Topic 5

1983 July

Water in the Atmosphere, Surface, and Subsurface

2009 March

- Properties of Water
- Humidity and Atmospheric Moisture
- Distribution of Water
- The Hydrologic Cycle
- The Water Balance Concept
- Groundwater Characteristics
- Groundwater Pollution
- Water Use

KEY LEARNING CONCEPTS

Chapters 7 (up to humidity) & 9

Unique Properties of Water

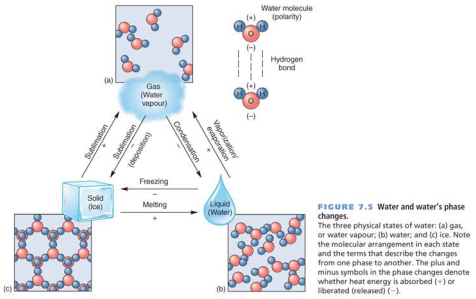


FIGURE 7.5 Water and water's phase changes. The three physical states of water: (a) gas, or water vapour; (b) water; and (c) ice. Note the molecular arrangement in each state and the terms that describe the changes from one phase to another. The plus and minus symbols in the phase changes denote whether heat energy is absorbed (+) or liberated (released) (−).

Phase Changes

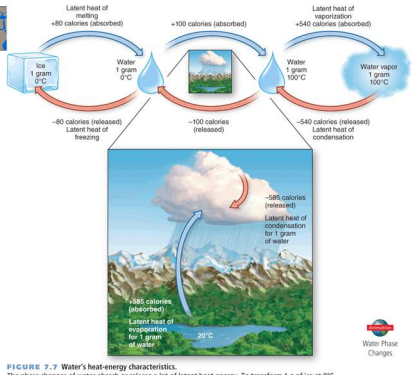


FIGURE 7.7 Water's heat-energy characteristics. The phase changes of water absorb or release a lot of latent heat energy. To transform 1 g of ice at 0°C to 1 g of water vapour at 100°C requires 720 cal: 80 + 100 + 540. The landscape illustrates phase changes between water (lake at 20°C) and water vapour under typical conditions in the environment.

Water on Earth

- All water above, at, or below Earth's surface is result of out-gassing
- A closed system; quantity is at equilibrium
- BUT changes in sea level occur due to:
  - **Eustasy** - variations in distribution of water, primarily glacial ice vs. liquid water
  - **Isostacy** - subsidence or uplift of continental landmasses

Distribution of Earth's Water Today

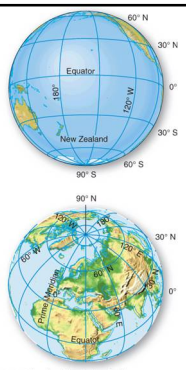
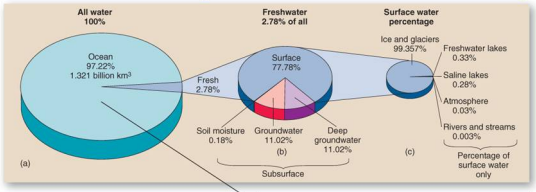


FIGURE 7.2 Land and water hemispheres.
Two perspectives that roughly illustrate Earth's ocean hemisphere and land hemisphere.

Distribution of Earth's Water Today



Earth's Water and the Hydrologic Cycle

Ocean	Earth's Ocean Area (%)	*Area (km^2)	*Volume (km^3)	Mean Depth of Main Basin (m)
Pacific	48	179 670	724 330	4280
Atlantic	28	106 450	355 280	3930
Indian	20	74 930	292 310	3960
Arctic	4	14 090	17 100	1205

*Values are x 1000; includes all marginal seas.

FIGURE 7.3 Ocean and freshwater distribution on Earth.
The location and percentages of (a) all water, (b) freshwater including subsurface water, and (c) surface water.

A Hydrologic Cycle Model

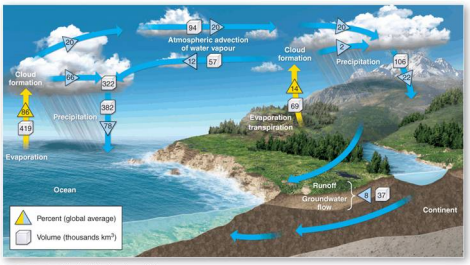


FIGURE 9.1 The hydrologic cycle model.
Water travels endlessly through the hydrosphere, atmosphere, lithosphere, and biosphere. The triangles show global average values as percentages. Note that all evaporation (86 + 14 = 100) equals all precipitation (78 + 22 = 100), and advection in the atmosphere is balanced by surface and subsurface water runoff when all of Earth is considered.

