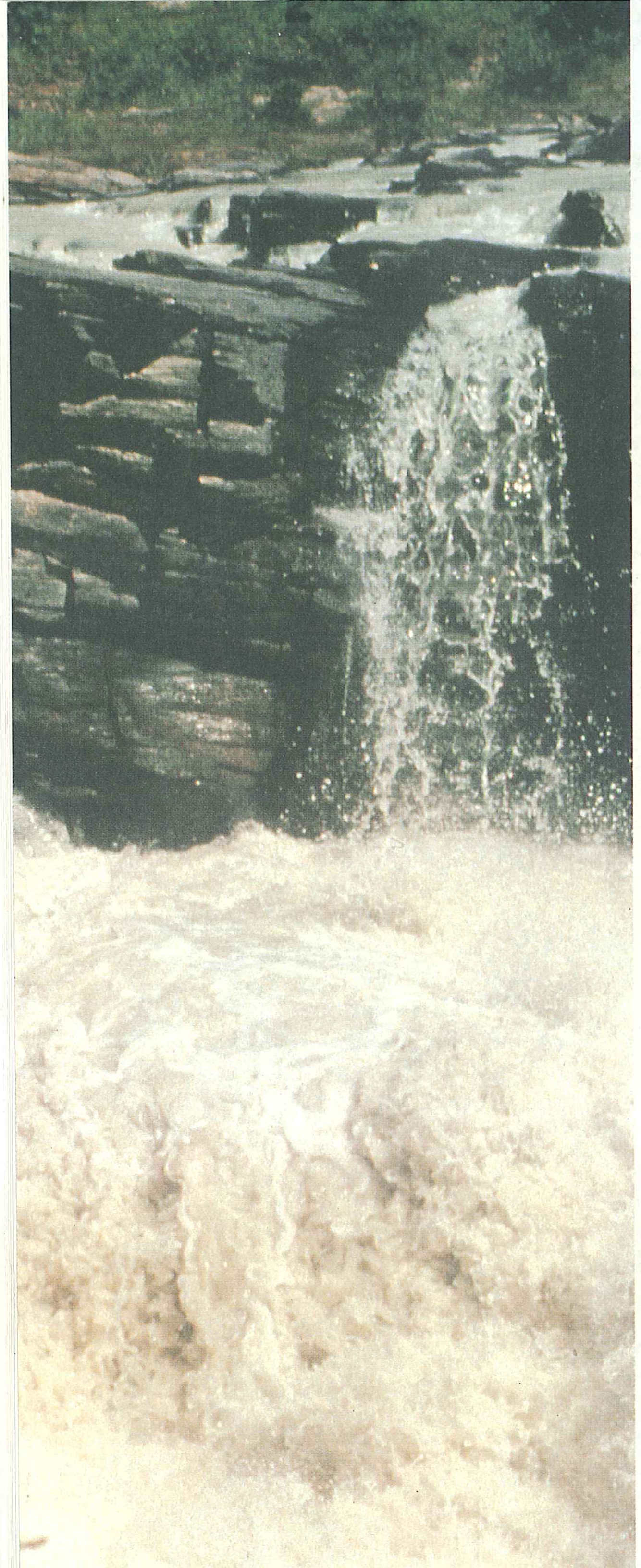

Introduction

The **hydrosphere** is that part of our planet where water, in its varied forms, is found. Water makes our planet distinct from all the others in the solar system. It shapes and reshapes the earth's surface, wearing down mountains, transporting sediments, and building new rock layers under the oceans. We use water as an energy source, for transportation, for recreation, and to irrigate our crops. In fact, water is the basis of all life as we know it. Increasingly, we are beginning to appreciate that water is among the most valuable of our natural resources, a resource that needs to be understood, protected, and conserved.

10•1 The Hydrologic Cycle

Figure 10.1 illustrates the location of water on the earth and gives average values for the amount of water found in each location at any time. While these values are relatively constant, the water itself frequently changes location, state, and chemical makeup.

The **hydrologic cycle** refers to the movement of water through the hydrosphere. The hydrologic cycle is a closed cascading system because water is neither added nor taken away from the system. (See Figure 10.2.)

