

## Chapter 17 - Water Use and Management

### Key Terms

aquifer	infiltration	water stress
artesian well	rain shadow	water table
condensation	recharge zone	withdrawal
condensation nuclei	relative humidity	zone of aeration
consumption	salt water intrusion	zone of saturation
desalination	saturation point	
dew point	sinkholes	
discharge	sublimation	
evaporation	subsidence	
groundwater	transpiration	

### Skills

1. Diagram the water cycle.
2. Characterize groundwater and surface water features.
3. Appraise human water use.
4. Evaluate the priorities of water use for ecological communities, agricultural use, or municipal use.
5. Review water conservation methods.
6. Debate the costs and benefits of water diversion projects. Address the ecological and economic aspects of the projects.

**Take Note:** Understanding water use is important for the AP student. Numerous nations remain in conflict over water rights, and comprehension of basic water issues is imperative. Prior AP essay questions have asked students to explain the pros and cons of water diversion projects. The question expected students to be familiar with several different projects to answer the question. Water and its uses are often addressed in the multiple-choice questions.

### Hydrologic Cycle

The hydrologic cycle is powered by the sun and gravity. Water is released from surface water through evaporation. Evapotranspiration is the loss of water from the leaves of a plant as they exchange gases necessary during photosynthesis. Sublimation is the conversion of solid water (ice) into the gaseous form directly, without a liquid stage. Once in the atmosphere the water molecules undergo condensation, and then precipitation occurs, returning the water to the earth. The water will infiltrate the soil and percolate down into the deeper layers of the soil or it will become runoff. The percolated water may become part of the groundwater, which flows steadily underground toward the ocean. The water may also be used by plants during photosynthesis. The runoff will become part of the surface water, entering lakes or flowing water systems. Relative humidity is the amount of water vapor in the air compared to the amount of water the air could hold at a given

temperature (the saturation point). Water coalesces around particles called condensation nuclei to form clouds. The temperature at which water condenses is the dew point. Clouds release precipitation to reenter the cycle.

Rain is dependent upon atmospheric circulation, proximity to water, and topography. Areas with high levels of precipitation have atmospheric circulation that contributes to the rising and cooling of the warm moisture-laden surface air. These areas include regions with colliding air masses, the windward side of mountains, and around the equator. Sinking dry air occurs at 30° north and south of the equator and on the leeward side of mountains. In these regions, deserts form. The formation of deserts on the dry, leeward side of mountains is attributed to the rain shadow effect. The clouds release their moisture as they rise, so only the windward side of mountains receive precipitation, thus creating a "shadow" that lacks rain on the opposite side of the mountain.

### Surface and Ground Water

Of all water on earth that is liquid water, 97 percent is in the ocean. Oceans moderate temperatures due to their current circulation and contain the majority of the earth's biomass. Most of the remaining fresh water is frozen in glaciers, icecaps, and snowfields. The largest of these ice sheets covers Antarctica.

After glaciers, groundwater makes up a large proportion of freshwater supplies. Groundwater is stored in porous underground rock, such as limestone or sand and gravel. This storage area is known as an aquifer. Aquifers may be surrounded by areas of impermeable rock (like shale or granite) or clay called aquicludes or aquitards. Such confined aquifers are typically under pressure and will readily flow when penetrated by drilling. These aquifers are called artesian aquifers. Other aquifers, known as unconfined aquifers, are not bounded at the top by an aquiclude and may form the water table. The water table is the highest level the water arises in the soil, thus forming the zone of saturation. The upper layer of soil is known as the zone of aeration, because the particles of soil are surrounded by air. Aquifers are filled in areas called recharge zones, which may not be near the aquifer. Groundwater does flow, and the rate of recharge must not exceed the rate of withdrawal or problems may occur. The largest aquifer in the United States is the Ogallala Aquifer, which lies primarily under Nebraska, Kansas, and north Texas. The water level in this aquifer has been dramatically lowered as water is removed for irrigation.

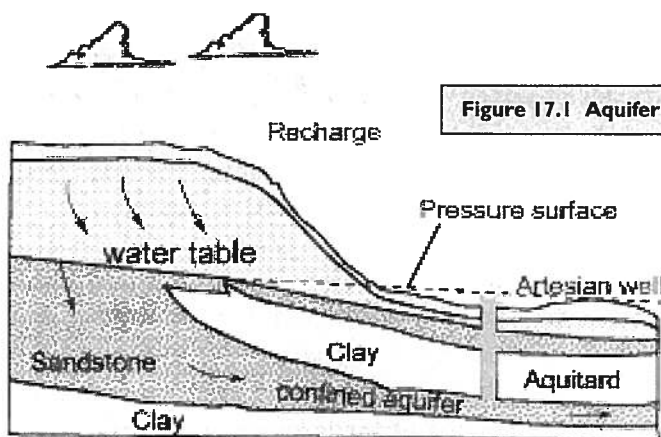


Figure 17.1 Aquifer structure

Water on the surface of the ground is called surface water, and it comprises less than 0.02 percent of all water. This water is in rivers, lakes, inland seas, streams, marshes, ponds, and swamps. The discharge of a river is the amount of water that passes a point in the water in a given amount of time. The river with the largest discharge is the Amazon, followed by the Orinoco. The North American river with the greatest discharge is the Mississippi River. Wetlands and swamps serve as recharge zones, purify water, and reduce erosion.

