CHAPTER 15

WATER RESOURCES

Summary

1. Water's unique properties include hydrogen bonds with strong forces of attraction, a high boiling point, a high heat capacity, evaporative cooling, an ability to dissolve many compounds, ultraviolet filtering capacity, strong cohesive forces, and expansion on freezing.

2. More than 97% of Earth's water is found in oceans and saline lakes. Approximately 0.01% of the Earth's water supply is available as fresh water. Management of the world's surface water and groundwater is a major 21st century challenge.

3. Irrigation accounts for about 70% of the water used worldwide. In China, 64% of the water withdrawn is used for irrigation; in the United States, about 87% is used for power plant cooling and irrigation combined; in Canada, only 12% is used for irrigation, and 68% is used for power plant cooling. Canada has an abundance of fresh water, but has the highest per capita use. Water problems are increasing, and there is increasing pressure for Canada to sell or share its water.

4. Freshwater shortages are exacerbated by dry climate, droughts, desiccation, and water stress.

5. Solutions for increasing our water supplies include building dams, importing water, using groundwater, desalinizing salt water, and practising water conservation. Advantages of dams and reservoirs include cheap electricity, reduction of downstream flooding, and year-round water for irrigation. Disadvantages include displacement of people and disruption of aquatic systems and the hydrological cycle. Moving large amounts of water from one area to another can transfer stream runoff from water-rich areas to water-poor areas and aid in the irrigation of farmland. It may also cause ecological, economical, and health disasters. Desalination increases the supply of fresh water but is expensive and produces large quantities of salt-rich wastewater.

6. Groundwater can be used for drinking and irrigation, and it has the advantages of local availability, low cost, no evaporation losses, and its potentially renewable nature. Some of the disadvantages of withdrawing groundwater include aquifer depletion from overpumping, subsidence, pollution, saltwater intrusion, and reduced water flow.

7. About 65 to 70% of the Earth's water is wasted through evaporation, leaks, and other losses. We can waste less water by lining canals, levelling fields, irrigating at night or using new irrigation techniques, practising polyculture or organic farming, growing water-efficient crops, using drought-resistant and salt-tolerant crop varieties, irrigating with treated urban wastewater, and importing water-intensive crops and meat.

8. Heavy rain, rapid melting of snow, the removal of vegetation, and the destruction of wetlands cause flooding. Floods frequently occur on floodplains, where people tend to settle because of fertile soil and the availability of irrigation water, transportation, recreation, and flat land that is conducive to building and agriculture.

9. To reduce flood damage, or the risk of flooding, we must avoid building on floodplains, removing water-absorbing vegetation, or draining wetlands.

10. To achieve a more sustainable use of the Earth's water, we must not deplete aquifers and we must preserve aquatic systems and water quality, use integrated watershed management, create agreements among regions and countries sharing surface water resources, use outside party mediation in water disputes between nations, market water

rights, raise water prices, waste less water, decrease government subsidies for supplying water, increase government subsidies for reducing water waste, and slow population growth.

Key Concepts and Learning Outcomes

After completing this chapter, students should be able to answer the following key questions.

15-1 Why Is Water So Important? Liquid Natural Capital

A. Water is important for several reasons.
   1. It keeps us alive.
   2. It sculpts the Earth's surface and moderates the climate.
3. It removes and dilutes wastes and pollutants.

B. Water is one of our most poorly managed resources.
   a. We waste it
   b. We pollute it.
   c. We charge too little for making it available.

15-2 How Much Fresh Water Is Available? Natural Recycling to the Rescue

A. Only about 0.01% of the Earth's water supply is available as fresh water in the soil, or in usable groundwater, water vapour, or lakes and streams; this supply is recycled.
   1. The hydrologic cycle collects, purifies, recycles, and distributes the world's freshwater supply.
   2. Overloading the Earth's water systems with slowly degradable and nondegradable wastes, and withdrawing underground water faster than it is replenished is compromising the hydrologic cycle.
   3. Some countries have more water than they need; some countries have far less.

15-3 What Is Surface Water? Water on Top

A. Water that does not infiltrate the ground or evaporate into the atmosphere is called surface runoff.
   1. The region from which water drains into a body of water is called its watershed, or drainage basin.
   2. Runoff that is referred to as reliable is stable from one year to the next, and can be counted on for a reliable water supply.

