# Water and its physical properties in the environment

Water is the most common and important substance on the earth's surface. Without it, life and its metabolic processes, as we know them would not exist.

It can be: 1) a <u>solvent</u> in which gases, minerals and other substances dissolve and in which all metabolic processes take place in,
2) a <u>constituent</u> of a plant; approximately 75 to 90% of a plant's fresh weight,
3) a <u>reactant</u> in which it acts as a substrate for metabolic reactions; e.g. photosynthesis, hydrolytic reactions, nitrogen metabolism.

## → *Specific properties of water*

### A. Volumetric heat capacity (VHC), where VHC = density (r) x specific heat (Cp)

| | VHC | $r$ (g cm$^{-3}$) | Cp (J $^{o}$K$^{-1}$ g$^{-1}$) |
|---|---|---|---|
| Water | 4.18 | 1.00 | 4.18 |
| Air | 0.0012 | 0.0012 | 1.01 |
| Quartz | 2.13 | 2.66 | 0.80 |
| Organic matter | 2.50 | 1.30 | 1.92 |

Thus, the high Cp of water allows it to stabilize temperatures (i.e. how isothermal are lakes?)

### B. Energy is required to change the state (solid, liquid, vapor) of water and heat capacity is a function of state.

2a. heat of fusion = 334.8 J g$^{-1}$ or 80 cal g$^{-1}$

2b. heat of vaporization = 2256.0 J g$^{-1}$ or 540 cal g$^{-1}$

**SO WHAT!** - because of the high heat of vaporization, water has a cooling effect when it evaporates and a warming effect when it condensates.

| 2c. heat capacity as a function of state | Cp (J $^{o}$K$^{-1}$ g$^{-1}$) |
|---|---|
| solid (ice) | 2.09 |
| liquid (water) | 4.18 |
| vapor | 1.84 |

### C. Viscosity and absolute volume (figure) is temperature dependent. Viscosity will affect the flow of water in the soil and through the xylem within the plant,

| Temp. | Viscosity (g cm$^{-1}$ s$^{-1}$) |
|---|---|
| $0^{o}$ | $1.79 \times 10^{-2}$ |
| $20^{o}$C | $1.00 \times 10^{-2}$ |
| $50^{o}$C | $0.55 \times 10^{-2}$ |

for this reason, ice floats on liquid water; it has a 9% greater volume

## D. Saturation water vapor pressure (SVP) and density (SVD) increase exponentially with temperature (figures).

Related to this:

- **SVP** is independent of elevation
- relative humidity (**RH**) = actual vapor pressure ($e$) / saturated vapor pressure ($e_o$)
- vapor pressure deficit (**VPD**) = $e_o - e$
- the dew point (**dp**) = the temperature to which unsaturated air at some pressure must be cooled to reach its condensation point
- in nature, RH, VPD and temperature all can change dramatically over the course of a day, but the actual vapor pressure ($e$) remains relatively constant.

**EXAMPLE** comparison of the humidity conditions in San Francisco (SF) and in Death Valley (DV), California;

| | DV, true | SF, true | SF, hypothetical |
|---|---|---|---|
| 1. R.H., % (absolute) | 10 (0.1) | 70 (0.7) | 10 (0.1) |
| 2. Dry bulb, °C | 45<br>(113°F) | 15<br>(59°F) | 15<br>(59°F) |
| Vapor Density, µg cm$^{-3}$ | | | |
| 3. @ saturation | 65 | 12.8 | 12.8 |
| 4. actual (RH x SVD) | 6.5 | 9.0 | 1.28 |
| Vapor Pressure, mbar | | | |
| 5. @ saturation | 95 | 17 | 17 |
| 6. actual (RH x SVP) | 9.5 | 11.9 | 1.7 |
| 7. VPD (sat. - actual) | 85.5 | 5.1 | 15.3 |
| 8. Dew point, °C | 6.3 | 9.6 | ~16 |

Thus, we can conclude that at equal humidities, DV has :

a) warmer air and lower humidities than SF

b) a five (5.2) times greater water vapor density than does SF

c) a nearly 6 (5.6) times higher saturation water vapor pressure than SF

d) a nearly seventeen (16.8) times higher VPD than SF

and, e) a dew point that is nearly 40 (38.7) degrees away from the dry bulb temperature (for SF it is only 5.4 degrees away from the dew point.