A watershed is the area of land that flows into a body of surface water. It is important that watersheds maintain their vegetation to reduce runoff and encourage infiltration.

### **Water Availability and Use**

More than one-sixth of the world's population lack access to adequate clean drinking water and half of the world's population lacks access to sanitation. The World Health Organization considers 264,000 gallons of water per person to be minimum level below which shortages will impede development and damage human health. Two-thirds of the world's households do not have running water and must travel outside the home to wells to retrieve water.

Human intervention in the hydrologic cycle includes ground and surface water depletion, ground and surface water pollution, and the clearing of vegetation. The clearing of vegetation, particularly in temperate and tropical rainforests, interferes with the water cycle by decreasing transpiration.

Areas that have enough water include Brazil, Canada, Russia, and the Congo, because they have relatively large amounts of precipitation in conjunction with large amounts of land. High population densities and low precipitation result in water stress, or the lack of available water required to sustain a population. A country that uses more than 20 percent of its available water is experiencing water stress. Droughts can exacerbate water stress. Land use practices tend to exacerbate the effects of drought, as seen by the Dust Bowl in the United States in the 1930s. ENSOs contribute to droughts in many parts of the world.

Water withdrawal is removing water from surface water or groundwater for human use. Consumption is using the removed water in such a way that it is not useful again as surface water. Water that is withdrawn but not consumed may become degraded by chemical or thermal pollution. Water withdrawal is a concern, because as the human population increases, the demand for fresh water dramatically rises. The greatest consumer of water for human use is water used in irrigation and other agricultural needs. In the world, two-thirds of water withdrawal is used for irrigation.

In the United States the greatest volume of domestic water is used to flush toilets, followed by bathing, laundry, and dishes. Industrial processes use about 20 percent of the U.S. water withdrawals. Power production accounts for 50-70 percent of this use. The greatest producer of degraded water is mining.

### **Irrigation Methods**

The original method of irrigation was to flood a field. Much of the water is lost to evaporation, so this method is inefficient. Sprinkler systems are also used, which also results in large amounts of

water lost to evaporation. Low energy precision application (LEPA) methods use a center pivot sprinkler, which reduces evaporation because the sprinkler heads are lower to the ground. Drip irrigation involves using underground or surface pipes, which apply the water directly to the soil, further reducing water loss. These water conserving irrigation methods also prevent waterlogging and soil salinization.

### Groundwater Withdrawal Problems

Groundwater is used for 40 percent of the municipal and agricultural needs in the United States. If water withdrawal exceeds recharge, several impacts occur. The water table can be dramatically lowered. If lakes are water table lakes, even surface water may be impacted by this loss of groundwater. Wells drilled into the aquifer may dry up, because the water table has been lowered. Sinkholes form when limestone dries out and crumbles due to excessive withdrawal. These sinkholes are localized damage. Sinkholes may also form when the water table rises again and limestone dissolves in the water. Sinkholes are prevalent in Florida around the Floridian Aquifer. They form quickly and have dropped cars and even houses into craters. Subsidence is the sinking of an area due to overdrawing of groundwater. The San Joaquin Valley in California is estimated to have sunk more than 30 feet in the last 50 years due to subsidence. Louisiana and Texas are subject to saltwater intrusion. This phenomenon occurs when fresh water is drawn out of an aquifer and salt water from coastal areas is pulled into the freshwater aquifer, thus contaminating it.

### Water Diversion Projects

Water diversion projects move water from its original location to a new site. Dams alter ecosystems dramatically, by flooding upstream areas and decreasing flooding downstream. Dams impact the aesthetic value of a flowing water system and create a new standing water ecosystem. The benefits of dams are numerous. The major positive impacts are the regulation of water flow and flood prevention below the dam. The reservoir can provide irrigation and drinking water and hydroelectricity. The lake created by the dam can provide the recreational benefits of fishing, boating, skiing, and bird watching.