Hydrologic Cycle

- A system that describes the transfer of water between:
  - Hydrosphere
  - Atmosphere
  - Lithosphere
- Energy obtained from Sun and force of gravity
- Includes all processes and mechanisms of transfer

Parts of the Hydrologic Cycle

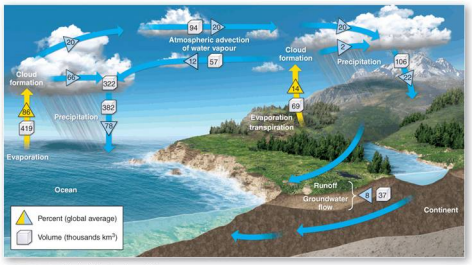
Movement Toward or Away from Earth's Surface

- Precipitation
- Evaporation/Transpiration
- Condensation
- Throughfall
- Interception
- Stemflow

Water at Earth's Surface and Subsurface

- Infiltration
- Percolation
- Sheetflow
- Channelized Flow
- Runoff
  - Saturated Overland Flow
  - Horton Overland Flow

A Hydrologic Cycle Model



Precipitation

Evaporation/ Transpiration

Condensation

Throughfall

Interception

Stemflow

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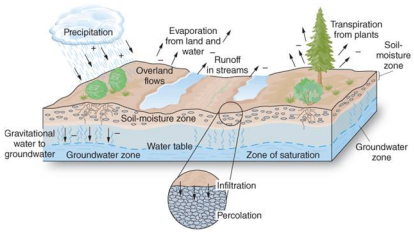
Surface Water
and Soil-Moisture Environment



Infiltration

Percolation

Runoff
- Saturated Overland Flow
- Horton Overland Flow

Sheetflow

Channelized Flow

FIGURE 9.2 The soil-moisture environment.
The principal pathways for precipitation include interception by plants; throughfall to the ground; collection on the surface, forming overland flow to streams; transpiration and evaporation from plants; evaporation from land and water; and gravitational water moving to subsurface groundwater.

Soil-Water Balance Concept

- Accounting of water inputs and outputs
- Developed by C. W. Thornthwaite to:
  - describe allocation of water
  - describe surplus or deficit at a location
  - determine timing and quantity of irrigation
  - develop a climatic classification

The Soil-Water Balance Equation

Water balance equation:

P (precipitation) = AE (actual evapotranspiration) + S (surplus) ± ΔST (change in soil-moisture storage)

AE = (PE (potential evapotranspiration) − D (deficit))

Explanation:

Moisture supply (rain, snow, frozen precipitation, and hail) = Actual moisture demand + Moisture oversupply (amount of moisture that exceeds PE, when moisture storage is full) ± Moisture savings (use [−] or recharge [+] of soil moisture)

Actual moisture demand = Moisture demand (potential evaporation and transpiration if moisture is available) − Moisture shortage (amount of unsatisfied PE; the demand not met either by P or by soil moisture)

FIGURE 9.3 The water balance equation explained.
The outputs (components to the right of the equal sign) are an accounting of expenditures from the precipitation moisture-supply input (to the left).

Global Water Balance Components

Precipitation Input (P)

in all forms (rain, snow, hail, sleet, fog, etc.)

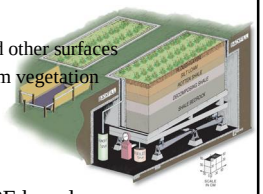
Note: this is annual P. How would P vary from month to month in Brandon?

FIGURE 9.5 Precipitation (P) in Canada, the continental United States, and northern Mexico—the supply.
Annual precipitation (water supply, P) in Canada and the United States. [Adapted from NWS, US Department of Agriculture and Environment Canada.]

Global Water Compone

Potential Evapotranspiration (PE)

- Evaporative demand of atmosphere
  - Fcn. of temperature and relative humidity
  - Includes:
    - Evaporation from soil and other surfaces
    - Transpiration of water from vegetation
  - Measured:
    - evaporimeter
    - Weighing lysimeter
  - Thornthwaite estimated PE based on mean monthly temperature and daylength



Potential Evapo-transpiration

Note: this is annual PE. How would PE vary from month to month in Brandon?

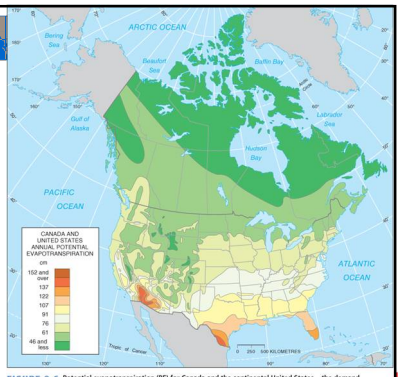


FIGURE 9.6 Potential evapotranspiration (PE) for Canada and the continental United States—the demand. (From C.W. Thornthwaite, "An approach toward a rational classification of climate," Geographical Review 38 (1948): 64. Adapted by permission from the American Geographical Society. Canadian data from M. Sanderson, "The climates of Canada according to the new Thornthwaite classification," Scientific Agriculture 28 (1948): 501–17.)

