Hydrogeology

Introduction to Hydrogeology

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Hydrologic Cycle

- Hydrology is the study of water in the broadest sense that deals with the occurrence, distribution, movement and chemistry of water present in the Earth.
- Hydrogeology is a component of hydrology that encompasses the inter-relationships of geologic materials and processes with water.
- Defined as the global pattern of continuously circulating water between the ocean, the atmosphere and land.
- Its dynamic operation and the interactive processes frame the entire theoretical study of hydrology.

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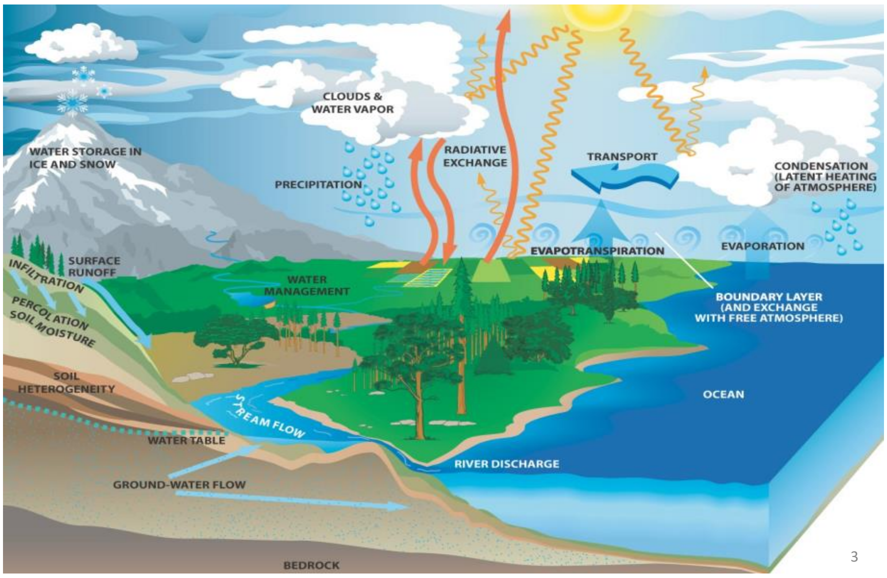
Hydrologic Cycle



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Hydrologic Cycle

Major characteristics:

- A dynamic system constantly powered by the solar radiation and embraced by constant flow
- A closed system to which no new water is added or lost in any significant amount.
- A recycling system which enables water to remain clean
- A system in balance barring the generally adverse impacts of human activities (pumping, damming, introducing into it contaminants...)
- An interactive system signified by water's readily changing states and moving between the atmosphere, ground-water aquifers, and surface water bodies.

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Hydrologic Balance

- Conservation of water mass in the hydrologic system is expressed as follows:
- **Inflow – Outflow = Change in Storage**
- For example, lake levels respond to the balance of inflow versus outflow. A given lake receives water from its drainage basin. This is inflow to the lake. Outflow of water may or may not occur.
- The boundary of the drainage basin is determined by the **drainage divide** (the topographic divide between adjacent drainage basins).

Hydrologic Balance

Sources of inflow:	Sources of outflow:
Precipitation	Evapotranspiration
Overland flow	Evaporation of surface water
Surface water	Surface water
Groundwater	Groundwater
Anthropogenic inputs (e.g. pipes)	Anthropogenic outputs

- When the system (lake) is at steady state, the inflow equals the outflow, and accumulation/storage change is zero.
- When the system (lake) is in a transient state, the difference between inflow and outflow is change in storage (which may be either positive or negative).

Hydrologic Balance

- Changes in **storage due to positive or negative accumulation occur as changes in the mass of** water in the following phases:
- Surface water
- Soil moisture
- Ice and snow
- Plant moisture
- Groundwater

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Hydrologic Balance

- Hence, on a basin-wide scale one might want to determine recharge to the groundwater that occurs from infiltration due to precipitation.
- If all the groundwater inflows, outflows, and storage processes are understood, then one could balance all these known properties to back out the amount of recharge.
- For example, in a basin in which a river receives discharge from groundwater, one can make assumptions to simplify the system and back out recharge. In a true "basin", one might assume that all groundwater is discharged to the river prior to the exit of the river from the basin.

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Hydrologic Balance

- One might also assume that the underlying bedrock is impermeable (notice that this is not true in many cases).
- In this system, the only input to the groundwater is recharge from precipitation, and the only outputs are Q and ET.
- If we assume that the basin is at steady state, e.g., no changes in storage of water in the surface or subsurface is occurring, then accumulation is zero. Hence, in this system, recharge must equal Q and ET.