## E. Water potential; Ψ (psi, expressed as a pressure in megapascals = MPa)

- the chemical energy contained in a parcel of water to do work - the ratio of Gibb's free energy to the partial molal volume of water, expressed relative to pure water
- by convention, pure water has a $\Psi = 0$
- plants and soil have $\Psi \leq 0$ (0.1 MPa = 1 bar)

- $\Psi = [RT / m_W \ V_W] \ \ln (e / e_o)$,
  where,
  $R$ = gas constant (8.31 J $^oK^{-1}$ $mol^{-1}$)
  $T$ = temperature ($^oK$)
  $m_W$ = molecular weight of water (18 g $mol^{-1}$)
  $V_W$ = specific volume of water (1.0 $cm^{-3}$ $g^{-1}$ @ $20^oC$)
  $(e / e_o)$ = RH from 4b above)

- Total water potential is the sum of three main components,

  (i) $\psi = P + \psi_\tau + \psi_\pi$

  (ii) $P$ = pressure or turgor potential (+ or -)

  (iii) $\psi_\tau$ = matric or adsorption potential (-)

  (iv) $\psi_\pi$ = osmotic potential (-)

  (v) water potential is reduced by the addition of solutes, addition of water-binding surfaces, negative pressures, and a reduction in temperature

  (vi) water moves from higher (less negative) to lower (more negative) water potentials

- Water potential gradients are responsible for the movement of water,

  from soil to root surfaces
  from root surfaces into the root xylem
  within the xylem
  from the xylem into the leaf

  5g. and then in the vapor state along gradients of vapor pressure,

  from the leaf into the air
  from the soil into the air

## F. Properties of water in the soil

- the amount of air pore space in a soil depends on the bulk density of that soil and the particle density, where

$$\% \text{ pore space} = 100 - [\text{bulk density} / \text{particle density}] \times 100$$

| | | |
|---|---|---|
| examples | sandy loam | 37 |
| | loam | 48 |
| | heavy clay | 56 |
| | clay + organic | 58 |

- pore size distribution is dependent on the soil particle sizes, where:

| Particle size | % pore space<br>coarse sand | <br>clay loam | <br>heavy clay |
|---|---|---|---|
| > 30 μm | 75 | 18 | 6 |
| 0.2 - 30 μm | 22 | 48 | 40 |
| < 0.2 μm | 3 | 34 | 53 |

(i) pore s > 30μm are too large to hold water, 0.2 - 30 μm pores hold water available to plants, <0.2 μm pores hold water too tightly for plants to extract ($\Psi$ is too negative)

(ii) the water potential can be calculated as $\Psi = 290/d$, where $d$ = the largest pore diameter that holds water

(iii) thus in soils the water potential is mostly determined by the matric potential

(iv) but water movement depends on osmotic gradients and plants actually get soil water from a thin coating on soil particles

- Soil water potential differs in different types of soils depending on their water content, known as their "moisture release characteristics" (desorption properties) - figures

- Adhesion of water molecules to soil particles allows "films" of water to exist on the particle surfaces, yet it also makes it more difficult to remove

So, question: how does all this influence water uptake and use in plants? - NEXT LECTURE

## General References on Water in a Botanical Context

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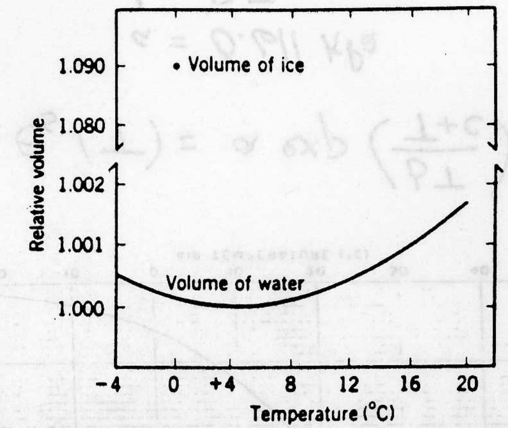


**Fig. 1.6.** Change in volume of water with change in temperature. The minimum volume is at 4°C, and below that temperature there is a slight increase in volume as more molecules are incorporated into the lattice structure. The volume increases suddenly when water freezes because all molecules are incorporated into a widely spaced lattice. Above 4°C there is an increase in volume caused by increasing thermal agitation of the molecules.