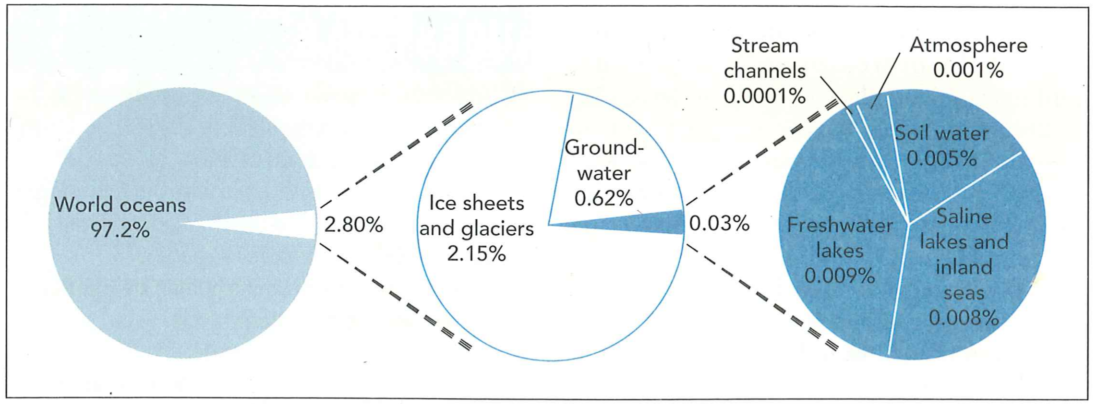

Figure 10.1 The Location of the Earth's Water

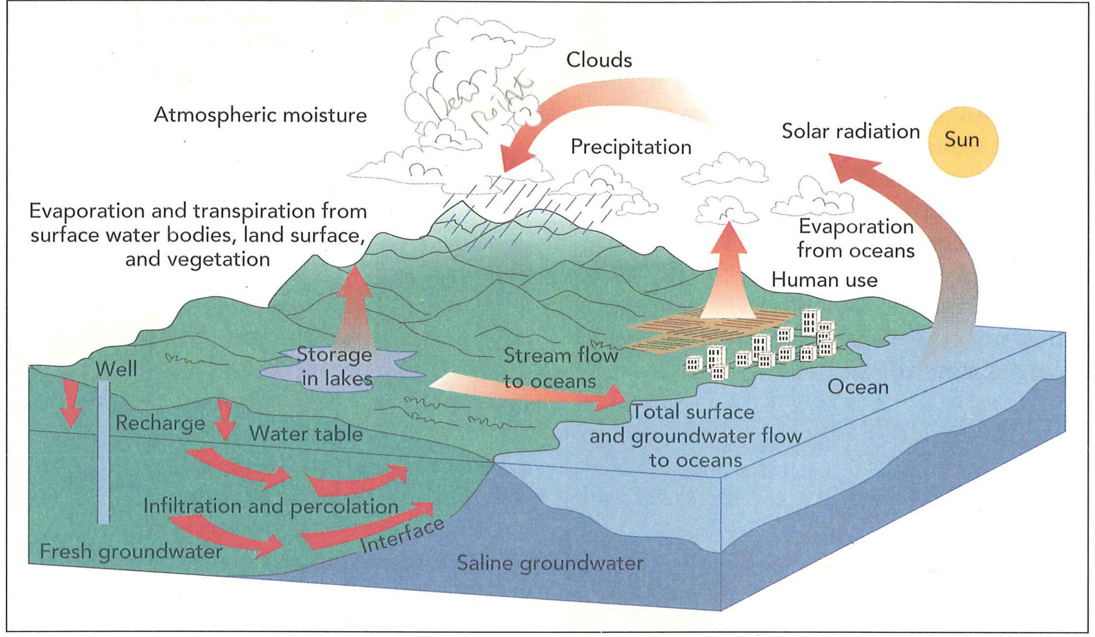

Figure 10.2 The Hydrologic Cycle

Storehouse	Average Time of Storage
Oceans	two thousand to four thousand years and more
Atmosphere	eight to ten days
Groundwater	from days to tens of thousands of years
Soil water	two weeks to a year
Lakes	a few days to many years
Rivers	two weeks
Glaciers and ice caps	ten to thousands of years

Figure 10.3 Storage Times in the Hydrologic Cycle

The journey of a molecule of water through the hydrologic cycle might take centuries or even longer to complete. The cycle is triggered by the evaporation of water from the earth's oceans, lakes, and rivers. This evaporation is made possible by the input of energy from our sun. Each place in the hydrologic cycle is a storehouse which "holds" its supply of water for various periods of time. Figure 10.3 gives the average length of time that a molecule of water spends in each of the storehouses in the hydrologic cycle. The physical properties or chemical makeup of water can vary from storehouse to storehouse and even within one storehouse. For example, water in the ground and in our oceans, lakes, and rivers is in a liquid state. In the atmosphere, water is present as an invisible gas — water vapour — and for short periods as a liquid or solid as it falls out of the atmosphere. The ice caps and ice sheets of the world contain water in a solid state. Energy is either consumed or released as the water changes state (Figure 10.4).

