Chapter 9: The Hydrosphere

I. The Hydrologic Cycle
   A. intro
      1. moisture inventory on earth (rounded) (Fig 9-1)
         a. oceans = 97.2%
         b. glaciers = 2.15%
         c. groundwater = 0.62%
         d. freshwater lakes = 0.009%
         e. saline lakes = 0.008%
         f. soil water = 0.005%
         g. stream, atmospheric, and biological water = 0.0011%
      2. component percentages are constant except during glaciation
         a. > 99% of moisture is in storage
         b. water frozen as ice in glaciers and continental ice sheets ≈ ¾ of planet’s fresh water
         c. <1% available for movement in hydrologic cycle
   B. Surface-to-Air Water Movement
      1. evaporation
         a. most moisture enters atmosphere through evaporation
         b. 86% of evaporated moisture derives from ocean surfaces
         c. extensive ocean surfaces in low latitudes where plentiful heat and wind facilitate evaporation
         d. water vapor from evaporation remains in atmosphere a few hours or days
         e. may move considerable distance, vertically (convection) or horizontally (advection)
      2. 14% derives from land surfaces through combination of evaporation and transpiration
   C. Air-to-Surface Water Movement
      1. water vapor in air condenses and returns to Earth’s surface as precipitation
         a. 78% falls on oceans
         b. 22% falls on land
      2. precipitation and evaporation/transpiration balance in time but not in place
         a. evaporation exceeds precipitation over the oceans
         b. precipitation exceeds evapotranspiration on land
         c. advection of maritime air onto land areas explains the imbalance
   D. Movement on and Beneath Earth’s Surface
      1. precipitation that falls on land
a. collects on the surface
b. **runoff**: that portion of Earth’s circulating moisture that moves in the liquid state from land to sea
c. **infiltration**: downward movement of water into the ground

2. runoff balances the 8\% excess of precipitation over evaporation taking place on the continents – keeps the oceans from dying up

E. Residence Times
1. enormous variation in cycling of individual molecules of water
   a. glacial ice: thousands of years
   b. water in buried rocks: thousands or millions of years
2. water moving through cycle is in almost continuous motion
3. at any given moment the atmosphere contains only a few days’ potential precipitation

II. The Oceans
A. How Many Oceans
1. world ocean divided into 4 principal parts
   a. Pacific
      1) occupies 1/3 of total area of Earth
      2) twice as big as any other body of water
      3) large tropical ocean
   b. Atlantic
   c. Indian
   d. Arctic: much smaller and shallower than the other 3 and mostly covered with ice
2. sea: sometimes used synonymously with ocean, sometimes to denote smaller body of water

B. Characteristics of Ocean Waters
1. Chemical Composition
   a. **salinity** of seawater: measure of concentration of dissolved salts
      1) mostly sodium chloride
      2) average salinity of seawater = 3.5\% (35 parts per thousand)
   b. variation in salinity
      1) low
         a) where rainfall is heavy and near the mouths of major rivers
         b) equatorial regions (heavy rainfall, cloudiness, humidity, river discharge)
         c) lowest in polar regions (minimal evaporation, considerable inflow of fresh water from rivers and ice caps)
      2) highest
         a) partly landlocked seas in dry, hot regions
         b) subtropics (precipitation is low, evaporation is high)
2. Increasing Acidity
   a. oceans absorb 1/3 of excess CO\textsubscript{2} released into the air each year by human activity which then forms carbonic acid → oceans becoming more acidic
   b. acid level of oceans:
1) currently ocean water is slightly alkaline, with a pH of 8.1
2) 0.1 lower (more acidic) than in pre-industrial era
3) estimate ocean pH could drop to 7.7 by end of century
c. likely consequences: a more acidic ocean will affect growth of organisms that require calcium carbonate to build their shells or exoskeletons:
   1) coral polyps
   2) foraminifera, microscopic creatures that occupy the bottom of the oceanic food web and are food for many fish