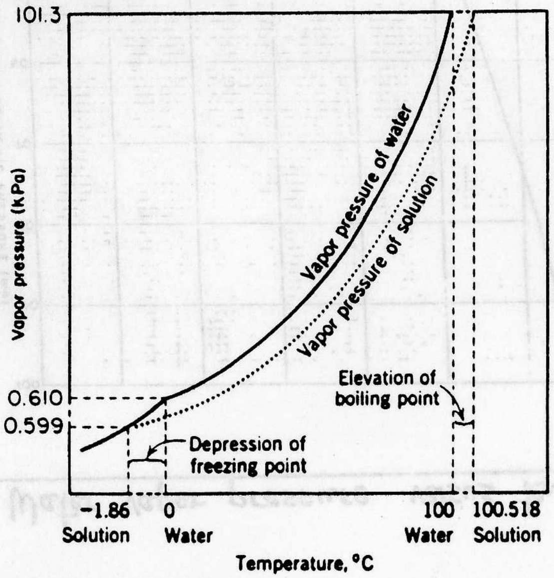


**Fig. 1.10.** Effects of 1 mole of nonelectrolyte per 1000 g of water (a 1 molal solution) on the freezing and boiling points and vapor pressure of the solution. Note that this diagram is not drawn to scale.

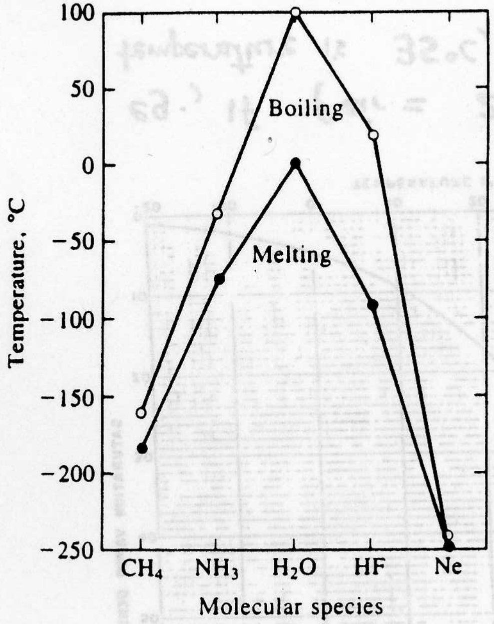


**Figure 2.1**

Boiling points and melting points for molecules with 10 protons and 10 electrons, showing the strikingly high values for water. Most biological processes take place from 0°C to 50°C, where water can be in the liquid state but the other substances cannot.

