# Global Water Resources and Use

CHAPTER 3

*All rivers run into the sea, yet the sea is not full: Unto the place from which rivers come, thither they return again.*

—Ecclesiastes 1:7

## FRESHWATER AND SALTWATER

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.

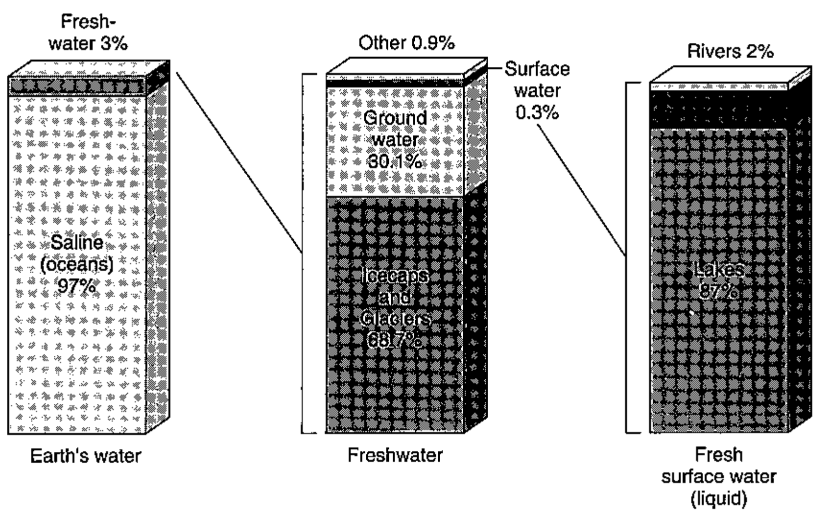


**Figure 3.1 Distribution of Earth's water**

Water has many unique properties:

1. Strong hydrogen bonds hold water molecules to each other.
2. The temperature of water changes slowly due to its high specific heat capacity.
3. Water has a high boiling point.

4. A lot of energy is needed to evaporate water.
5. Water dissolves many compounds.
6. Water filters out harmful UV radiation in aquatic ecosystems.
7. Water adheres to many solid surfaces.
8. Water expands when it freezes.

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 (Iceland, Norway, and so on). Lowest per capita freshwater supplies are in areas with low rainfall and high populations (Egypt, Israel, and so on).

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.

## LAKES

Most lakes on Earth are located in the Northern Hemisphere at higher latitudes and are generally found in mountainous areas, rift zones, areas with ongoing or recent glaciations, or along the courses of mature rivers. Processes that form lakes include: (1) tectonic uplift of a mountain range that creates a depression that accumulates water; (2) advance and retreat of glaciers that scrape depressions in the Earth's surface where water accumulates (e.g., the Great Lakes of North America); (3) salt or saline lakes that form where there is no natural outlet or where the water evaporates rapidly and the drainage surface of the water table has a higher-than-normal salt content (e.g., the Great Salt Lake, the Aral Sea, and the Dead Sea); (4) oxbow lakes formed by erosion in river valleys; and (5) crater lakes formed in volcanic craters and calderas that fill up with water more rapidly than they empty (e.g., Crater Lake in Oregon).

All lakes are temporary over geologic time scales, as they slowly fill in with sediments or spill out of the basin containing them. Changes in the level of a lake are controlled by the difference between the input and output compared to the total volume of the lake. Significant input sources are precipitation onto the lake, runoff carried by streams and channels from the lake's catchment area, groundwater channels and aquifers, and artificial sources from outside the catchment area. Output sources include evaporation from the lake, surface and groundwater flows, and any extraction of lake water by humans. Variations in climate conditions and human water requirements will create fluctuations in the lake level. Artificial lakes are constructed for hydroelectric power generation, recreational purposes, industrial use, agricultural use, or domestic water supply.

Lakes have three zones: the littoral zone, which is a sloped area close to land; the photic or open-water zone, where sunlight is abundant; and the deep-water benthic zone. The depth to which light can reach in lakes depends on turbidity, or the amount and type of suspended particles in the water. These particles can be either sedimentary (i.e., silt) or biological (e.g., algae or detritus) in origin.

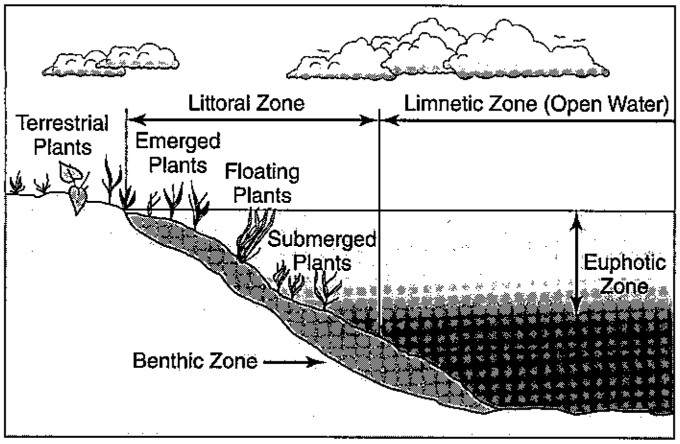


**Figure 3.2 Lake zonation**

A Secchi disk can be used to determine the level of turbidity or eutrophication in a lake.