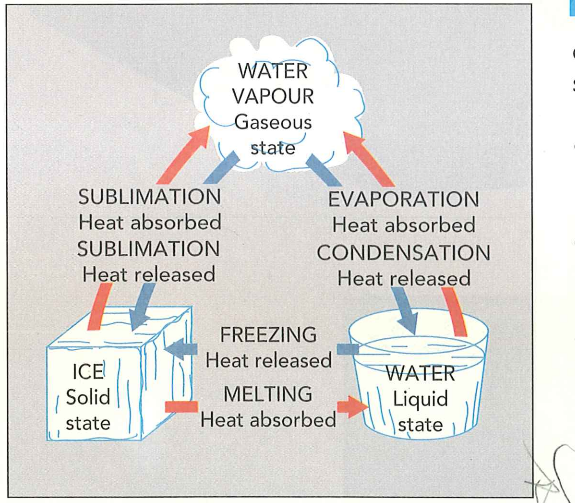

Figure 10.4 Changes of State of Water

QUESTIONS

1. Which storehouses of water do you come in contact with on a regular basis? How do these storehouses affect your life?
2. In your own words, explain why the hydrologic cycle is considered to be a closed cascading system. Refer to Chapter 1, page 8.
3. a) List three ways in which human beings have changed the hydrologic cycle.
   b) Briefly explain each change.
4. How might the hydrologic cycle be affected if the net radiation available at the earth's surface were dramatically increased? Consider each of the storehouses of water in your answer.

10·2 Saltwater Storehouses: The Earth's Oceans

Since the oceans of the world contain 97 percent of the planet's water, they can be thought of as the primary reservoir or storehouse for the hydrologic cycle. The following facts about the earth's oceans give some indication of the size of this saltwater storehouse.

- The oceans have an average depth of 3800 m and cover approximately 71 percent of the earth's surface.
- The deepest trenches in the oceans plunge over 11 000 m downwards and could easily swallow Mount Everest.
- The total volume of water contained in the world's oceans approaches one and a half billion cubic kilometres.
- By far the most common landscapes on earth are those associated with the **abyssal plain**, the huge bottom regions of the oceans.

It's a Fact. . .

The water in the Marianas Trench in the Pacific Ocean reaches a depth of 11 000 m, which is over 2000 m greater than the height of Mount Everest.

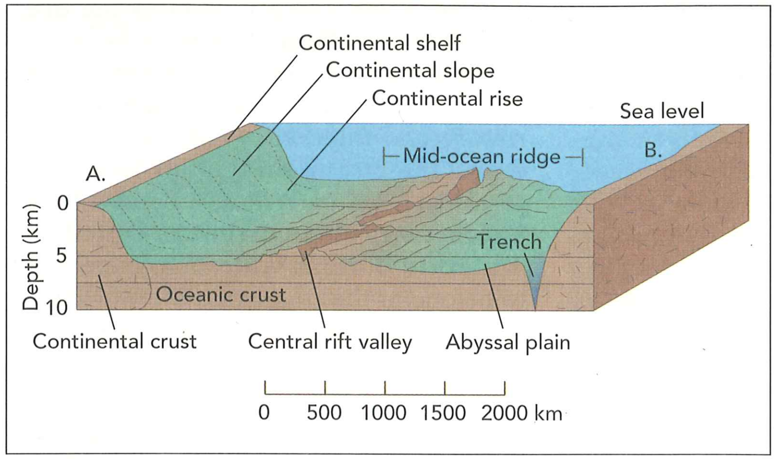

Figure 10.5 **Simplified Diagram Showing the Major Features of the Ocean Floor** The ocean bottom is not the flat, uninterrupted plain we once believed it to be. Flat areas of the abyssal plain are interrupted by mountain ranges, trenches, and by mid-oceanic ridge systems that formed when two of the earth's plates moved away from one another.