The costs of dams are also to be considered. Dams are expensive to build but have relatively low operating costs. They destroy riparian ecosystems. They increase the temperature of the water below the dam and decrease its dissolved oxygen. If the river flows to the ocean, the estuary becomes more salty due to the lack of influx of fresh water. There is also a decreased flow of nutrients to estuaries and nutrient-rich sediment downstream, important for maintenance of aquatic species downstream. The sediment that used to flow down the river collects in front of the dam, resulting in the need to dredge the reservoir. Reservoirs lose a tremendous amount of water to evaporation due to the large surface area.

Additionally, dams interfere with the spawning and thus survival of anadromous fish. Anadromous fish species are fish that spawn in fresh water and spend their adult life in the ocean. As they need to spawn, they return to the river in which they were hatched. These fish include salmon, sturgeon, and some trout species. Dams on rivers interfere with spawning because the mature fish cannot move upstream to breed. To alleviate this problem, fish ladders have been installed to allow the adult fish to bypass the dams. Several species of trout and salmon are bred in hatcheries to

increase their numbers. The smolt die going downstream as they pass through the hydroelectric turbines. To alleviate this problem, smolt and fry from hatcheries are trucked around dams and placed into the water below the dam. Some strains of Coho, Chinook, and Sockeye salmon and some steelhead trout have been placed on the endangered species list and are managed by a recovery plan by the NMFS because they are anadromous fishes.

### Specific Water Diversion Projects

The Everglades is a 50-mile wide river that flows through south Florida toward Florida Bay. In the 1960s the U.S. Army Corps of Engineers wanted to help drain the Everglades for agriculture and development and to alleviate damage from flooding. To drain the area, the Kissimmee River, which drained the wetlands around Lake Okeechobee, was straightened via canals from its original meandering state. The state of Florida, in conjunction with the federal government, is cleaning up the mercury and phosphate pollution in the Everglades and restoring the natural meanders to the Kissimmee River.

The fourth largest inland sea has become a salty desert. The Aral Sea, bounded by Kazakhstan and Uzbekistan, has shrunk more than 60 percent of its water volume and 75 percent of its size since the 1960s. The sea was fed by the Amu Darya and Syr Darya rivers, diverted for irrigation of cotton and rice. As the waters feeding the sea were diverted and evaporation continued, the sea became more and more salty, destroying lucrative fishery. Corroded ships sit in sand, miles from water. The health issues in the region include lung diseases from salt storms, anemia, and thyroid and kidney diseases. The infant mortality and cancer rates have increased dramatically. Mono Lake in California has suffered from water diversions, as well. This lake has lost one-third of its surface area, destroying the habitat of migratory and wading birds.

The James Bay project built in Canada diverted three rivers from the Hudson Bay and created lakes in forests and tundra. Caribou drowned trying to follow migratory paths across flooded regions, and indigenous people, the Cree, were harmed due to loss of traditional hunting and fishing grounds. The soil was contaminated with mercury in the area, and the flood waters caused the mercury to enter the food chain.

When the flow of the Nile River was impeded by the building of the High Dam in Aswan, Egypt, in the 1960s, schistosomiasis cases increased in the area. The dam created Lake Nassar, a body of standing water in which the snails required to transmit schistosoma parasites could thrive. The snails cannot survive in flowing water. A similar situation arose on the Senegal River due to the Diama Dam and could perhaps be a problem at Three Gorges. The dam is being built in an area endemic for schistosomiasis, so increasing the standing water is likely to increase the disease incidence.

The Three Gorges Dam, under construction across the Yangtze River in China, will be the world's largest hydroelectric dam. This dam is covering ancient cities and is displacing over 1 million people. The dam is built along a fault, and grave concerns regarding its safety have not been adequately addressed.

## Desalination

Desalination is the process of removing water from salty or brackish water, creating fresh water and a salty brine. One process used to carry out desalination is reverse osmosis, in which energy is used to force water through a semipermeable membrane against the concentration gradient. Distillation may also be used, in which the water is heated to boil out the salt, then condensed as fresh water. This method has been used a lot in the Middle East due to the lack of water in the region. Water produced by desalination is about four times more expensive than other water. In the United States, many regions are turning to desalination due to water shortage. For example, a desalination plant was built in Tampa, Florida, to accommodate the burgeoning population and its demand for fresh water. The plant uses the waste heat from an electrical plant (cogeneration) to power reverse osmosis. Perhaps the greatest environmental impact of desalination is the disposal of the salty brine.

## Other Ways to Increase Water Supplies

Many other ways have been suggested to increase freshwater supplies. Cloud seeding with salts or dry ice has been recommended to increase precipitation. However, the hydrologic cycle in some areas makes this idea extremely difficult to implement. Harvesting icebergs from the poles has been recommended, but the impacts to warmer regions will need to be taken into consideration if such a method is employed. Another method currently being examined is called aquifer storage and recovery. In this method, surface runoff is collected, treated, and pumped into aquifers for future use.