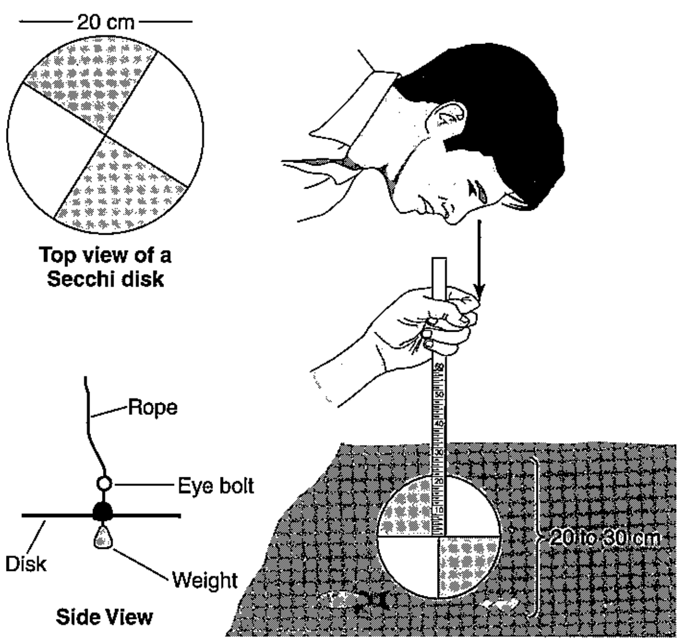


**Figure 3.3 Secchi disk**

The material at the bottom of a lake can be composed of a wide variety of inorganic material, such as silt or sand, and organic material, such as decaying plant or animal matter. The composition of the lake bed has a significant impact on the flora and fauna found near the lake, as it contributes to the amount and the types of nutrients available. A lake may be in-filled with deposited sediment and gradually become wetland.

Oligotrophic lakes are generally clear due to low nutrient levels and have little plant life. Mesotrophic lakes have good clarity and an average level of nutrients.

Eutrophic lakes are enriched with nutrients, resulting in large amounts of plant growth with possible algal blooms. Hypertrophic lakes have been excessively enriched with nutrients, have poor water clarity, and are subject to devastating algal blooms. These lakes usually result from human activities, such as heavy use of fertilizers or sewage outlets in the lake catchment area. Such lakes are of little use to humans and have a poor ecosystem due to decreased amounts of dissolved oxygen.

Because of the high specific heat capacity of water, lakes moderate the surrounding region's temperature and climate. In the daytime, a lake can cool the land beside it with local winds, resulting in a sea breeze; at night, it can warm it with a land breeze.

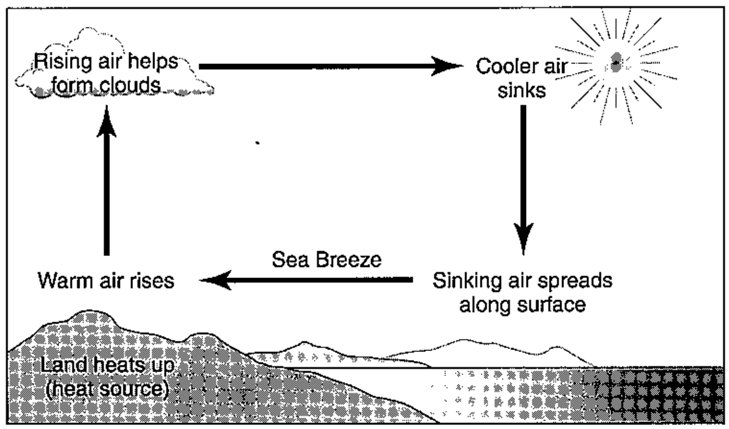


**Figure 3.4 Sea breeze**

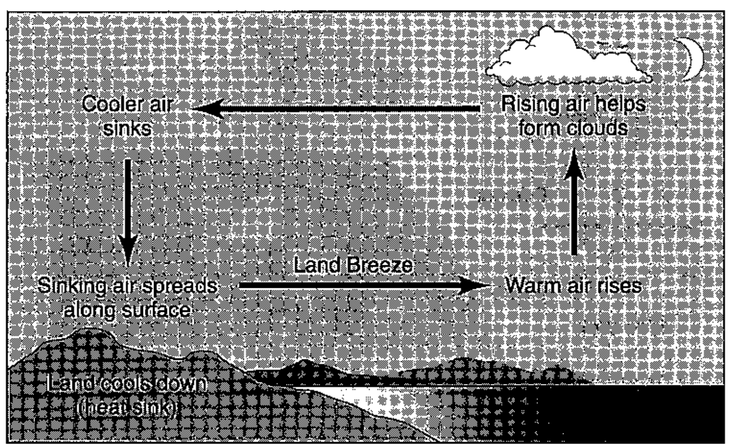


**Figure 3.5 Land breeze**

The stratification or layering of water in lakes is due to density changes caused by changes in temperature. The density of water increases as temperature decreases until it reaches its maximum density at about 39°F (4°C), causing thermal stratification—the tendency of deep lakes to form distinct layers in the summer months. Deep water is insulated from the sun and stays cool and denser, forming a lower layer called the hypolimnion. The surface and water near the shore are warmed by the sun, making them less dense, so that they form a surface layer called the epilimnion.