The world's oceans contain salt water — a complex mixture of water and at least 80 other chemical elements. In addition to the elements of hydrogen and oxygen which make up the water itself, eight other elements (chlorine, sodium, magnesium, sulphur, calcium, potassium, bromine, and carbon) are of prime importance. Many of these elements combine to form chemical compounds called **salts**, the most common of which are sodium chloride, magnesium chloride, and sodium sulphate. (See Figure 10.6.) These elements and compounds are carried into the oceans by rivers. Over time, they accumulate and increase the salinity of the water. **Salinity** refers to the total weight of dissolved salts. The average salinity of sea water is 3.5 percent, or 35 000 parts per million; however, the salinity can vary due to temperature and location. In areas of high evaporation and low rainfall, such as the Red Sea, salinity values exceed 4 percent. In seas which have colder water and a greater input of fresh water, such as the Baltic Sea, the salinity can be less than 1 percent.

Name of Salt	Chemical Formula	Grams of Salt per 1000 g of Water
Sodium chloride	$NaCl$	23.0
Magnesium chloride	$MgCl$	5.0
Sodium sulphate	Na_2SO_4	4.0
Calcium chloride	$CaCl_2$	1.0
Potassium chloride	KCl	0.7
With other minor ingredients to total		34.5

Figure 10.6 Composition of Seawater

Variations in salinity combined with the variations in water temperatures give rise to two distinctive zones in the oceans. The upper zone, heated by sunlight, is distinct from the lower zone, in which the water is much colder and more dense. The boundary between the two zones — the **thermocline** — usually begins at a depth of about one kilometre. The characteristics of these two zones are so different that there is only a very limited exchange of water between them. Some recent estimates by oceanographers suggest that a molecule of water, on average, remains for a thousand years in the deeper ocean zone before it moves into the warmer, more active surface zone.

8•5

The study of the oceans is made more complex by the constant movement of water through them. Ocean currents are relatively shallow flows of water usually found in the upper 1000 m of ocean water. They are of prime importance in distributing heat from equatorial zones to mid-latitude and polar areas. But this surface flow cannot take place without a counterbalancing replacement flow of water; this deep water circulation occurs in oceans at depths below 1000 m, carrying cold, dense water towards the equator. Figure 10.7 illustrates the deep water circulation that occurs in the world's oceans. Figure 8.18 (page 149) showed the warmer surface flows. In Antarctica, the dense, cold water flows down the continental shelf to form a great deep-sea current at a depth of four kilometres. This current is called the **Antarctic Bottom Water** and is believed to be one of the triggers to the worldwide circulation of water in the oceans. The **North Atlantic Deep Water Current**, in the northern hemisphere, has a similar effect. It carries a flow of water 20 times that of all the freshwater rivers in the world combined. Deep water flows in the ocean combine with the surface flows and with the global wind systems to distribute heat over the globe.