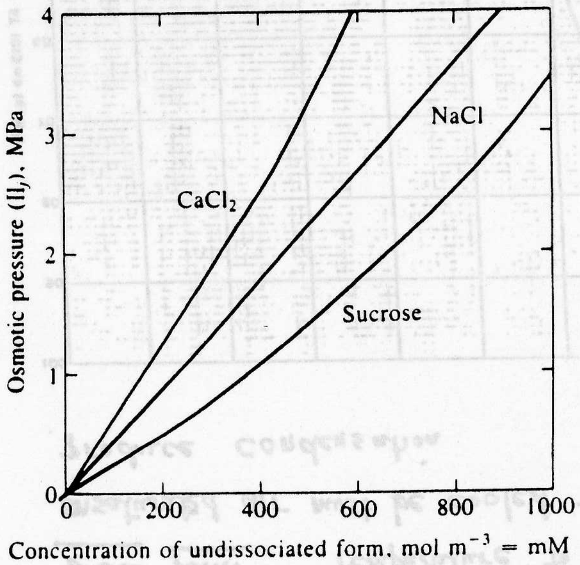
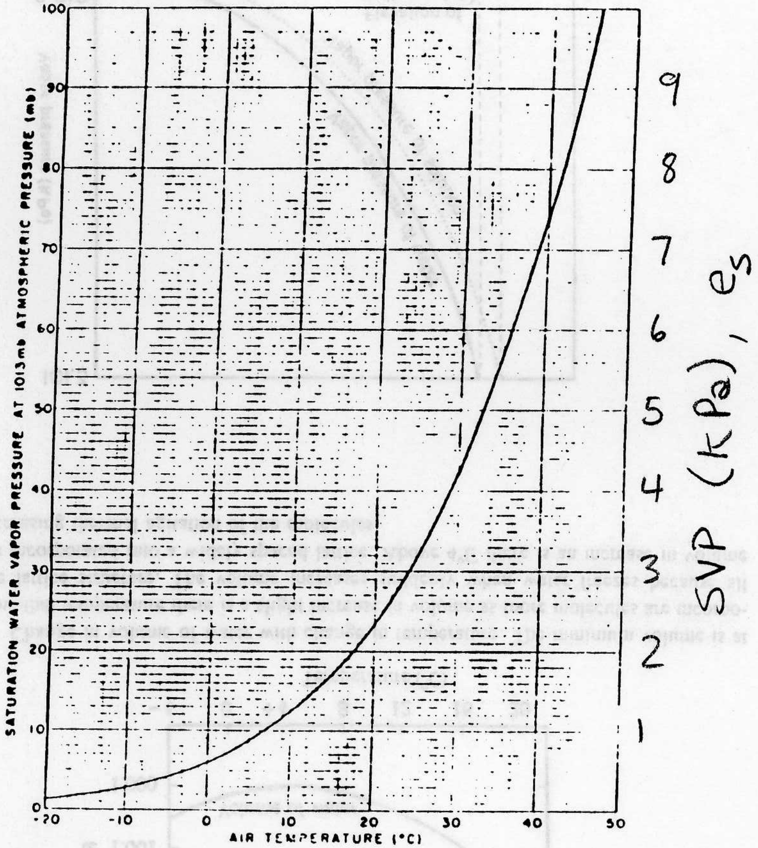


**Figure 2.7**

Relationship between concentration and osmotic pressure at 20°C for a nonelectrolyte (sucrose) and two readily dissociating salts (NaCl and $CaCl_2$). The different slopes indicate the different degrees of dissociation for the three substances. Data for osmotic pressure are based on the freezing point depression (see Weast and Lide, 1989).

## Water vapor pressure versus temperature



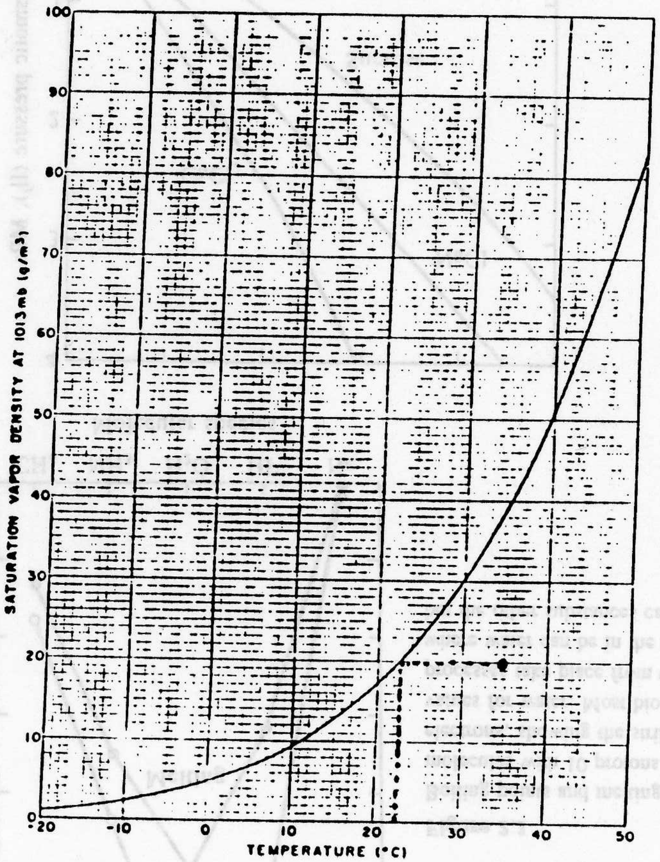
$$e_s(T) = a \exp\left(\frac{bT}{T+c}\right)$$