## Water Conservation

The easiest method to conserve water is to use less. Flushing toilets is the primary municipal water use in the United States, so low-flow toilets may be used, which use 1.6 gallons per flush as opposed to the older models, which used up to 8 gallons of water. Low-flow shower heads and high-efficiency washers and dishwashers dramatically reduce water use. To encourage consumer water conservation, they should be given rebates for purchasing water conserving appliances, toilets, and shower heads. Municipalities can also charge consumers more for their water to reflect water shortages. Water subsidies can be decreased and watershed management can be better controlled to alleviate water problems. Consumer education regarding water conservation strategies is imperative to encourage compliance. Industrial water can be recycled to decrease water use. Agricultural water waste can be decreased by more efficient irrigation methods.

One method to conserve municipal water used in irrigation is to have nonpotable reuse of the water. Gray water is water collected in a house from showers and sinks. This water does not enter the sewer or septic tank, but is collected to water lawns and gardens. A similar reuse is reclaimed water, in which the city purifies sewage effluent to the point of discharge and provides it as irrigation water. The positive impacts of reclaimed water are numerous. There is no need to use potable water for irrigation, nor does the sewage effluent have to be dumped into surface water. Additionally the water can naturally percolate into soil, increasing groundwater stores. Arid areas can also employ xeriscaping, or planting native species that require little to no watering.

### Chapter 17 Questions

1. Stream discharge is
  - a. the length of a river times its deepest point.
  - b. the distance the water flows from the headwater to the mouth.
  - c. the speed the river travels past a fixed point.
  - d. increased in the summer due to increased temperatures.
  - e. the volume of water the river holds at any given time.
  
2. Materials that prevent the flow of groundwater are called
  - a. aquifers.
  - b. aquicludes.
  - c. wells.
  - d. limestone.
  - e. artesian.
  
3. Removal of excessive amounts of groundwater in coastal areas may result in
  - a. saltwater intrusion.
  - b. permeability damage.
  - c. subsidence.
  - d. aquifer recharge.
  - e. surface water depletion.
  
4. All of the following processes involve water moving with gravity except
  - a. infiltration.
  - b. percolation.
  - c. precipitation.
  - d. transpiration.
  - e. runoff.
  
5. Which of the following water diversion is correctly matched with its problem?
  - a. increased schistosomiasis in the Aral Sea region
  - b. increased saltiness of the Yangtze in China due to the Three Gorges Dam
  - c. reduced water flow through the Everglades has caused a reduction of biodiversity
  - d. Mono Lake in California experiences flooding due to irrigation canal placement
  - e. James Bay has increased in saltiness due to the water diversion for irrigation purposes
  
6. The greatest amount of fresh water is found in
  - a. groundwater.
  - b. inland seas.
  - c. lakes and ponds.
  - d. ice and snow.
  - e. rivers and streams.
  
7. Which of the following is not an impact of dams?
  - a. greater flooding below the dam
  - b. impeded breeding in anadromous fishes
  - c. reduced sediment flow downstream
  - d. lowered dissolved oxygen in the water downstream
  - e. increased salinity in estuaries fed by dammed rivers
  
8. Which of the following policies would be a disincentive, or "stick," that would encourage water conservation in a municipality?
  - a. increasing water costs to reflect water shortages
  - b. increasing the availability of reclaimed water
  - c. providing rebates for low-flow toilets and shower heads
  - d. providing rain barrels to catch rainwater for watering lawns
  - e. providing a property tax break on homes that use xeriscaping

9. Sinkholes result from
- a. saltwater intrusion.
  - b. raising the water table.
  - c. increased evaporation of groundwater.
  - d. excessive removal of groundwater.
  - e. increased flow of surface water during the spring after snowmelt occurs.
10. The greatest use in municipalities of fresh water is
- a. bathing.
  - b. washing dishes.
  - c. flushing toilets.
  - d. laundry.
  - e. food preparation.

### Chapter 17 Answers

- 1. c. Stream discharge is the speed the river travels past a fixed point.
- 2. b. Materials that prevent the flow of groundwater are called aquicludes.
- 3. a. Removal of excessive amounts of groundwater in coastal areas may result in saltwater intrusion.
- 4. d. Transpiration is the movement of water vapor from a tree's leaves into the atmosphere.
- 5. c. Reduced water flow through the Everglades has caused a reduction of biodiversity.
- 6. d. The greatest amount of fresh water is found in ice and snow.
- 7. a. There is less flooding below a dam.
- 8. a. Increasing water costs to reflect water shortages would be a disincentive, or "stick," that would encourage water conservation in a municipality. The other choices would be incentives, or "carrots."
- 9. d. Sinkholes result from excessive removal of groundwater.
- 10. c. The greatest use in municipalities of fresh water is flushing toilets.