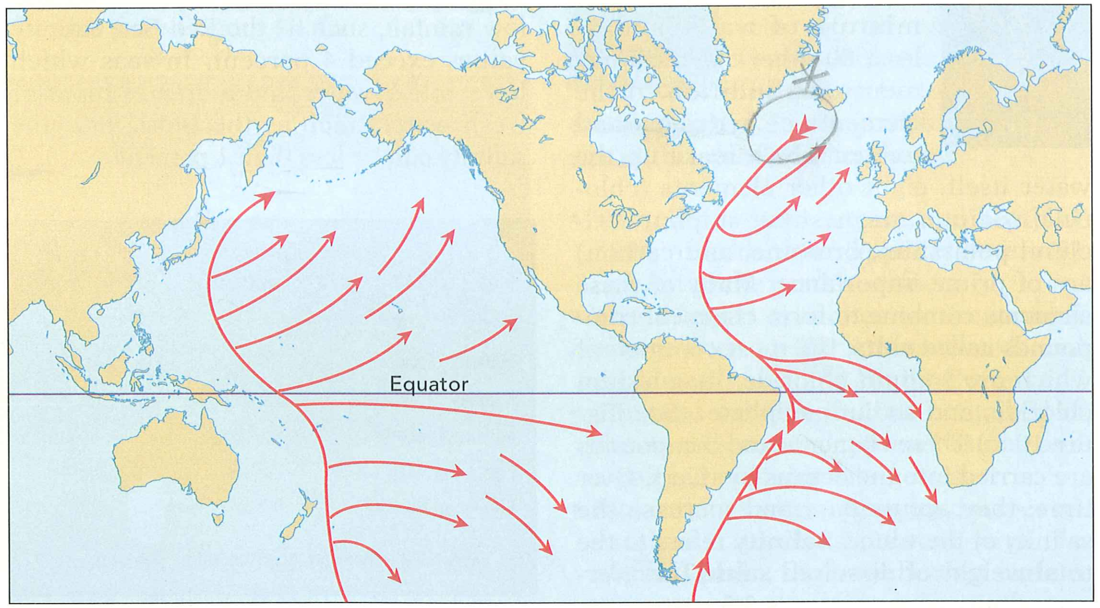

Figure 10.7 Deep Water Circulation

11•3/11•4

The abundant life of the ocean's ecosystems is concentrated in the continental shelf and slope areas along the edges of land masses. In these areas, minerals and nutrients are fed into the water by run-off from the adjacent land masses. Sunlight penetrates most of the way to the bottom and provides energy for photosynthesis. Microscopic plants and animals thrive here forming the basis for rich food chains. However, we are just beginning to explore the ocean's depths and a great deal is yet to be learned concerning the deeper areas of the oceans. For example, in 1960 when scientists explored the dark, cold waters of the Marianas Trench in the bathyscaphe Trieste, their spotlights revealed a fish at a depth of almost 11 000 m. Until this voyage it was thought that no life could exist at such depths. Recently, more evidence has emerged of rich ecosystems existing around, and depending upon, ocean vents, which emit hot gases and heat, providing the energy and nutrients for life forms. These, and other explorations, are leading to new understandings of the ocean storehouses of water.

QUESTIONS

5. Viewed from a satellite the earth is really not earth at all, as its surface is primarily water. Suggest two other names for our planet other than "earth".
6. Use an atlas to list the eight largest saltwater bodies found on the earth's surface. Record your list in order from largest to smallest.
7. Ocean levels have fluctuated a great deal throughout geologic history. Use a physical map of the world from an atlas to identify those areas of the coasts that would be flooded if sea level were to rise by 100 m. Shade this area on an outline map of the world.
8. Examine Figures 10.7 and 8.18. What patterns, similarities, or differences can you observe between these two maps of ocean currents?

10·3 Freshwater Storehouses

Glaciers and Ice Sheets

16•2

Seventy-five to seventy-seven percent of all the fresh water on earth is frozen in glaciers and ice sheets. Most of this water, approximately 96 percent, is found in the earth's two major ice sheets, one located on the island of Greenland and the other located in Antarctica. The Antarctic ice sheet reaches depths of over three kilometres and covers 13 million km^2. Attached to the Antarctic ice sheet are a number of ice shelves. An ice shelf is a large mass of ice, part of which is anchored to land and part of which is floating. The largest is the Ross ice shelf, with a surface area of over 500 000 km^2. It is feared that a warming of the earth's climate might cause the

Ross ice shelf to slip off the land mass of Antarctica into the ocean, causing a global rise in sea level.

In comparison with Antarctica, Greenland's ice sheet appears small. However, the Greenland ice sheet contains over 8 percent of the earth's fresh water and covers an area twice the size of Ontario. As with the Antarctic sheet, the depth of the ice on Greenland exceeds three kilometres in places.

The remainder of earth's frozen water is locked up in alpine glaciers found in many of the world's mountainous areas. Glaciers and glaciation are discussed in Chapter 13.

Groundwater

The second most important freshwater storehouse in terms of volume is **groundwater** — water found beneath the earth's surface. This means of storage contains 22 to 24 percent of the earth's fresh water. Some of this groundwater is found at very shallow depths and remains in the soil or rock for only very short periods of time. This water often seeps into rivers and lakes to become part of the surface flow or is used by vegetation. Most of the groundwater, however, is located at depths below 600 m and can remain in the earth's crust for thousands of years.

The **water table** is the level beneath the earth's surface below which the soil and rock are saturated with groundwater. At this level, all the pores and air spaces are full of water. The depth of the water table varies with the climate of an area and the properties of the bedrock. In areas that have humid climates and where impermeable rock layers are found near the earth's surface, the water table can be as shallow as one metre, while in areas of permeable rock and dry climates, the distance below the surface to the water table can exceed several hundred metres. This combination makes it difficult and expensive to access groundwater for surface use. Sometimes the geological structure assists rather than hinders the extraction of groundwater. Alternate layers of permeable and impermeable rock can give rise to artesian springs. (See Figure 10.8.)