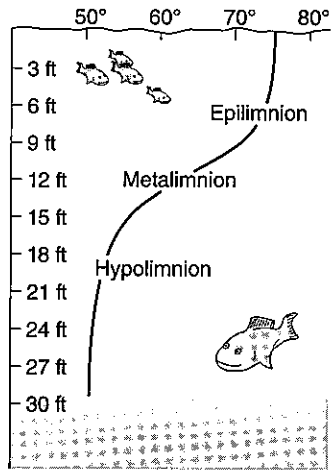


**Figure 3.6 Thermal stratification**

Seasonal turnover refers to the exchange of surface and bottom water in a lake or pond that happens twice a year (spring and fall). During the summer, the sun heats water near the surface of lakes, which results in a well-defined warm layer of water occurring over a cooler one (stratification). As the summer progresses, temperature differences increase between the layers, and a thin middle layer, or thermocline, develops, where a rapid transition in temperature occurs. With the arrival of fall and cooler air temperatures, water at the surface of lakes begins to cool and becomes heavier. During this time, strong fall winds move the surface water around, which promotes mixing with deeper water—a condition known as *fall turnover*. As the mixing continues, lake water becomes more uniform in temperature and oxygen level. As the winter approaches in areas where subfreezing temperatures are common, the lake surface temperatures approach the freezing mark (water is most dense at 4°C). Thus, as lake waters move toward freezing, the water sinks to the lake bottom when it reaches 4°C. Colder water remains above, perhaps eventually becoming capped by an ice layer, which further prevents the winds from stirring the water mass. With spring the surface ice begins to melt, and cold surface waters warm until they reach the temperatures of the bottom waters, again producing a fairly uniform temperature distribution throughout the lake. When this occurs, winds blowing over the lake again set up a full circulation system known as *spring turnover*.

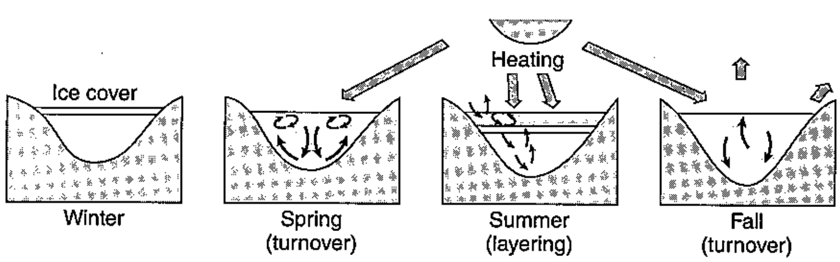


**Figure 3.7 Seasonal lake turnover**

## WETLANDS

Wetlands include swamps, estuaries, marshes, and bogs. Wetlands are characterized by a water table that stands at or near the land surface for a long enough season each year to support aquatic plants. They are considered the most biologically diverse of all ecosystems and occur where the soil is either permanently or seasonally saturated with moisture, often covered partially or completely by shallow pools of water. The water found in wetlands can be saltwater, freshwater, or brackish. Plant life found in wetlands includes mangrove, water lilies, cattails, sedges, tamarack, black spruce, and cypress. Animal life includes many different amphibians, reptiles, birds, and mammals.

Wetlands have historically been drained for real estate development or flooded for use as recreational lakes. By 1993, half of the world's wetlands had been drained. Wetlands provide a valuable flood control function and are very effective at filtering and cleaning water.

**RELEVANT TREATY**

**Ramsar Convention (1971):** International treaty designed to address global concerns regarding wetland loss and degradation. The primary purposes of the treaty are to list wetlands of international importance and to promote their wise use, with the ultimate goal of preserving the world's wetlands. Methods include restricting access to the majority portion of wetland areas, as well as educating the public to combat the misconception that wetlands are wastelands. Also known as the Convention on Wetlands of International Importance.

## AQUIFERS

An aquifer is a geologic formation that contains water in quantities sufficient to support a well or spring. Unconfined aquifers have as their upper boundary the water table. Typically (but not always), the shallowest aquifer at a given location is unconfined, meaning it does not have a confining layer between it and the surface. Unconfined aquifers usually receive recharge water directly from the surface, from precipitation or from a body of surface water (e.g., a river, stream, or lake). Confined aquifers have the water table above their upper boundary and are typically found below unconfined aquifers. The term "perched" refers to groundwater accumulating above an area of low permeability such as clay. The unsaturated zone is directly below the surface and contains some water. In the unsaturated zone, water and air fill the voids between soil or rock particles. Deeper in the ground is the zone of saturation. In the zone of saturation, the subsurface is completely saturated with water. The point where the zone of aeration meets the zone of saturation is known as the water table. Water table levels fluctuate naturally throughout the year based on seasonal variations. In addition, the depth of the water table varies.