15-4 What Is Groundwater? Water Down Below

A. Water that percolates down through the ground and is stored in pores, fractures, crevices, and other cracks is groundwater, an important freshwater source.
   1. The zone of aeration is close to the surface, and pores and spaces in this zone contain a mixture of air and water.
   2. In the zone of saturation, the spaces in the ground are filled with water.
   3. The water table is located at the top of the zone of saturation.
   4. An aquifer is a water-saturated geological formation made up of sand, gravel, or bedrock.
      a. Fairly watertight layers of rock or clay below the aquifer keep water from seeping out.
      b. Most aquifers recharge very slowly. Groundwater moves from higher to lower elevations.
      c. Natural recharge replenishes an aquifer through the precipitation that percolates down through soil and rock.
      d. Lateral recharge is replenished from nearby streams.
   5. Water mining withdraws water from deep, underground, ancient deposits of water that have little, if any, recharge. These aquifers are considered nonrenewable.

15-5 How Much of the World's Reliable Water Supply Are We Withdrawing? Taking Half Now and More Later

A. Withdrawal is the total amount of water we remove from water bodies or aquifers. Some may be returned to its source.
   1. Water taken from streams to cool power plants is returned to the stream, but the higher water temperature causes thermal pollution downstream from the return, and disrupts aquatic life.
   2. Water that is withdrawn from a source, but is not available for reuse due to evaporation, seepage into soil, contamination, or movement to another area, is called consumptive water.
   3. The world's demand for water now requires 54% of the world's reliable runoff of surface water.
      a. We could be using 70 to 90% by 2025.
      b. In some places, usage rates are exceeding the available reliable runoff.

15-6 How Do We Use the World's Fresh Water? Watering Crops Is Number One

A. Irrigation uses 70% of the fresh water we withdraw from surface water or aquifers.
   1. This produces about 40% of the world's food.
   2. About 85% of this irrigation water is not returned to its water basin.
   3. Industries use 19% of fresh water.
   4. Cities and residencies use 11% of reliable runoff.
   5. The daily minimum amount of water needed to support 75% of the world's people is equal to the amount of water used to irrigate the world's golf courses.

15-7 What Causes Shortage of Fresh Water? Climate and Demand

A. The major water resource problem is too little water.
B. Water scarcity arises from dry climates, drought, dry soil, and too many people using the water supply.
   1. A drought occurs when precipitation is at least 70% lower than usual, and evaporation is higher than normal for more than 21 days.
   2. Desiccation occurs when the soil dries out because of deforestation and overgrazing.
   3. Increasing numbers of people relying on a limited runoff produce a low per capita availability of water, which leads to water stress. Water stress comes when the volume of reliable runoff per capita drops to below 1700 cubic metres per year.
   4. Water scarcity occurs when per capita water availability falls below 1000 cubic metres per year.
   5. Almost 41% of the world's population lives in river basins located in 20 countries that suffer from either water stress or water scarcity. This figure could reach 40 countries by 2020 and 60 countries by 2050.
   6. The volumes of water in some of the world's largest lakes have shrunk by 83 to 92% since 1960, mainly because of withdrawal for irrigation and industry. Periods of prolonged drought in some countries are also a contributing factor.

15-8 How Many of the World's People Do Not Have Access to Enough Fresh Water? Aquatic Inequality

A. A United Nations study found that one in eleven people do not have access to adequate, affordable, and clean water.
   1. Many poor people have no access and/or cannot afford clean water at a reasonable cost.
   2. They suffer from aquatic and/or hydrological inequality.

15-9 How Can We Increase Freshwater Supplies? Withdraw More and Waste Less

A. Freshwater supplies can be increased by building dams to store water for later use, importing water from elsewhere, using groundwater, and utilizing desalination processes.
   1. People in developed countries usually live near water supplies.
   2. People in developing countries must make do with what is available.

3. Water used to keep golf courses green is a significant waste of water: 9.5 million m^3, enough to meet needs of 4.7 million individuals.

15-10 Who Should Own and Manage Freshwater Resources? Government versus Private Ownership

A. Most people believe that everyone has a right to clean water.
   1. Most water resources are owned by governments and managed as publicly owned resources, but a number of governments are hiring private companies to manage water. There have been mixed results, and the lesson learned is that governments need to maintain strict oversight of these contracts.
   2. Many are opposed to privatized water systems because
      a. they feel that water is an important public resource, and
      b. efforts to return the system to public control can lead to severe economic penalties.