Aquifers are important storehouses for fresh water deep in the earth's crust. These are underground layers of porous and permeable rock through which water moves easily. The United States obtains one quarter of its freshwater supply from a network of underground aquifers, taking out of the groundwater which has been held in the earth for thousands or even millions of years. One such aquifer is the Ogallala, which supplies New Mexico, Texas, Wyoming, Colorado, Oklahoma, and Kansas with much of their freshwater needs. Underlying an area of over 550 000 km^2 and at depths ranging from 400 to 1800 m, the water contained in the Ogallala is being consumed 50 times faster than nature can replace it. In some areas, the ground has sunk and wide trenches have formed as the water was removed from underground. Some estimates suggest that 40 percent of the water stored in the Ogallala has already been consumed and that the remaining amount will be reduced by a further 40 percent over the next 30 years. Tens of millions of

It's a Fact...

On a per capita basis, Canada has twice as much fresh water available than any other country in the world. In absolute amounts, Brazil has the most available fresh water in the world.

It's a Fact...

The words "permeability" and "porosity" are often misunderstood. Porosity refers to the percentage of the total volume of rock that is occupied by openings, whereas permeability refers to the ability of the rock to transmit water. The two terms have no direct relationship to one another. A rock might be porous, but the pores might be small and not connected; therefore, the permeability might be low. If the pores are large and are interconnected, then the permeability will be high.

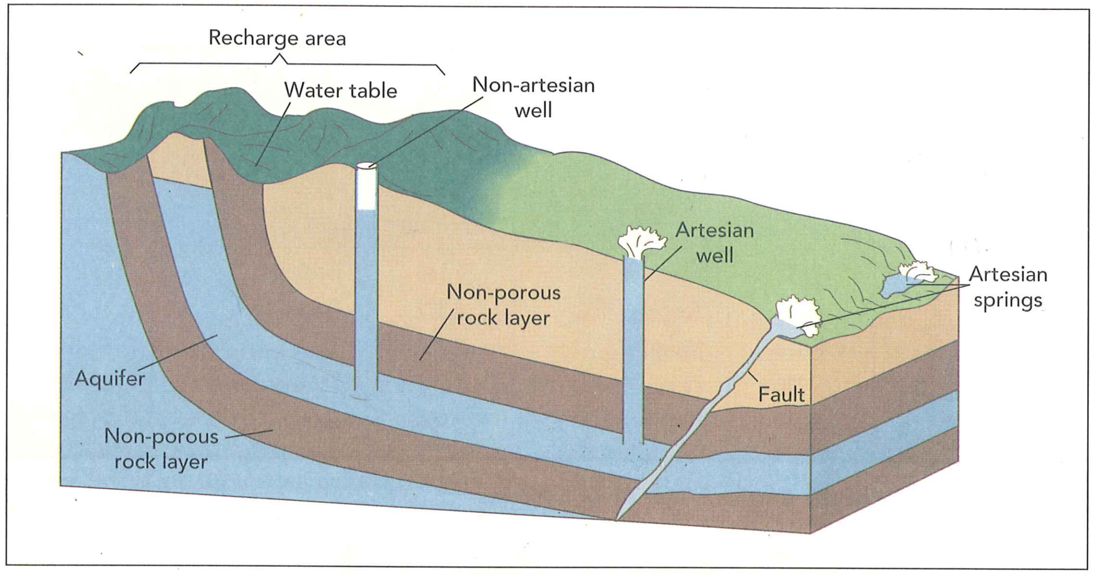

Figure 10.8 **Artesian Wells, Artesian Springs, and Aquifers** Two conditions are necessary for an artesian system: a confined aquifer and water pressure sufficient to make the water in a well or spring rise above the aquifer. The water in a non-artesian well rises to the same height as the water table in the recharge area. In the artesian well, water flows out at the surface without pumping due to the water pressure built up in the aquifer.

people and a very significant percentage of America's agriculture is dependent on an aquifer which is rapidly disappearing.

Rivers and Lakes

Although the earth's rivers and lakes are the most visible of the freshwater storehouses, and the ones which most often directly affect our lives, they represent less than one half of one percent of the planet's fresh water. In addition to being perhaps the most important of the earth's sculptors, rivers provide us with hydro-electricity, transportation routes, recreational waterways and, in some cultures, with religious symbols. All the rivers in Canada discharge approximately 68 000 m^3 of water a second into the world's oceans, with two river systems, the St. Lawrence and the Mackenzie, accounting for a third of this total.