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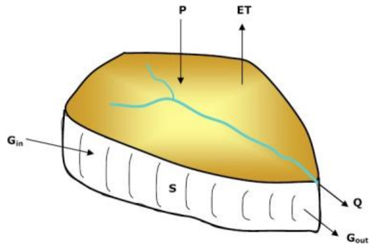
Hydrologic Balance

$$\frac{\partial S}{\partial t} = P + G_{in} - (Q + ET + G_{out})$$



At steady state: $\frac{\partial S}{\partial t} = 0$

$Q = P + (G_{in} - G_{out}) - ET$

What does the steady state assumption imply ?

How accurate is the steady state assumption and at what scales?

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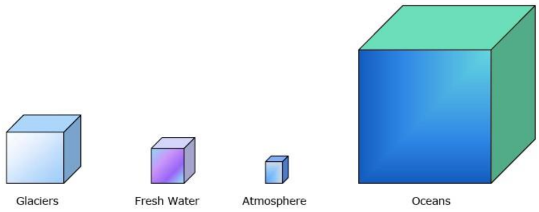
Relative volumes of various kinds of water

Item	Area 10^6 km^2	Volume km^3	Percent of total water	Percent of fresh water
Oceans	361.3	1,338,000,000	96.50	
Groundwater:				
Fresh	1,34.8	10,530,000	0.76	30.10
Saline	134.8	12,870,000	0.93	
Soil moisture	82.0	16,500	0.0012	0.05
Polar ice	16.0	24,023,500	1.7	68.6
Other ice and snow	0.3	340,600	0.025	1.0
Lakes:				
Fresh	1.2	91,000	0.007	0.26
Saline	0.8	85,400	0.006	
Marshes	2.7	11,470	0.0008	0.03
Rivers	148.8	2,120	0.0002	0.006
Biological water	510.0	1,120	0.0001	0.003
Atmospheric water	510.0			
Total water	510.0			
Fresh water	148.8			



Relative volumes of water in glaciers, fresh water, atmosphere and oceans.

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Review of Hydrologic Fluxes: Evapotranspiration

- Evaporation is the process by which liquid water is converted into a gaseous state. This process requires large amounts of energy, e.g., 2.4×10^6 J (5.7×10^5 calories) of heat energy is required to convert 1 kilogram of liquid water to the vapour phase.
- At any given temperature, the air can hold only a given amount of moisture, which is referred to as the **saturation humidity**. The saturation humidity increases with the temperature of the air. The **relative humidity** (expressed as %) is the ratio of the measured humidity ($g_{water}/m^3{}_{air}$) to the saturation humidity. Evaporation ceases when 100% relative humidity is reached.

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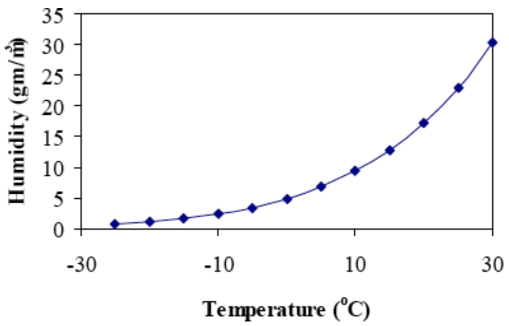
Evapotranspiration



- Sunlight and wind drive evaporation. Wind removes vapor water from the water surface, thus keeping the absolute humidity low above that surface.
- By keeping the absolute humidity low, the driving force for evaporation remains strong.

Evapotranspiration

- <u>Transpiration</u>
- Plants pump water from the ground to the atmosphere through a process called transpiration. Transpiration increases with size and density of vegetation, but is also controlled by sunlight (transpiration is only important during the growing season) and available soil moisture (when the soil moisture drops below the so-called "**wilting point**" no water can enter the plant roots).
- The combined loss of water to the atmosphere via the processes of evaporation and transpiration (total water loss) is called **evapotranspiration**. If the soil moisture drops below the wilting point, "actual evapotranspiration" will be less than "potential evapotranspiration".

Precipitation

- When air mass with RH less than 100% starts to cool without loosing moisture, the RH increases to 100% and air mass becomes saturated-- condensation occurs.
- However condensation requires a surface or nucleus on which to form: Cloud Condensation Nuclei.
- Formation of precipitation
  - Convective
  - Frontal
  - Orographic
- Measured with rain gauges
- Area average or Effective Uniform Depth (EUD)
  - Arithmetic Average
  - Theissen Method (Non--uniform distribution of Gauges)
  - Isohyetal Method (--do--)

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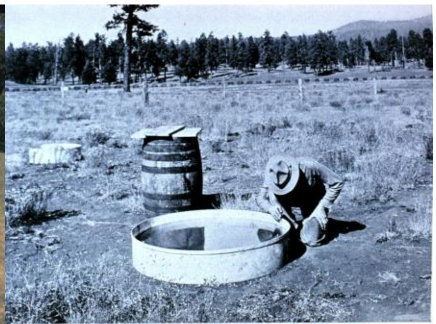