15-11 What Are the Advantages and Disadvantages of Large Dams and Reservoirs? Mixed Blessings

A. Dams and reservoirs capture and store runoff water. There are an estimated 800 000 dams that restrict the flow of rivers worldwide.
   1. The water is released to control floods, generate electricity, and irrigate lands.
   2. Reservoirs may also provide for swimming, fishing, and boating.
   3. Dam and reservoir construction displaces people and floods productive land.
      a. Ecological and economic services are impaired in the construction of dams and reservoirs.
      b. About 60% of the world's major river basins are strongly or moderately fragmented and disturbed.
      c. At least 25% of the world's freshwater fish species are threatened or endangered.
      d. Reservoirs behind dams often fill up with silt.
      e. The Aswan Dam in Egypt was built for power generation and irrigation.
         1) Its construction slowed water flow and caused an increase in plants in the water.
         2) Snails also increased in number. They act as an intermediate host for the trematode worm that causes schistosomiasis.
      f. The increase in infected snails has resulted in a greatly increased incidence of the disease in domestic animals and people in contact with the water.
      g. The purpose of the Columbia River Treaty, an agreement between Canada and the United States is to control the flow of the river.
         1) The Columbia is the largest river on the west side of North America, and it has 150 dams.
         2) The treaty aims to avert flood problems in the United States, while generating shared revenues from hydropower and providing water for irrigation
         3) The treaty as led to reduction of river salmon population by 94%.
         4) At the earliest, either country can withdraw in 2024, if notice is given in 2014.

15-12 Can We Correct Nature's Inconvenient Allocation of Water Resources? Perhaps, but Carefully

A. There is a limit to how much water can be taken out of a basin before the disruption of the water cycle causes other ecological problems.
   1. Tunnels, aqueducts, and underground pipes can transfer stream runoff collected by dams and reservoirs from water-rich areas to water-poor areas.
   2. They also create environmental problems. Most of the world's dam projects and large-scale water transfers illustrate the important ecological principle that you cannot do just one thing.
   3. There are almost always a number of unintended environmental consequences (Figure 3-6).

15-13 What Are the Advantages and Disadvantages of Withdrawing Groundwater? Avoid Too Many Straws in the Glass

A. Most aquifers are renewable sources.
   1. Aquifers provide drinking water for about 25% of the world's people.
   2. The advantages of withdrawing groundwater are as follows:
      a. Aquifers are widely available.
      b. There are no evaporation losses.
      c. They are cheaper to extract than most surface waters.
      d. They are renewable sources of water if the
         1) withdrawal rate does not exceed the recharge rate, and
         2) the aquifer does not become contaminated.
   3. The disadvantages of withdrawing groundwater include
      a. falling water tables,
      b. land subsidence,
      c. long-lasting effects if polluted,
      d. saltwater intrusion near coastal areas,
      e. reduced water flows into water bodies, and
      f. increased cost and energy use from deeper wells.
   4. China, India, and the United States are overpumping their aquifers.
   5. Groundwater is being withdrawn at four times its replacement rate in the United States.
      a. The huge Ogallala Aquifer, underlying eight states in the arid high plains, has serious water overdraft problems.
      b. California's Central Valley is suffering from serious groundwater depletion. This area supplies half the country's fruit and vegetable agricultural production.
   6. Saudi Arabia gets 70% of its drinking water from the world's largest desalination complex on its coast.
      a. Deep aquifers supply the rest.
      b. These aquifers are mostly nonrenewable fossil aquifers.
      c. Most irrigated agriculture may disappear within 10 to 20 years.
      d. This overuse of aquifers will
         1) limit food production, and
         2) increase the gap between the rich and poor in some areas.
   7. Withdrawing water from deep aquifers sometimes allows sand and rock to collapse and the land above the aquifer to subside.
      a. Recharge of these compressed aquifers is no longer possible.
      b. Parts of Mexico City, built on a lakebed, have sunk by 8 metres, due to groundwater overdraft.
   8. Sinkholes can form due to excessive groundwater withdrawal.
      a. They form when the roof of a cavern or underground conduit collapses.
      b. They can form suddenly, with no warning.

B. Contamination of aquifers, from saltwater intrusion, occurs along some coastal areas in the United States.

15-14 Can Deep Aquifers Supply More Water? Solution or Pipe Dream?