Deficit (D)

- PE is satisfied by either:
  - precipitation (monthly)
  - or soil moisture storage (monthly)
- If PE is not met, a deficit (D) occurs
  - Example, in a given month:
    - P = 60 mm, but PE = 100 mm
    - Soil Moisture Storage = 20mm
    - Is there a deficit (D)?

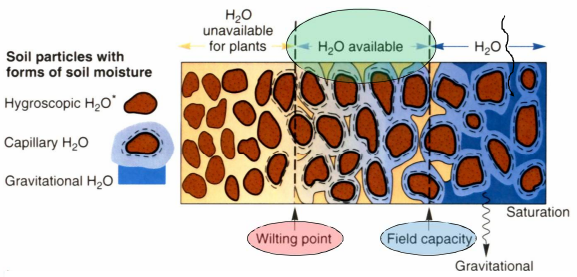
Actual Evapotranspiration (AE)

- Difference between PE and D is AE
  - Example, in a given month:
    - P = 60 mm, but PE = 100 mm
    - Soil Moisture Storage = 20mm
    - Deficit (D) = 20 mm
    - What is AE?
    - Would irrigation be required?

Surplus (S)

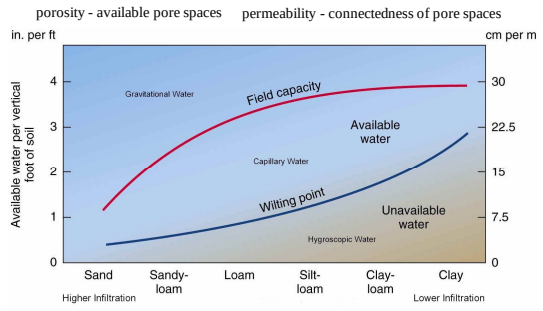
- Occurs when:
  - P > PE AND soil moisture storage (ST) is at field capacity (amt. highly variable)
  - Surplus either:
    - collects in ponds, puddles, etc. called detained water
    - percolates through soil as gravitational water and recharges groundwater
    - runs off as sheetflow or channelized flow
- **Problem:** Thornthwaite model assumes that all excess precipitation goes into soil moisture storage until field capacity is attained, doesn't consider Horton overland flow or detained water

Soil Moisture Storage (ST)



Wilting point occurs when all available capillary water has been used
Field capacity occurs when soil is holding the max. amount of capillary water

Soil Porosity and Permeability



Water Budget Graph

- Graphic depiction of water balance
- Depicts distribution and use of available water at a given location
- Most locations experience seasonal deficits and surpluses
- Problem is often timing rather than availability of water

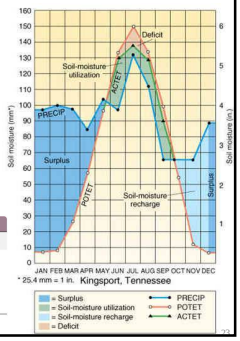


Table 9.1 Annual, March, and September Water Balances for Kingsport, Tennessee

	PRECIP	=	(POTET	−	DEFIC)	+	SURPL	±	ΔSTRGE
Annual	1119.0	=	(781.0	−	16.0)	+	354.0	±	0
	(44.1)	=	(30.7	−	0.6)	+	(14.0)	±	0
March	97.0	=	(24.0	−	0)	+	73.0	±	0
	(3.8)	=	(0.9	−	0)	+	(2.9)	±	0
September	66.0	=	(99.0	−	8.0)	+	0	−	25.0
	(2.6)	=	(3.9	−	0.3)	+	0	−	(1.0)

Note. All quantities in millimeters (inches).

Sample Water Budgets

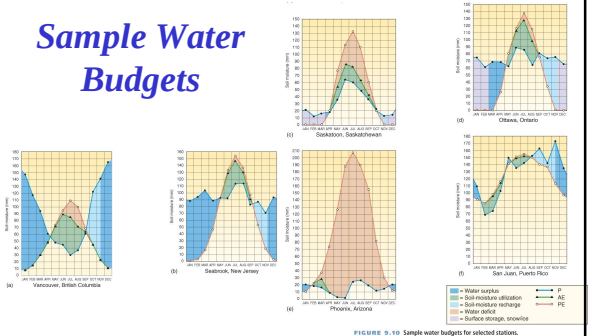


FIGURE 9.10 Sample water budgets for selected stations.