$a = 0.611$ kPa

$b = 17.5$

$c = 240.97$°C

**Dew point** - temperature to which unsaturated air must be cooled to produce condensation



eg., If $\rho_{air} = 20\ g\ m^{-3}$ and air temperature is 35°C, then dew point = 22.5°C

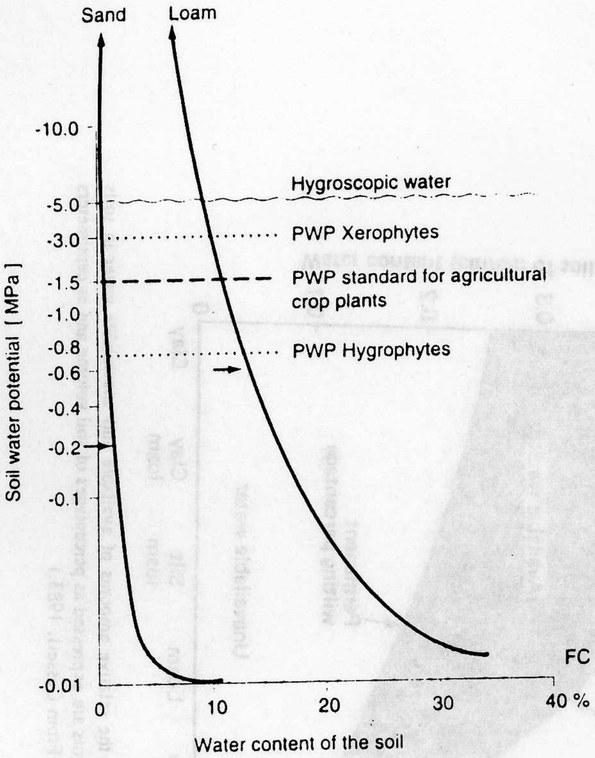


**Fig. 4.7.** Diagram showing the relationship between the water potential of soil and its water content (for a sandy and a loam soil). Conventional threshold value for field capacity (FC) is −0.015 MPa, for permanent wilting (PWP) −1.5 MPa; at values more negative than −5 MPa and there is only hygroscopically bound water. The average values shown for the different plant types depend on the type of soil (soil texture, pore size) and the vegetation; they may also be lower due to adjustment of the plants to water deficiency. The *arrow* is referred to in the text. (After Kramer 1949; Laatsch 1954; Slavíková 1965)

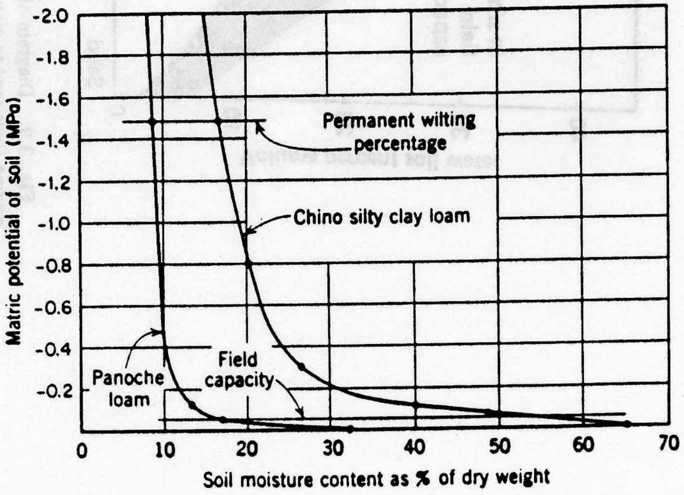


**Fig. 3.8.** Matric potentials of a sandy loam and a clay loam soil plotted over water content. (Curve for Panoche loam is from Wadleigh *et al*., 1946; curve for Chino loam from data of Richards and Weaver, 1944.)