3. Temperature
   a. generally surface seawater temperatures decreases with increasing latitude
      1) ~80° F in equatorial regions
      2) ~28° F (average freezing point for seawater) in polar regions
   b. **western sides** of oceans generally **warmer** than eastern margins because of major ocean currents

4. Density
   a. seawater density varies with temperature, salinity, and depth
   b. high density: low temperatures, high salinity, deep water
   c. **surface layers of seawater contract and sink in cold regions; deeper water rises to surface in warm areas**

III. Movement of Ocean Waters
   A. Tides
      1. Causes of Tides
         a. cause: gravitational attraction of moon and sun
         b. tides are bulges (high tide) in the sea surface on the side of Earth facing the moon and on the opposite side, and simultaneous sinks (low tides) halfway between
         c. primarily vertical motions of water except along coastlines
         d. magnitude of tidal fluctuations is variable in time and place
         e. tidal cycle:
            1) two complete tidal cycles have duration of about 24 hours 50 minutes
            2) flood tide: actual movement of water toward the coast
            3) high tide: maximum water level at end of the flood tide period
            4) ebb tide: gradual movement of water away from the coast
            5) low tide: minimum water level at end of the ebb tide
      2. Monthly Tidal Cycle
         a. tidal range: vertical difference in elevation between high and low tide
         b. spring tide:
            1) higher than normal tidal range
            2) occurs when Earth, moon and sun are positioned in a straight line
            3) occurs twice each month, at time of full and new moon
         c. neap tide:
1) lower than normal tidal range
2) occurs when sun and moon are located at right angles to one another in respect to Earth
3) occurs twice each month, at the first and third quarter moons

d. tidal range also affected by proximity of Earth and moon in moon’s elliptical orbit (distance varies by 31,200 miles or 12%)
   1) perigee: when Earth and moon are closest point to each other – tides are greater than at apogee
   2) apogee: when Earth and moon are at farthest point from each other

3. Global Variation in Tidal Range
   a. enormous variation dependant on shape of coastline and sea bottom configuration
   b. ranges:
      1) average ≈ 5-10 ft
      2) in partly landlocked seas it’s negligible
      3) greatest tidal range in Bay of Fundy, eastern Canada (50 ft)

B. Currents
1. shift vast quantities of water both horizontally and vertically
2. causes
   a. wind flow (primary driver of surface currents)
   b. contrasts in temperature
   c. variation in salinity
3. influenced by
   a. size and shape of ocean
   b. configuration and depth of sea bottom
   c. Coriolis effect

4. Deep Ocean Circulation
   a. thermohaline circulation: circulation of deep ocean water caused by differences in water density that arise from differences in salinity and temperature – water sinks if its salinity increases or its temperature decreases, mostly in high latitude oceans
      1) cold, dense water sinks in North Atlantic and flows south deep below the surface
      2) joins eastward moving deep, cold, high salinity water circulating around Antarctica
      3) flows north and rises in Indian and Pacific Oceans and flows toward North Atlantic
      4) can take centuries to complete a circuit
   b. concern that increased melting of Greenland glaciers due to global warming may disrupt North Atlantic downwelling of water