Groundwater

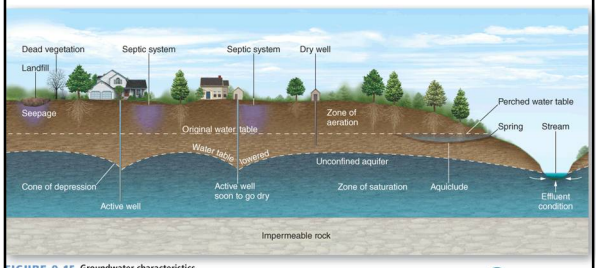


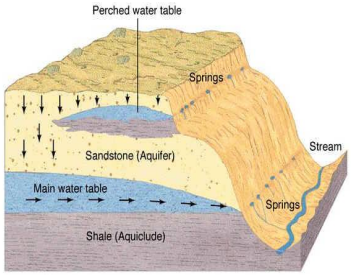
FIGURE 9.15 Groundwater characteristics.
Subsurface groundwater characteristics, processes, water flows, and human interactions. Follow the concepts across the illustration from left to right as you read along in the text.

Animation
Why Is There a Water Table?

Aquifers and Aquicludes

Aquifer - rock or sedimentary unit of sufficient porosity & permeability is able to store and transport significant amounts of water

Aquiclude - rock or sedimentary unit insufficient porosity or permeability **does not** contain or transport significant amounts of water



Aquifers, Wells, and Springs

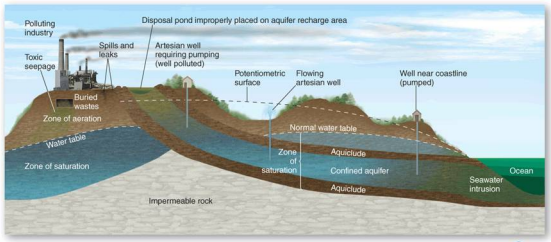


Figure 9.15

Animation
Forming a Cone of Depression

Aquifers, Wells, and Springs

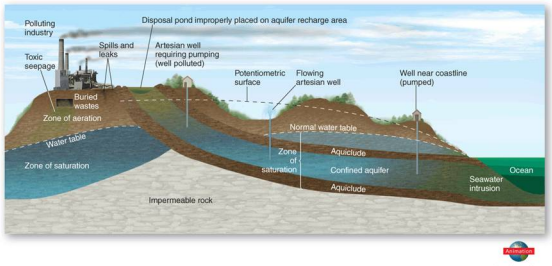


Figure 9.15

Forming a Cone of Depression

Groundwater and Streamflow

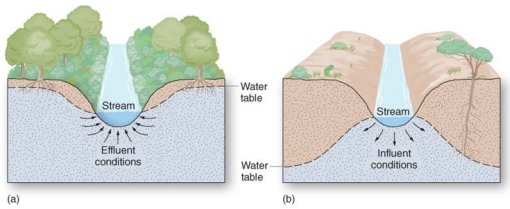
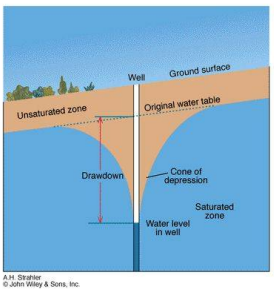


FIGURE 9.17 Groundwater interaction with streamflow.
(a) Effluent stream base flow is partially supplied by a high water table, characteristic of humid regions.
(b) Influent stream supplies a lower water table, characteristic of drier regions. The water table may drop below the stream channel, effectively drying it out.

Groundwater Use

- Volume of available water varies; called **specific yield**
- Draw down results in a **cone of depression, water law**
- **Groundwater mining** occurs when pumping exceeds recharge and results in:
  - Subsidence due to decreased pore water pressure
  - Encroachment of sea water in coastal areas



A.H. Strahler
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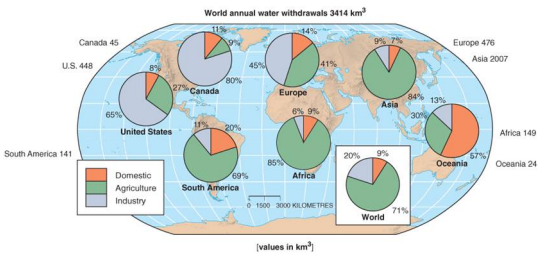
Groundwater Pollution

- Groundwater pollution categorized according to the origin of the source
  - Nonpoint source pollution originates over a large area e.g. herbicide or pesticide application
  - Point source pollution originates at a specific site e.g. hazardous waste dump, contaminant spill, or injection well

Water Use

Consumptive vs. Non-consumptive vs. Instream Uses



Vulnerability