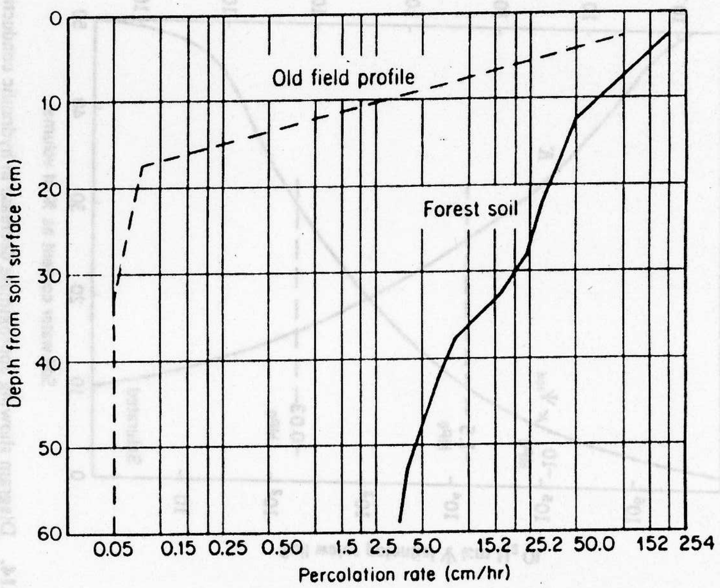


**Figure 4.6** Comparison of rates of infiltration into a forest soil and an adjacent old field on the same soil type. Figure 4.3 shows the differences in capillary pore space in the two soils. From Kramer (1983), after Hoover (1949).

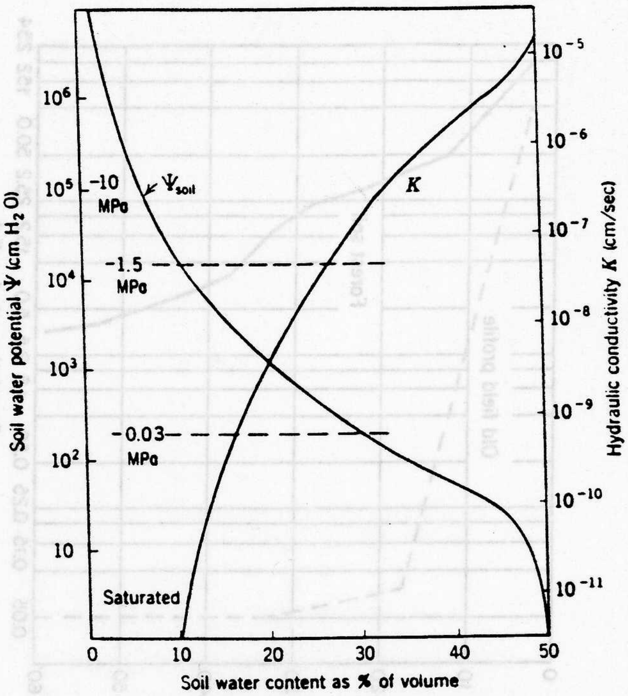


**Fig. 3.14.** Diagram showing approximate decrease in hydraulic conductivity (*K*) and soil water potential (Ψ) with decreasing soil water content. (After Philip, 1957.)