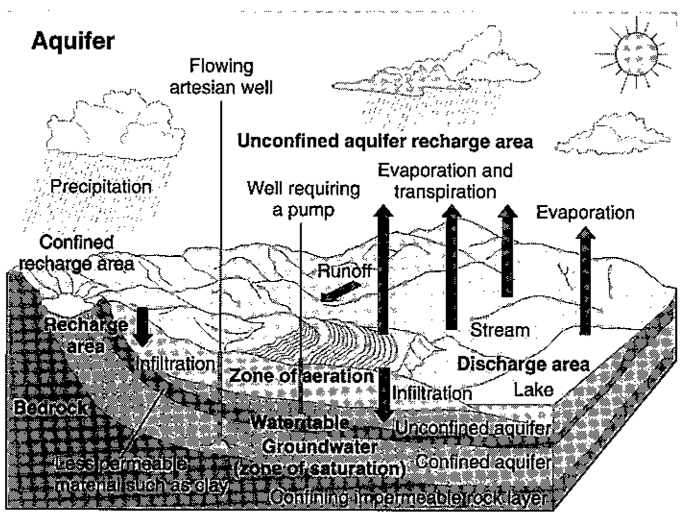


Figure 3.8 A typical aquifer

## OCEANS

Approximately 71% of the 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%. The oceanic crust is composed of a dense, thin layer of solidified volcanic basalt as compared to the thicker but less dense continental crust, which is composed primarily of granite. The ocean floor spreads from mid-ocean ridges, where two tectonic plates adjoin. Where two plates move toward each other, one plate subducts or moves under another plate (oceanic or continental), leading to an oceanic trench.

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. Oceans are divided into specific zones:

### Oceanic Zones

| | |
|---|---|
| **Aphotic** | The depths beyond which less than 1% of sunlight penetrates. |
| **Benthic** | The ecological region at the lowest level of a body of water. |
| **Disphotic** | The zone that is dimly lit and does not have enough light penetrating from the surface to carry out photosynthesis. |
| **Neritic** | Extends from the low tide mark to the edge of the continental shelf, with a relatively shallow depth extending to about 650 feet (200 m). Generally well-oxygenated water, low water pressure, available light for photosynthesis, and relatively stable temperature and salinity levels. High biodiversity. Also known as sublittoral or photic zone. |
| **Oceanic** | The region of open sea beyond the edge of the continental shelf; includes 65% of the ocean's open water. |
| **Pelagic** | Includes all open ocean regions. |
| **Photic (Euphotic)** | The depth of the water that is exposed to sufficient sunlight for photosynthesis to occur. Biologically diverse. |

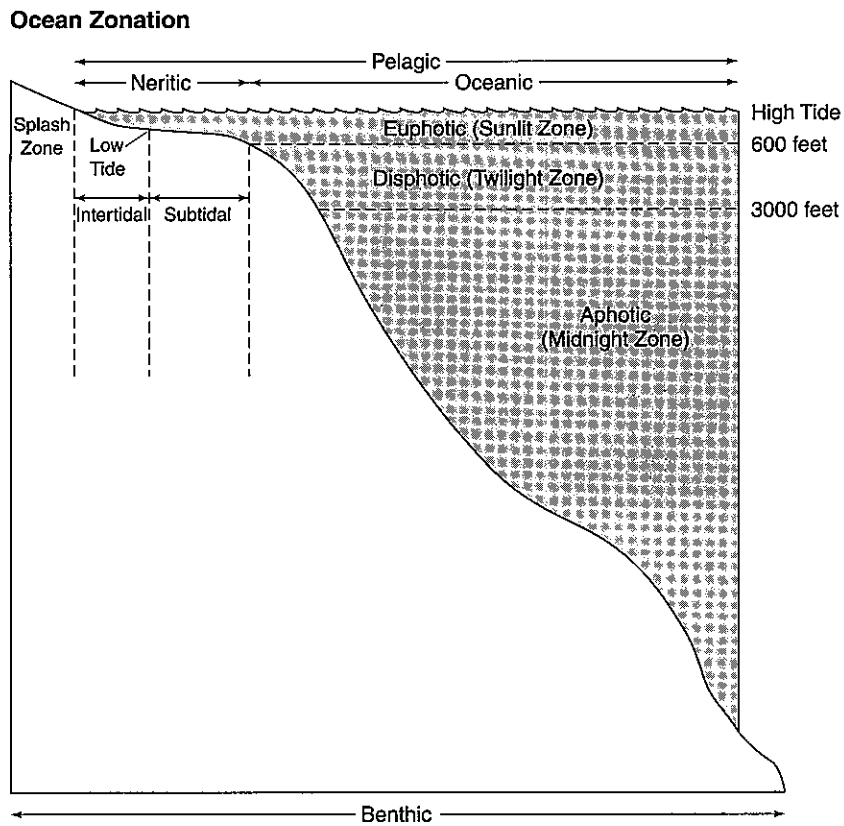


**Figure 3.9 Ocean zonation**

## OCEAN CIRCULATION

The Northern Hemisphere is dominated by land and the Southern Hemisphere 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). They serve to distribute the heat generated near the tropics. Deep-water, density-driven currents are controlled primarily by differences in temperature and salt content. Denser, saltier water sinks, and less-dense water rises. 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).