5. People and the Environment: The Great Pacific Garbage Patch
   a. 10% of the 200 billion tons of plastic produced each year ends up in the ocean
      1) plastic garbage patch is 1-2 times the size of Texas
      2) increasing tenfold every decade
3) plastic does not biodegrade – it photo degrades into smaller and smaller pieces
4) accumulates in the subtropical gyres in the area of the subtropical highs
   a) eastern garbage patch: between Hawaii and California
   b) western garbage patch between Japan and Hawaii
5) a major culprit is plastic garbage bags
   a) came into widespread use in early 1980s
   b) 500 billion – 1 trillion produced each year
b. associated environmental hazards:
   1) marine animals mistake the floating plastic for food and they starve to death
   2) marine animals become entangled in plastic bags or canned drink plastic rings and starve to death
   3) chemicals in plastic breakdown into toxins that contaminate fish that feed on the plastic as well as those, including humans, that feed on the fish
   4) arguably the biggest threat to the planet’s marine life
C. Waves
   1. result in changes in shape of the ocean surface but little displacement of water
   2. movement of energy rather than matter
IV. Permanent Ice – The Cryosphere
A. 2\textsuperscript{nd} largest moisture storage reservoir (after oceans)
B. ice on land
   1. 10\% of Earth’s land surface is covered with ice
   2. alpine glaciers, ice sheets, ice caps
C. oceanic ice
   1. fresh water: salt not taken up when water freezes
   2. largest ice pack: covers most of the Arctic Ocean
   3. in last decade formerly stable ice shelves on Antarctica, such as the Larsen-B, have disintegrated
D. Permafrost:
   1. \textbf{permafrost}: permanently frozen subsoil
   2. occurs in high latitudes and high altitudes: widespread in northern Canada, Alaska, and Siberia
   3. \textit{People and the Environment}: Thawing Permafrost in Alaska
      a. active layer:
         1) upper portion of permafrost that thaws in summer
         2) upper 12-40 inches around Fairbanks, Alaska
      b. permanently frozen ground
         1) extends down perhaps 165 feet
         2) beginning to thaw
      c. impacts of thaw:
         1) causes roads and pipelines to deform
         2) reduces number of days can explore for oil in tundra
3) increased release of CO$_2$ and methane from increased rate of decomposition of organic material

V. Surface Waters
   A. surface water represents 0.02% of world's total moisture supply
   B. Lakes
      1. lake: body of water surrounded by land
      2. Lake Baykal, Siberia – world's largest (by volume) and deepest freshwater lake
      3. salt lakes
         a. 40% lake water is saline
         b. Caspian Sea: 75% of non-oceanic saline water
         c. any lake with no natural drainage outlet will become saline
         d. Great Salt Lake, Utah
      4. geographic distribution of lakes
         a. regions glaciated in recent geologic past
         b. rift valleys – eastern and central Africa
         c. sinkholes in limestone areas such as Florida
      5. lakes are temporary landscape features
   6. Human Alteration of Natural Lakes
      a. diversion of streams impact lakes, for example Mono Lake, California and the Aral Sea
      b. Aral Sea, Central Asia, Uzbekistan-Kazakhstan
         1) once the world's 4$^{th}$ largest lake
         2) now only 10% of its original size
         3) inflowing water diverted for irrigation projects to boost agricultural production
      c. Lake Chad, Africa
         1) once one of Africa's largest lakes; now only 10% of its original size
         2) climate change in region has likely led to ongoing drought
   7. Reservoirs
      a. artificial lakes constructed by humans
      b. reasons: flood control; reliable water supply for agriculture or municipalities; hydroelectric power
      c. impacts: loss of land; altered ecosystems; rapid sedimentation

C. Swamps and Marshes
   1. flat areas submerged in water at least part of the time but shallow enough to permit the growth of water tolerant plants
   2. swamp: trees dominate plant growth
   3. marsh: grasses and rushes dominate plant growth
   4. associated with coastal areas, broad river valleys, or recently glaciated areas

D. Rivers and Streams
   1. extremely dynamic component of the hydrologic cycle
   2. occurrence closely related to precipitation patterns
   3. **drainage basin**: all the land area drained by a river and its tributaries
4. 2 dozen great rivers produce ½ world’s total stream discharge
d. **Amazon River**: 20% world’s discharge (3x combined discharge of all US rivers)
e. **Mississippi** River: largest river in North America
   a. drainage basin covers 40% land area of 48 states
   b. accounts for 1/3 discharge of all US rivers