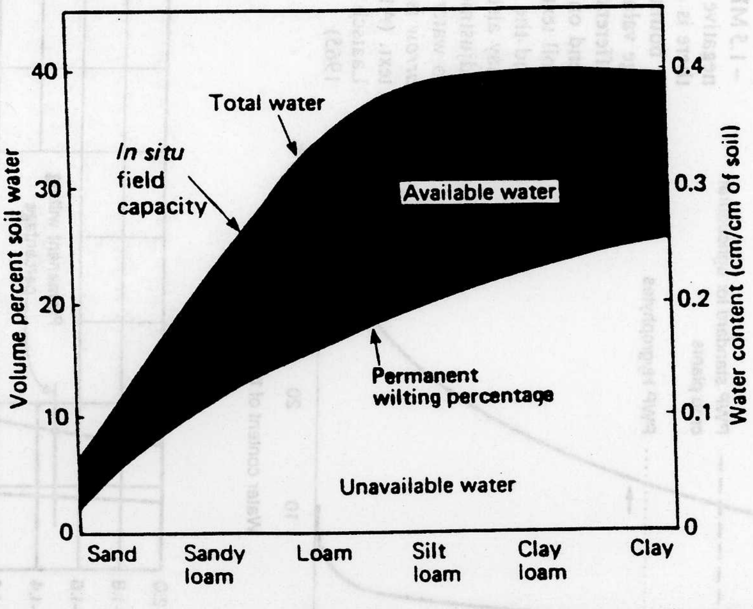


**Fig. 3.9.** Diagram showing the relative amounts of available and unavailable water in soils ranging from sand to clay. Amounts are expressed as percentages of soil volume and as centimeters of water per centimeter of soil. (From Cassell, 1983.)

# Water on Earth

- Total = 1,385,985,000 km$^3$
    - Fresh water = 35,029,000 km$^3$ 2.53% of total
    - Soil water = 16,500 km$^3$ 0.001% of total
    - Glacial water = 24,064,000 km$^3$ 1.74% of total
    - Atmospheric water = 12,900 km$^3$ 0.0009% of total
    - Water cycled = 11,000,000 km$^3$ 0.77% of the total

- How much is one km$^3$ ? -- it is about two New York City blocks on a side, cubed (❐)
- So, 1.4 billion cubic kilometers of water (all the water on Earth) frozen into one *big cube* would be about the distance from NY, NY to Charleston, SC, on a side, cubed (❐)!
- All the water on Earth has cycled through the water cycle at some stage give enough time
- Less that one percent (0.77%) of all the Earth's water cycles each year
- Water on Earth is increasing slightly each year from Ice Comets (≈ 300,000 tons/yr.)

## Water Statistics

Water is the single most important factor limiting crop production globally, ahead of any other physical stress or biological agent (e.g., pests and pathogens)

Reduction in crop yields due to water deficits are estimated to be upwards of 65% globally and between 77-85% in most developing nations

As of March 2005, losses or crop failures due to water deficits top US$95 billion annually and is increasing by 1.1 to 1.7% each year since 1976

One-third of the total global harvest of food comes from 17% of the world's cropland that is irrigated and today (2005) two-thirds of the world's fresh water goes to agriculture.

If we improved the "efficiency" of the water used by crops by 10-15% through better breeds and agricultural practices, we could feed all of the people of the world today and improve the stores of fresh water on Earth well into the 22nd century

At current rates of deforestation in temperate and tropical regions on Earth, there will be 2% per year less fresh water, 3.5% per year greater soil erosion, and 1 to 2% per year loss of productive "croplands" and "natural lands"

## Pending Water Crisis

It is estimated that 32-37% of the word's groundwater is now depleted with no foreseeable way to reverse this

North America has the highest freshwater use of any country at over 1,700 $m^3$ per person per year vs. Africa with the lowest at 250 $m^3/p/yr$. or Europe, in a similar climatic zone, at 730 $m^3/p/yr$.

Lack of water to irrigate crops and for use by people is estimated to become the single most important reason over which global wars will occur in the next 50 years; more than wars over oil or any other natural resource

<u>Sources</u>:

*Water in Crisis*, by Peter Gleick (1993) Oxford University Press, Oxford, UK

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*Pillars of Sand. Can the irrigation miracle last?* by Sandra Postel (1999) W.W. Norton & Co., NY.

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