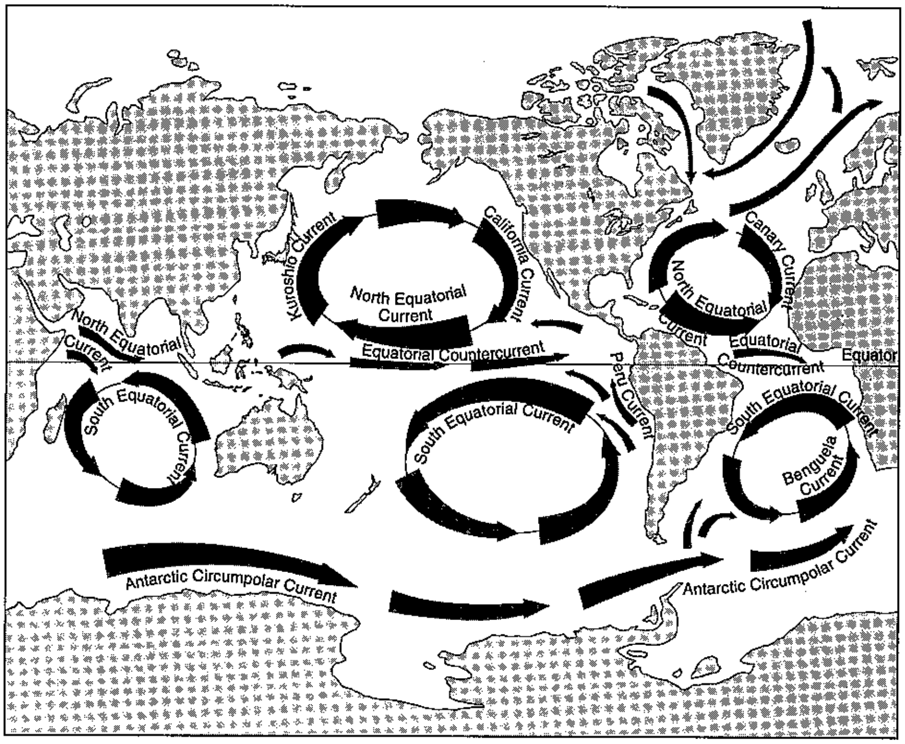


Figure 3.10 Ocean surface currents

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:

1. Significant slowing of the ocean circulation that transports warm water to the North Atlantic
2. Large reductions in the Greenland and West Antarctic ice sheets
3. Accelerated global warming due to carbon cycle feedbacks in the terrestrial biosphere
4. Decreases in upwelling
5. 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.

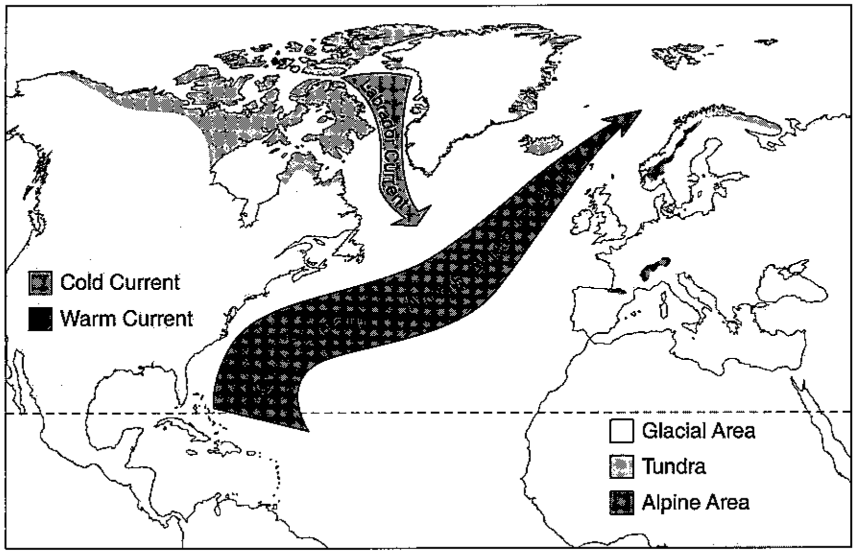


**Figure 3.11 Gulf Stream**

## 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. For more information on global warming and its effect on thermohaline circulation, refer to Chapter 11.