From U. S. Forest Service

GAGING THE THIRST OF THE AIR

The observer is measuring the depth of water in the evaporation pan with a graduated glass tube (burette)

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Runoff

- Runoff is the total flow (overland flow, interflow, and groundwater flow) to a stream.
- Overland Flow: Some rain or snow melting will drain across the land to a stream channel, and such topographic movement of a thin film of water on land surface is called overland flow.
- Interflow: Most of the infiltrated water will percolate more or less vertically through the unsaturated zone. However, the infiltrated water may move horizontally in the unsaturated zone where layers of soil with a low permeability exist beneath the surface. The horizontal movement of water in the unsaturated zone is referred to as interflow

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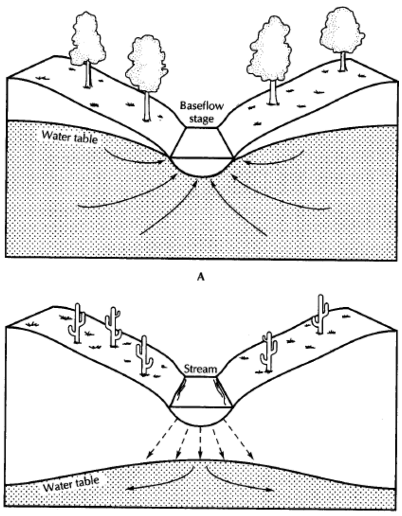
Runoff

- Streams gain or lose water from/to the surrounding aquifer depending on climate. In humid regions, a typical stream receives groundwater discharge and the stream discharge increases as one travels downstream, even if no tributaries occur.
- This is a **gaining stream**, or an **effluent stream**. For a gaining stream, the hydraulic gradient of the surrounding aquifer is toward the stream
- In arid regions, a typical stream receives water from overland flow, interflow, and baseflow at high elevations. At lower elevations, the bottom of the stream channel may be higher than the local water table, and water may drain from the stream to the ground (Figure 3-2B). Such a stream is called a **losing stream**, or an **influent stream**.



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Water functions and applications

Functions
• Regulatory (climate, nutrient/sediment transport)
• Life sustaining (humans need 3-8 ltr/day) - 95% of rural residents depend on groundwater.
• Habitat for a lot of aquatic species

Main uses
• Agriculture (freshwater irrigation)-50% from groundwater
• Industry (cooling) – 33% catered by groundwater.
• Drinking water and other domestic uses
• Energy (hydro-power)
• Transport (mainly on oceans & large rivers

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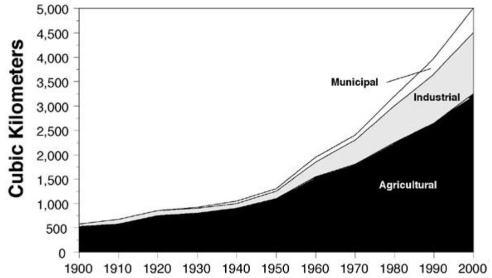
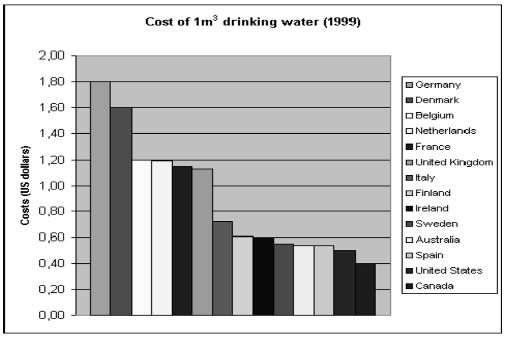
Importance of water: Scarcity….





Freshwater is an everyday problem for more than one billion people.

- More than 50 countries cannot provide safe and adequate freshwater for domestic use.
- By 2025, 12 more African countries will join the 13 that already suffer from water stress or water scarcity
- Mining occurs in arid countries: For example, groundwater extraction in Israel is 15-20% above safe yield.
- Agricultural sector supplies 5% of the gross national product, but drains 70% of the country's water.

Bar graph of cost of drinking water

Importance of water: Conflicts…..

The River Nile:

- Fixed amount of water available, 85% from Ethiopian highlands
- Next 25 year:
  – Doubling of population to 300 million
  – Economic development: Ethiopia and Sudan depends on Nile water
  – Building of dams would lead to war with Egypt
- Solution…?