A. Scientists are evaluating deep aquifers, at depths of 0.8 kilometres, as future water sources.
   1. Seismic and core-drilling techniques are used to locate these large fossil aquifers.
   2. There are two major concerns about tapping fossil aquifers.
      a. The geological and ecological impacts of pumping water from these aquifers are unknown.
      b. There are no international treaties or agreements indicating who has the rights or ownership of the water underlying several different countries.

15-15 How Useful Is Desalination? A Costly Option

A. A different method of producing fresh water is to desalinate water (remove salt) from oceans or brackish groundwater.
   1. One desalination method is distillation. Salt water is heated until it evaporates and condenses as fresh water; the salts are left behind as solids.
      a. Desalination is very expensive because of the amount of energy used.
      b. Large amounts of wastewater, needing disposal, are produced in the desalination process.
   2. Another method of desalination is reverse osmosis, which involves pumping salt water at high pressure through a thin membrane.
   3. Middle Eastern countries produce about 50% of the desalinated water in the world.
   4. Desalination is currently only feasible for water-short wealthy countries.

15-16 Can Cloud Seeding and Towing Icebergs Improve Water Supplies? Solutions or Pipe Dreams?

A. Twenty-five countries, including the United States, have experimented with cloud seeding. Dry ice (or tiny particles of chemicals such as silver iodide) is seeded into clouds to act as nuclei for raindrops.
   1. There is controversy over the use of cloud seeding.
      a. It does not work well in very dry areas because there are few clouds in these regions.
      b. Some reports state that there is no evidence that cloud seeding actually works.
      c. Large amounts of the cloud-seeding chemicals are introduced into soil and water systems, and may harm people, wildlife, and agricultural output.
      d. Seeding has led to legal disputes over the ownership of cloud water.
   2. Some analysts proposed towing icebergs from the Arctic or Antarctica to arid coastal regions.

15-17 What Are the Benefits of Reducing Water Waste? A Win-Win Solution

A. About 65 to 70% of water that we now use is wasted through evaporation, leaks, and other losses.
   1. The World Resources Institute believes that it is technically and economically possible to reduce water losses to 15%.
   2. According to experts, water is wasted for two main reasons.
      a. It is underpriced, mainly due to government subsidies, allowing water to be pumped at below-market prices.
      b. There is a lack of government subsidies for improving the efficiency of water use.

15-18 How Can We Waste Less Irrigation Water? Deliver Water Precisely When and Where Needed

A. Improved irrigation techniques could save water.
   1. Centre-pivot low-pressure sprinkler irrigation directs water onto a crop, rather than flood irrigation, which loses about 40% of the water through evaporation, seepage, and runoff.
   2. Low-energy precision application (LEPA) sprinklers use less water and energy. They spray water closer to the ground, and in larger droplets, than the centre-pivot low-pressure sprinkler.
   3. Surge valves or time-controlled valves on conventional gravity-flow irrigation systems send water down irrigation ditches in pulses, rather than in a continuous stream. This can increase efficiency to 80% and reduce water use by 25%.
   4. Drip irrigation or microirrigation systems are the most efficient ways to supply crops with small amounts of water.
      a. Small holes in a network of perforated plastic tubing deliver drops of water at a slow and steady pace to plant roots.
      b. In drip systems, 90 to 95% of the water reaches the crops.
   5. Many poor farmers cannot afford modern methods of irrigation.

a. In Bangladesh, pedal-powered treadle pumps are used to move water through irrigation ditches.
b. In other areas, buckets or small tanks with holes are used.

15-19 How Can We Waste Less Water in Industry, Homes, and Businesses? Copy Nature, Raise Prices, Improve Efficiency

A. There are many steps that we can take to waste less water in industries, homes, and businesses.
1. We can reduce water use in the following ways.
a. Replace green lawns and ornamental shrubbery with vegetation adapted to the local climate.
1) This practice reduces water use by 30 to 85%.
2) It reduces the amount of labour, fertilizer, and fuel needed.
b. Use drip irrigation and fix water leaks.
c. Raise water prices, use water metres, and charge for all municipal water use.
d. Make conservation a requirement in water-short cities.
e. Use waterless composting toilets.
f. Use water-saving toilets, showerheads and front-loading clothes washers.
g. Collect and reuse household water for irrigating lawns and decorative plants.
h. Purify and reuse water in homes and businesses.