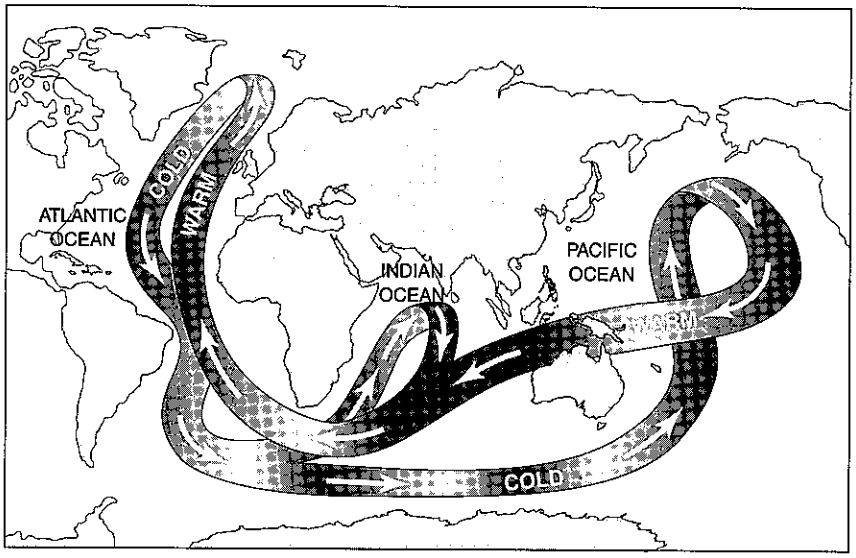


**Figure 3.12 The Great Ocean Conveyor Belt**

## Upwellings

Upwellings occur when prevailing winds produced through the Coriolis effect, and moving clockwise in the Northern Hemisphere, push warmer, nutrient-poor surface waters away from the coastline. This surface water is then replaced by cooler, nutrient-rich deeper waters. The deeper waters contain high levels of nitrates and phosphates, which result from the decomposition and sinking of surface water plankton. When these nutrients are brought to the surface through upwelling, they supply necessary nutrients for phytoplankton, which form the base of the oceanic food chain.

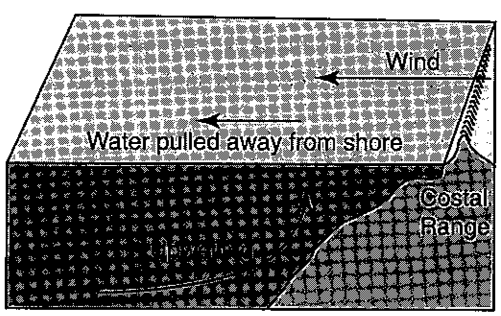


Figure 3.13 Upwelling

## Ekman Transport Spiral

The Ekman transport spiral is a natural process by which wind causes movement of water near the ocean surface. Each layer of water in the ocean drags with it the layer underneath. Because of the Coriolis effect, the ocean's surface movement is 45° to the right of the direction of surface wind in the Northern Hemisphere and 45° to the left in the Southern Hemisphere. If such a current transports water away from a coast, it creates an upwelling of deep nutrient-rich sea water.

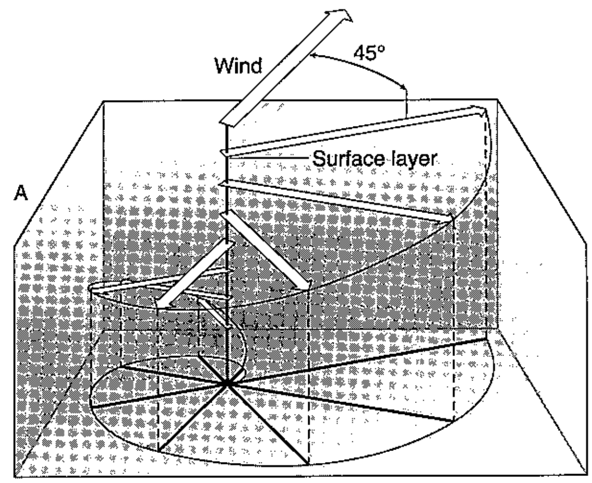


Figure 3.14 Ekman transport spiral

## AGRICULTURAL, INDUSTRIAL, AND DOMESTIC USE

About 70% of freshwater is used for agriculture. Use of water for agriculture depends upon national wealth, climate, and degree of industrialization. Canada uses about 10% of its freshwater resources for agriculture, whereas India uses about 90%. Up to 70% of water intended for agriculture in developing countries may not reach crops due to seepage, evaporation, and leakage. Drip irrigation, the most efficient type of irrigation, is used on less than 1% of crops worldwide.

### Advantages of Drip Irrigation

1. Increased efficiency. Almost all water reaches crops—no runoff.
2. Less energy required. Lower water demand results in less pumping costs.
3. Lower demand on aquifers or depleted water resources.
4. Crop yield increases—fertilizer is accurately applied directly to roots of plants and can be monitored. Reduces salinization and nitrate and phosphate runoff.
5. Tubing systems can be adapted to meet contours of the land and can be changed as needed.
6. Correct amounts of water means plants are neither waterlogged nor water stressed.

Industry uses about 25% of all freshwater, ranging from a high of about 75% in Europe to less than 5% in developing countries. Water used for cooling power plants is the largest sector. Water returns 60 times its economic value when used for industrial purposes rather than for agriculture.

Domestic uses of freshwater include water being used for flushing toilets, bathing, drinking, and so on. People living in developed countries use about 10 times more water for personal use than people living in less-developed countries.