Potential water conflicts, for example:

- Egypt, Ethiopia and Sudan (Nile water for irrigation)
- India and Bangladesh (Ganga River, dams)
- USA and Mexico (Colorado river)
- South Africa and Namibia (Okavango delta)

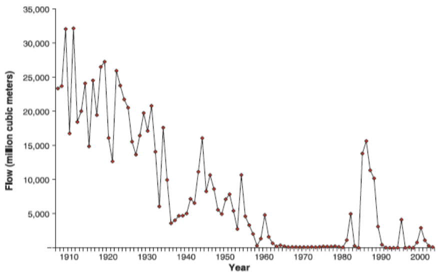


Fig. 1. Colorado river flows below all major dams and diversions, 1905 to 2001. Data are flows of the Colorado River as measured at U.S. Geological Survey Gage 09-5222, 35 km downstream from Morelos Dam. As shown, flows reaching the Colorado River delta have dropped to near zero in most years.

Other uses of water: Wastage

Consumption per capita:
- African Countries: 47 ltr/day
- Asian Countries: 85 ltr/day
- Netherlands: 128 ltr/day
- UK: 334 ltr/day
- USA: 700 ltr/day

Recreational :
- Excessive gardening- sprinkler on rainy day ??
- Golf course in the deserts ??
- Outdoor swimming pools
- Carwash

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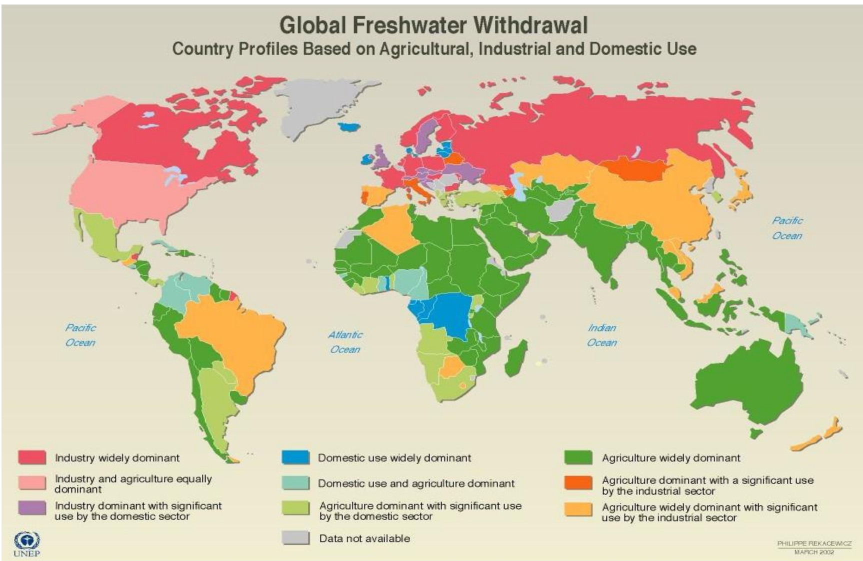
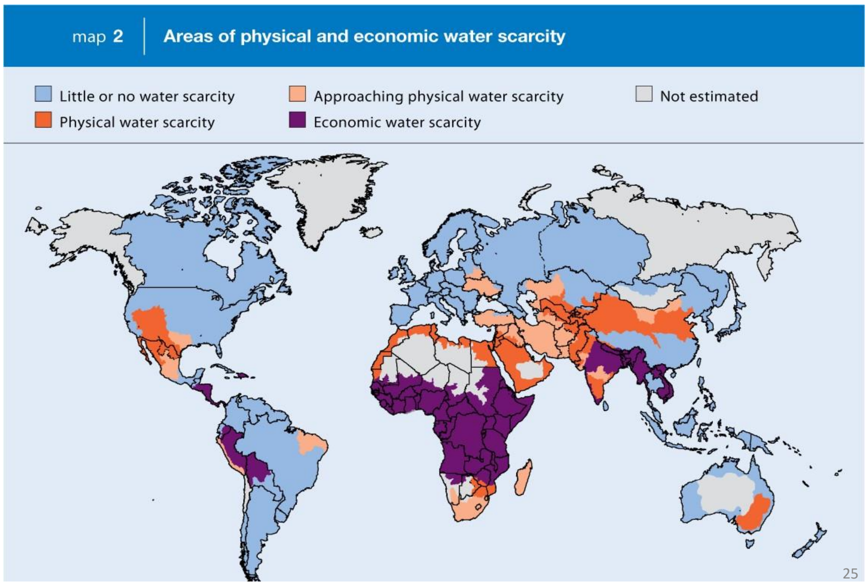
Global freshwater withdrawal



Source: Based on data fromTable FW1 in *World Resources 2000-2001, People and Ecosystems: The Fraying Web of Life*, World Resources Institute (WRI), Washington DC, 2000.

Global water scarcity



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Water resources: Factors

- Quantity (too much or too little water on annual basis)
- Timing (wet season flooding, dry season shortages)
- Quality (physical, chemical and biological)

Water is often in the *wrong quantities* *at the* *wrong time* *or of the* *wrong quality* *to be* available for human consumption

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