VI. Underground Water
A. intro
   1. many times as much underground water as water in lakes and streams and much more widely distributed
   2. source: precipitation that percolates directly into soil or seeps downward from lakes and streams
   3. **porosity**
      a. percentage of the total volume of a material that consists of voids
      b. determines water quantity that can be held in subsurface material
   4. **permeability**
      a. ability to transmit ground water
      b. determined by size of pores and their degree of interconnectedness
   5. rate at which water passes through rock depends on both porosity and permeability
      a. clay: high porosity (many interstices/openings)
      b. clay: low permeability (interstices are so tiny that molecular attraction binds the water to the clay flakes) → clay traps large amounts of water
   6. **aquifer**: a permeable subsurface rock layer that can store, transmit and supply water
   7. **aquiclude**: an impermeable rock layer that is so dense as to exclude water
   8. **hydrologic zones** (subsurface zones vertically from top to bottom):
      a. zone of aeration
      b. zone of saturation
      c. zone of confined water
      d. waterless zone

B. Zone of Aeration
   1. mixture of solids, water, and air
   2. interstices filled partly with water, partly with air
   3. water can evaporate, be absorbed by plants and transpired, or seep downward into zone of saturation

C. Zone of Saturation
   1. all pore spaces are fully saturated with water
   2. **groundwater**: moisture in this zone
   3. **water table**: top of the saturated zone
      a. follows the general configuration of the land surface above it
      b. lakes, swamps, marshes, or permanent streams form where water table intersects the surface
      c. geographic variations:
         1) closer to surface in valley bottoms; more distant beneath a ridge or hill
2) higher in humid regions than arid regions

4. **perched water table**: localized zone of saturation that develops above an aquiclude

5. **cone of depression**: water table drop surrounding a well

6. water percolates down through saturated zone under influence of gravity, leading it from areas where water table is high toward area where it is lower

D. **Zone of Confined Water**
1. separated from zone of saturation by impermeable rock
2. **artesian well**: free flowing well created when pressure in confined aquifer is sufficient to force the water to the surface
3. geographic distribution erratic; underlies many arid or semiarid regions

E. **Waterless Zone**
1. overlying pressure increases rock density so there are no pores
2. begins several kilometers below land surface

F. **Groundwater Mining**
1. accumulation of underground water is tediously slow; its use by humans can be distressingly rapid
   a. U.S. Southwest recharge (replenishment) rate averages 0.2”/year
   b. yearly pumpage by farmers is often 30”/year -- 150 years of recharge

2. The **Ogallala Aquifer**
   a. largest US aquifer
   b. underlies 225,000 mi² of the southern and central parts of Great Plains
   c. series of limey and sandy layers
   d. ranges in thickness from a few inches (Texas) to 1,000 feet (Nebraska Sandhills)
   e. water has been accumulating for 30,000 years

3. tapping the waters of the Ogallala
   a. farmers began in early 1930s
   b. → rapid spread in high-yield farming into areas never before cultivated
   c. → sinking water table

4. future prospects
   a. farmers shifting to crops that require less water
   b. water and energy conserving measures
   c. estimate in next 4 decades 5 million acres now irrigated will revert to dry-land production
   d. problem: groundwater is no respecter of property boundaries
   e. geographic differences
      1) Nebraska Sandhills: deepest aquifer, minimal water use, relatively rapid recharge rate – withdrawal averages 10% of recharge
      2) southwestern Kansas: withdrawal rate 20x recharge rate

G. **People and the Environment: Subsidence from Groundwater Extraction**
1. water table drop can lead to land subsidence
2. U.S. regions with significant land subsidence due to groundwater pumping:
   a. California’s San Joaquin Valley
      1) groundwater withdrawn largely for crop irrigation
      2) water table has dropped as much as 400 ft.
      3) land has subsided almost 29 ft.
   b. Las Vegas, Nevada where land has subsided as much as 6 feet since 1950
3. InSAR (Satellite Interferometric Synthetic Aperture Radar) used to map areas of subsidence and faulting due to groundwater pumping