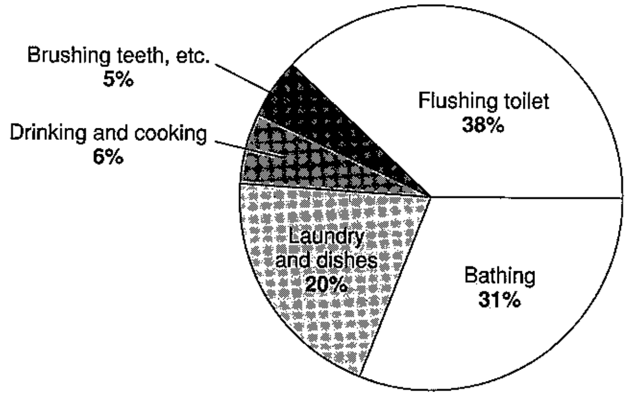


Figure 3.15 Water use

## SURFACE AND GROUNDWATER ISSUES

Surface water infiltrates and percolates through the soil into aquifers—layers of porous rock, sand, and gravel where water is trapped above a nonporous layer or bedrock. The surface area in which water infiltrates into the aquifer is called the recharge zone. If pollution enters an aquifer, the aquifer is no longer a source of safe drinking water. Movement of water through aquifers is very slow. Artesian wells occur where the water breaks through to the surface. 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. When removal of water exceeds the recharge rate, the land sinks (subsidence). Depletion of water in aquifers also leads to sinkholes and saltwater intrusion—a condition in which seawater replaces the freshwater in the aquifer, making it unusable for human use. The region where water-saturated soil meets water-unsaturated soil is called the water table. The water table is unique to a region and can rise and fall with rainfall variations, depletion rates, and so on.

### Water-Renewal Rates

| Source of Water | Average Renewal Rate |
|---|---|
| Groundwater (deep) | ~ 10,000 years |
| Groundwater (near surface) | ~ 200 years |
| Lakes | ~ 100 years |
| Glaciers | ~ 40 years |
| Water in the soil | ~ 70 days |
| Rivers | 16 days |
| Atmosphere | 8 days |

**CASE STUDIES**

**San Joaquin Valley:** Groundwater-related subsidence is the sinking of land resulting from groundwater extraction. Land subsidence occurs when large amounts of ground water 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 six feet (2 meters) per year. Such a dramatic change in land elevation causes massive impacts on buildings and infrastructure, such as cracking and tilting.

Groundwater is considered to be one of the last "free resources," as anybody who can afford to drill can draw up water according to their ability to pump. Thus, the extraction of groundwater becomes a Tragedy of the Commons, with high economic externalities.

## GLOBAL PROBLEMS

Both water shortages and rising sea levels are 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.

### Rising Sea Levels

Rising sea level is primarily due to two factors: thermal expansion of water and the melting of ice caps and glaciers. Thermal expansion of seawater involves increasing the distance between neighboring water molecules, and this distance increases with increasing temperature. Translated over the mean depth of the ocean 2.4 miles (3.8 km), a 1-degree increase in temperature will cause a sea level rise of about 28 inches (70 cm).

During the end of the last ice age about 18,000 years ago, when global temperatures were about 10°F (5°C) warmer than they are today, sea level was about 430 feet (130 m) higher than it is today. Much of the rise was due to ice that was on land melting and filling the oceans. When ice that is floating on the water melts, it does not contribute to a rise in sea level. However, it does affect climate.

With higher sea levels and more water covering Earth's surface, more heat energy is absorbed by the water and less is reflected back into space, resulting in higher temperatures.

During the 20th century, sea levels rose 6–8 inches (15–25 cm). Approximately 1–2 inches (2–5 cm) of the rise resulted from the melting of mountain glaciers. Another 1–2 inches (15–25 cm) resulted from the expansion of ocean water that resulted from warmer ocean temperatures. Best scientific estimates indicate that sea levels will rise 7 inches (18 cm) by the year 2030 and 23 inches (58 cm) by the year 2090. Climate models have suggested that temperatures in polar regions will increase more and at a faster pace than in other areas of the world. Since 1995, more than 5,400 square miles, an area equal to Connecticut and Rhode Island combined, have broken off the Antarctic ice shelves and melted.

Several other factors contribute to rising sea levels:

1. Land buildup or erosion of mountains (isostatic adjustments)
2. Plate tectonic effects
3. Sedimentation
4. Groundwater and oil extraction
5. Changes in ocean currents and tides
6. Distribution changes in the water cycle.

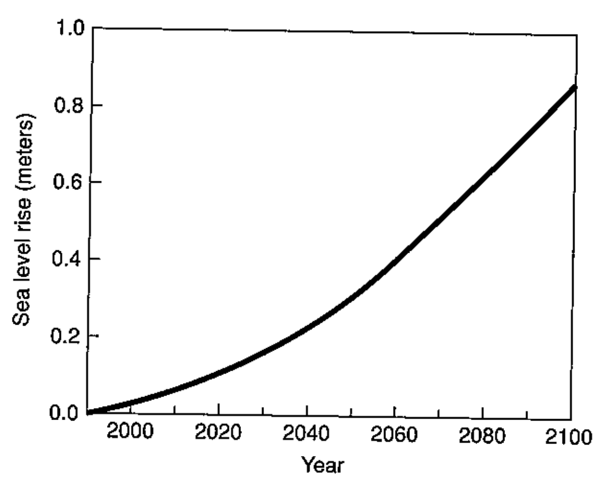


**Figure 3.16 Projected rise in sea level**

Wetlands are the most-impacted areas affected by rising sea levels. A 1-foot (30 cm) increase in sea level would result in up to 40% of the U.S. wetlands being destroyed. Other impacts would include: erosion of beaches and bluffs, salt intrusion into aquifers and surface waters, inundation of seawater into low-lying areas, and increased flooding and storm damage.