Lakes occupy natural and human-made depressions in the earth's crust. They can range from small ponds to huge water bodies which rival the earth's seas in size and importance.

The Great Lakes of North America hold close to 20 percent of the world's freshwater supply found in lakes and rivers. Most of the lakes in Canada were filled with glacial meltwater some 10 000 years ago. The input of ground, atmospheric, and river water into these lakes today has established an equilibrium with the amount flowing and evaporating out of the lakes. Careful management of our fresh waters is vital.

Ranked by Length		Ranked by Drainage Basin		Ranked by Discharge	
River	Length (km)	River	Area of Drainage Basin (1000 km^2)	River	Discharge (m^3/s)
Nile	6 690	Amazon	6 150	Amazon	175 000
Amazon	6 570	Congo	3 822	Congo	39 000
Mississippi	6 020	Mississippi	3 230	Negro	35 000
Yangtze	5 980	Plata	3 100	Yangtze	32 190
Yenisey	5 870	Ob-Irtysh	2 990	Orinoco	25 200

Figure 10.9a Some of the Earth's Major River Systems

River	Length (km)	Area of Drainage Basin (1000 km^2)	Discharge (m^3/s)
St. Lawrence	3 460	1 463	14 160
Mackenzie	4 063	1 766	7 930
Yukon	3 380	855	5 098

Figure 10.9b Major Canadian River Systems

Ranked by Surface Area		Ranked by Volume of Water		Ranked by Depth	
Lake	Area (km^2)	Lake	Volume (km^3)	Lake	Depth (m)
Superior	82 261	Baikal	22 995	Baikal	1 620
Victoria	62 940	Tanganyika	17 827	Tanganyika	1 471
Huron	59 580	Superior	12 258	Malawi	706
Michigan	58 020	Malawi	6 140	Great Slave	614
Tanganyika	32 000	Michigan	4 940	Crater	589

Figure 10.10 The Earth's Major Freshwater Lakes

It's a Fact...

In terms of water use per capita, the United States leads the world with a usage rate of 1986 m^3 annually. Canada is in second place with an annual usage rate of 1172 m^3.

Atmosphere

Although miniscule in terms of the amount of water which it holds, the earth's atmosphere plays a fundamental role in distributing and circulating water through the hydrologic cycle. Without the process of evaporation, virtually all of the earth's water would eventually end up in the oceans. The earth's rivers and lakes would dry up and soil moisture in the important upper levels of the crust would disappear. It is the atmosphere that picks up water from the oceans, lakes, and rivers and transports it to the land. The energy for this process is provided by solar radiation.

Evaporation is the change of state from liquid to vapour, while **condensation** is the change of state from vapour to liquid. Evaporation can be thought of as the starting point for the hydrologic cycle. The amount of evaporation is primarily a function of air temperature; hot air can hold more water vapour than cold air. Figure 10.11 illustrates the effect that the temperature of air has on its ability to hold water vapour. Wind strength, the nature of the surface, and air turbulence are other factors that can influence the evaporation rate.

It's a Fact...

Every year, approximately 453 000 km^3 of water are evaporated from the surfaces of the world's oceans. (1 km^3 = 1 billion m^3 = 1 trillion litres)

The term "humidity" refers to water vapour in the atmosphere. If you collected and weighed all the water vapour contained in a given volume of air, then you would have the **absolute humidity**, which is usually expressed in g/m^3. The amount of water vapour in a given volume of air compared to the maximum amount of water vapour which that air could hold is the **relative humidity** of the air. The relative humidity is a ratio usually expressed as a percentage. A relative humidity reading of 100 percent means that the air is saturated, that is, it is holding all the water vapour that it possibly can at that temperature. Cooler air has less ability to hold water than warm air; thus, if the temperature of an air mass decreases but the amount of water vapour in the air remains the same, the relative humidity will increase. The temperature at which air is saturated is called the condensation or dew point; at this point the air cannot hold any more water vapour. If the temperature of saturated air is lowered, condensation occurs.