15-20 How Can We Reduce the Use of Water in Removing Industrial and Household Wastes? Changing the Way We Deal with Wastes

A. We cam mimic the way nature deals with wastes.
1. We should not continue the following practices:
a. industrialized countries using drinking-quality water to flush wastes
b. sewage treatment plants removing nutrients, dumping them into water bodies, and overloading aquatic systems with nutrients
c. toxic industrial wastes being flushed into sewers without first removing all the harmful chemicals at treatment plants.
2. Five principles can be used to redesign the way we manage sewage and industrial wastes while saving great quantities of water.
a. Use pollution prevention and waste reduction to decrease industrial wastes.
b. Ban the discharge of industrial toxic wastes into municipal sewer systems.
c. Rely more on waterless composting toilets rather than conventional ones.
d. Return nutrient-rich sludge produced at waste treatment plants to the soil as fertilizer.
e. Shift to new ways to treat sewage that mimic the way nature breaks down and recycles nutrients in organic waste material.

15-21 What Causes Flooding? Rain and People

A. Flooding occurs when heavy rain and snowmelt cause streams to overflow into the adjacent area (the floodplain).
1. People settle on floodplains because
a. the soil is fertile,
b. there is ample water,
c. nearby rivers are used for transportation and recreation, and
d. the land is flat and suitable for crops, buildings, highways, and railroads.
2. Natural benefits of floods include
a. the deposit of nutrient-rich silt after floodwaters recede, and
b. a recharge of the groundwater and wetlands areas.
3. Floods also kill thousands of people and cause great losses through property damage.
a. Floods are usually considered natural disasters, but since the 1960s, several types of human activities have contributed to a sharp rise in deaths and damages. Such activities include
1) the removal of water-absorbing vegetation;

2) the draining of wetlands, which increases the incidence of flooding because wetlands normally absorb floodwaters and reduce the severity of floods, and
3) paving and building on floodplains, which increase the chance of more severe floods.

4. The Red River of Manitoba floods regularly.
   a. A system of channels has helped to reduce many floods.
   b. In 1997, record levels of winter snow accumulation, followed by a spring storm flooded 5% of the farmland in Manitoba.
      1) Six thousand people were evacuated.
      2) The potential for damage remains in any area where settlements are built on floodplains.

15-22 How Can We Reduce Flood Risks? Think about Where You Want to Live

A. Reduce flood risk by controlling river water flows, preserving and restoring wetlands, and identifying and managing flood-prone areas.
   1. Channelization, a process of straightening and deepening streams, reduces upstream flooding, but increases stream velocity and removes bank vegetation.
   2. Levees or floodwalls built along the sides of streams contain and accelerate the stream flow.
      a. These structures increase the possibility for damage downstream.
      b. They do not protect against waters that are unusually high.
         1) In 1993, two-thirds of the levees along the Mississippi were damaged or destroyed.
         2) In 2005, levees were breached in Hurricane Katrina, flooding 80% of New Orleans.
   3. Building dams can also reduce the threat of flooding by storing water in a reservoir for later slow release.
   4. Preserving existing wetlands and restoring degraded wetlands preserves natural flood control.
   5. Identifying and managing flood-prone areas helps to reduce flood damage.
   6. Use of the precautionary principle means that we should think carefully about where approval is given for housing construction.

15-23 How Can We Use Water More Sustainably? A Blue Revolution

A. To use water more sustainably, we need to conserve, increase water prices, preserve forests on watersheds, and slow population growth.
   1. A blue revolution to conserve water would include several of the following components:
      a. Use of technology to irrigate crops more efficiently and to save water
      b. Removal of subsidies that underprice water, but guarantee low prices for low-income consumers, and rewarding of reductions in the volume of wastewater produced.
      c. Developing new waste production and treatment systems that
         1) accept only nontoxic materials,
         2) use less or no water to treat wastes,
         3) return nutrients in waste to the soil, and
         4) mimic nature's decomposition and recycling processes

      d. Leave enough water in rivers to protect wildlife, ecological processes, and the natural ecological services provided by rivers.
   2. Ecological restoration efforts show that wildlife and ecological health will return.
      a. We can use and waste less water.
      b. We need to support government policies that result in more sustainable use of water and better ways to treat industrial and household wastes.
      c. We should lower water use, reduce meat consumption, and prevent water pollution.