Much of the world's population—20%—lives in coastal regions, and half of the world's population lives within 120 miles (200 km) of the coast. Asia, Latin America, and the Caribbean have the highest percentages of people living near the coast.

## CONSERVATION

Several conservation methods can be used to increase the quantity of available freshwater:

### Methods to Increase Supplies of Freshwater: Description and Drawbacks

- **Changes in personal habits:** Turn off shower while washing. Wash only full loads of clothes and dishes; turn off water when brushing teeth. Check for and repair leaks around the home. Use a broom when cleaning driveways and patios. Adjust sprinklers to prevent runoff. Water at night or early morning.
- **Construct dams and reservoirs:** Interferes with fish migration and destroys natural rivers. Leakages, earthquakes, evaporation, sediment buildup, and displacement of people are also consequences. Up to 60 million people worldwide (many being indigenous minorities) have been relocated due to dam and reservoir construction.
- **Desalinate water:** Rate of production is low and is expensive (three to four times more expensive than any other process). Issues of brine disposal.
- **Drip irrigation:** Drip irrigation conserves water by reducing evaporation, but it is expensive. Most large agricultural corporations can afford it, but small, independent farmers cannot. Not suitable for annual crops.
- **Education:** Informing and educating the public on water conservation.
- **Encourage the use of recycled products that require less water to produce:** Costs of collecting products may be outweighed by savings.
- **Engineer systems to collect more runoff:** Water may be high in pollutants and expensive to reprocess.
- **Levy taxes or user fees:** Prices would go up on products. International competitiveness would be affected.
- **Line irrigation channels and cover canals:** Prevents loss of irrigation water through seepage and evaporation. Initial and maintenance costs are expensive.
- **Meter all water used:** Municipalities would recoup money on meter installation with paying less to water suppliers.
- **Plant crops that do not require as much water and xeriscaping:** Xeriscaping reduces urban runoff. Issues of market economies, crop prices and demand, weather patterns, and so on.
- **Rebates or legislation of low-flush toilets, shower restrictors, etc.:** Rebates would be offered by water companies, which, over time, would recoup costs by having to buy less water from suppliers.
- **Reduce government subsidies:** Increased water costs would be passed on to consumers and result in greater personal conservation.
- **Reprocess (recycle) water:** The public is not supportive of using reprocessed toilet water. Reprocessed water could be used for irrigation but would require separate pipeline systems. Reuse of gray water is becoming popular in new developments.
- **Seed clouds:** Water availability to other areas would be affected.
- **Tiered price scale:** Would reduce effective family income for larger families. Could be remedied through exemptions or allocated share of water per family member.

- **Use of icebergs:** Expensive and most of it would be lost before it reached final destination.
- **Use more groundwater:** If rate of use exceeds rate of recharge, then subsidence, sinkholes, and saltwater intrusion could occur.

**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.
- **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 sodium chloride in the alkaline soils to become 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 created many issues with indigenous people whose land was flooded.
- **Ogallala Aquifer:** The Ogallala Aquifer underlies eight states from Texas to North Dakota. The Ogallala Aquifer used to hold more freshwater than all freshwater lakes, streams, and rivers on Earth. Due to pumping of this groundwater for agricultural, domestic, and industrial uses, many locations are experiencing water shortages.
- **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.

**TIP**

Case studies can be brought into your essay answers to bring a historical connection to the question. Try to bring at least one case study into your essays—your score will go higher. You will also find several multiple-choice questions on the test that focus on case studies. Only the most relevant case studies are included in this book.

**RELEVANT LAWS**

- **Water Resources Planning Act (1965):** Provided for plans to formulate and evaluate water and related land resource projects and to maintain a continuing assessment of the adequacy of water supplies in the United States.
- **Coastal Zone Management Act (1972):** Provided funds for state planning and management of coastal areas.
- **Water Resources Development Act (1986):** Established and maintains dam safety programs.
- **National Estuary Program (1987):** Designed to identify nationally significant estuaries and to restore and protect them.

**QUICK REVIEW CHECKLIST**

- ☐ **Properties of Water**
  - ☐ name five physical properties of water
  - ☐ various forms and amounts of freshwater available (lakes, glaciers, ice caps, etc.)
- ☐ **Ocean Circulation**
  - ☐ causes of currents (winds, densities, temperature, thermoclines, etc.)
  - ☐ differences between Northern Hemisphere and Southern Hemisphere currents
  - ☐ causes and consequences of increases in ocean temperatures
- ☐ **Water Usage**
  - ☐ agricultural usage (various forms, advantages and disadvantages of irrigation)
  - ☐ industrial usage (relative amount compared to other uses, recycling methods)
  - ☐ domestic usage (relative amount compared to other uses)
- ☐ **Surface Water vs. Groundwater**
  - ☐ relative amount of freshwater available
  - ☐ relative renewal rates
  - ☐ pollution (current status, mitigation)
- ☐ **Rising Sea Level**
  - ☐ historical perspective
  - ☐ contributing factors
  - ☐ impact (financial and cultural)
- ☐ **Conservation**
  - ☐ name five conservation methods for industrial, agricultural, and domestic water usage