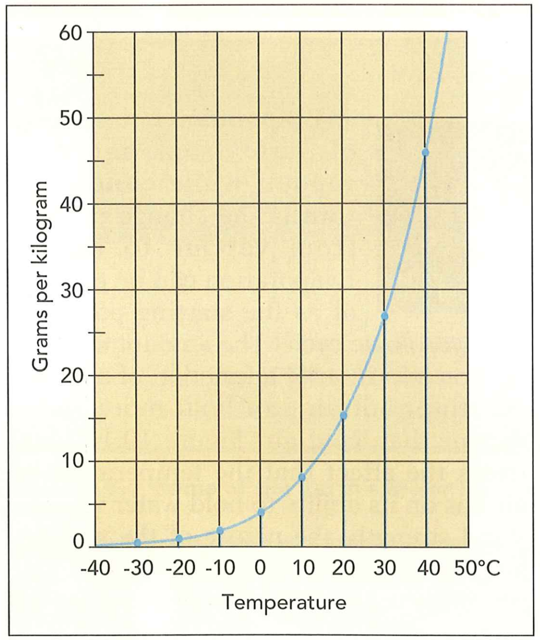

Figure 10.11 Maximum Amount of Water Which a Mass of Air at Various Temperatures Can Hold

Condensation can take many forms. Dew commonly occurs at night as the air temperature falls and water vapour slowly condenses on exposed surfaces. People wearing glasses who move from the cold outdoors to a warm house also experience dew as the cold glass causes the air in contact with it to cool, leading to condensation on the glass. Fog is also a form of condensation and occurs most often when warm, moist air is cooled by coming into contact with a cold surface. Fogs occur regularly in coastal regions where air which originates over a warm current of water contacts colder air found over a cold ocean current and condensation takes place. For example, the dense fogs which form over the Grand Banks off the coast of Newfoundland are the result of the mixing of the air masses associated with the cold Labrador Current and the warmer Gulf Stream. Fogs can also occur due to the cooling that results from the radiation of longwave energy from the earth's surface at night. As the earth cools, the temperature of the air above it drops and condensation occurs.

복사열

In order to condense in the atmosphere, water vapour needs **hygroscopic particles** in the air. Hygroscopic particles are microscopic in size and can be dust, pollen, pollution, salt crystals, or a number of other solid particles that can attract water vapour. Often ice particles form the nuclei around which water vapour condenses. In the case of fogs and clouds, the water vapour droplets do not reach sufficient size to be precipitated out of the atmosphere. When the droplets of water or ice in the clouds become too large and heavy for the air to support, precipitation occurs. The most common forms of precipitation are rain and snow. Hail, sleet, and freezing rain are the other types of precipitation. Raindrops can be as small as 0.5 mm; at this size, precipitation is described as "drizzle". The normal size of raindrops is between 1 and 2 mm. When larger than 5 mm, raindrops become unstable and usually break up.

Snow occurs when atmospheric temperatures are below the freezing point, while sleet, a mixture of rain and snow, often occurs when the air temperature is close to the freezing point. Freezing rain can occur when rain falls through a layer of sub-zero air and is cooled to the point where it can freeze upon contact with a cold surface. Hail is the most damaging form of precipitation. It occurs when strong updrafts of air in thunderstorms transport water droplets upwards where they freeze, grow in size, and fall. This process can occur over and over with the hailstones growing in size each time they are carried upwards. When the hail eventually reaches the earth, it can inflict severe damage on crops and buildings and has been known to injure people.

In recent years, scientists have come to realize that the hydrosphere, and especially the oceans, are of fundamental importance in influencing global systems which involve the energy and chemical balances of the lithosphere, biosphere, and atmosphere. The concept of the oceans as merely large basins or containers of water has been shattered as we gain more knowledge of the crucial role they play in regulating the globe's climate and the atmosphere's chemical composition.

QUESTIONS

9. Fresh, clean water is becoming a scarce resource. List all the ways in which fresh water is used in your home. Identify five conservation methods that could be instituted today in your home in order to reduce the amount of fresh water that your family consumes.
10. Suppose you are the Water Commissioner for the State of Oklahoma. Recent studies have shown you that the Ogallala aquifer is fast being depleted. Suggest five actions that the state could take to reduce the consumption of fresh water from the Ogallala aquifer.
11. One example of the process of condensation is when eye glasses "fog up" when you come into a warm room from the cold outside. Identify three other forms of condensation that you have witnessed or know about. What conditions triggered the condensation?
12. As the temperature of an air mass drops, its ability to retain moisture decreases. Similarly, as the temperature rises, more moisture can be held. Show this relationship in a diagram.