Surface Water Hydrology

Definition of Hydrology - Natural Science that deals with the transport and distribution of water (liquid, gas, solid) in the atmosphere, on and beneath the earth's surface.

As Hydrologists - Interested in forecasting means, extremes, and time histories of hydrologic events and processes.

As Engineers - Charged with the evaluation, planning and design of facilities to best utilize mitigate and manage water resources including catasphic hydrologic events.

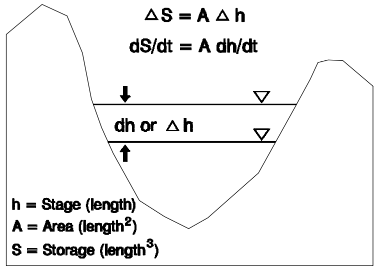
As a reference -

Average Global Precipitation ≈ 101.6 cm/yr (40 in/yr)
Average U.S. Precipitation ≈ 76.2 cm/yr (30 in/yr)
Average Florida Precipitation ≈ 139.7 cm/yr (55 in/yr)

In theory, we use "first principles" to evaluate hydrologic events and processes.

i.e.
1. Conservation of Mass (Continuity)
2. Conservation of Momentum (Newton's 2nd Law)
3. Conservation of Energy (2nd Law of Thermodynamics)
4. Equation of State ($PV = nRT$) for Gases

<u>Continuity</u>



Σ INFLOWS - Σ OUTFLOWS = Δ STORAGE

An inventory of all sources, sinks, and storages is a <u>Water Budget</u>.

<u>Transport Mechanisms</u>

1. Energy
    a. Potential
    b. Kinetic
    c. Heat
2. Mass
3. Momentum

Introduction to hydraulic design must start with understanding of the <u>hydrologic cycle</u>. (Storages and Transport Processes)

Hydrology Definitions

History

1. First dam built across the Nile, 4000 B.C.
2. Romans measured stream flow, 97 A.D.
3. Modern hydrology, 1900-1930 "Period of Empiricism"
4. Many of the present day agencies formed as a result
5. Hydrology has evolved as an analytical science in the last half century

Computers in hydrology

Film about Florida Hydrology

Hydrologic cycle terms, definitions

Water budgets

$$I - O = \frac{ds}{dt}$$

Watersheds and watershed divides, catchments, etc.

$$(P - R - G - E - T = DS)$$

Runoff coefficients: C = R/D

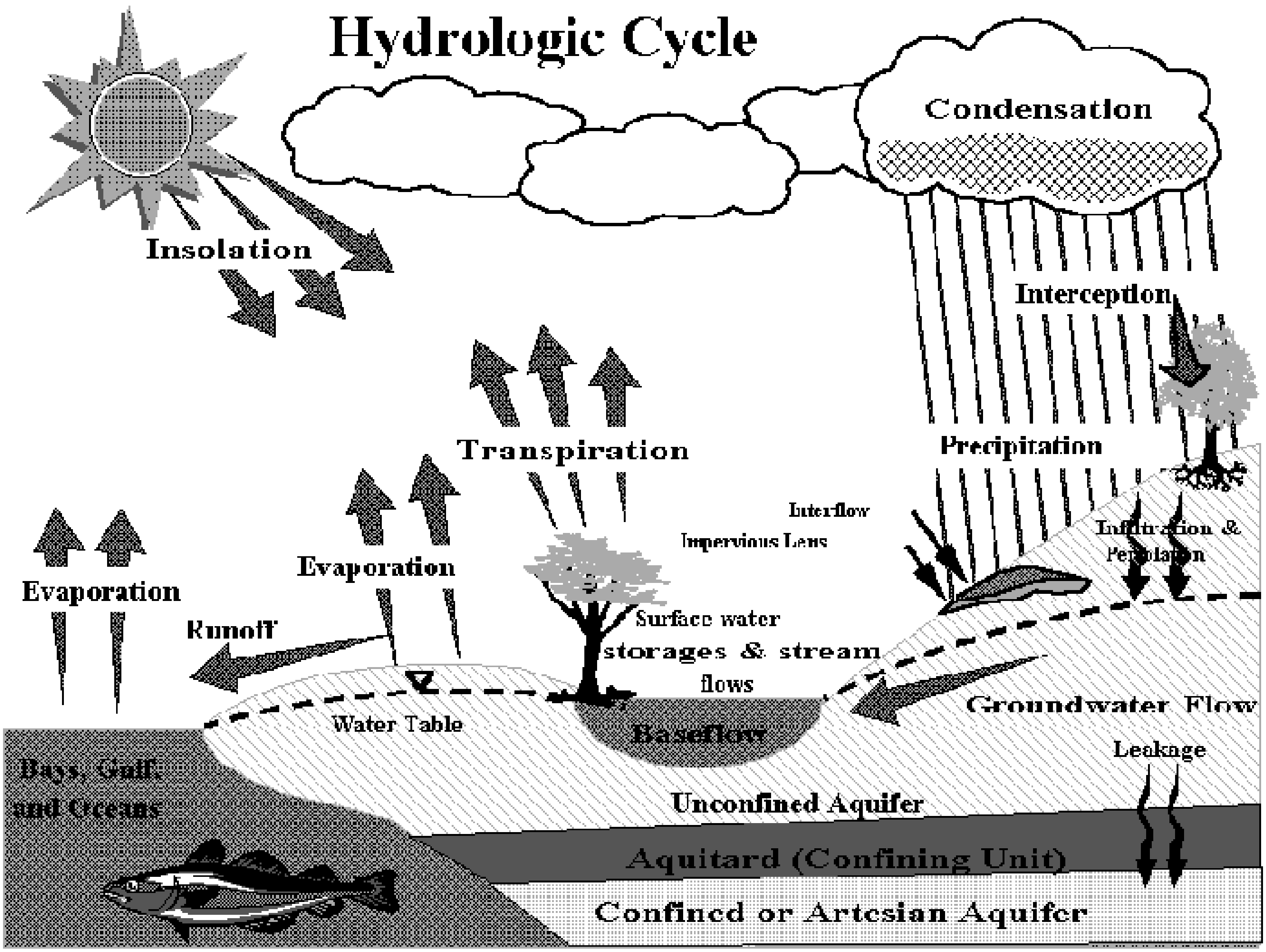
Water balance units:

inches	(flux units)
cfs	
ac-ft	(1 ac-ft = ~ 1/2 cfs)
1 ac = 43560 ft^2	
MGD	(1 MGD = 1.55 cfs)
1 m^3/s	(1 m^3/s = 22.8 mgd)
1 gal	(1 ft^3 = 7.48 gal)
1 $mile^2$	(1 $mile^2$ = 640 acres)

Water balance for a pond

problem 1.1 lake, Bedient
Homework: Read Ch. 1 - p. 10, p. 1.1, 1.2 (Bedient), Florida Water Story

Hydrologic Cycle



Hydrologic systems are quite complex but behave according to 3 elemental laws of nature (so called conservation laws):

1. **Conservation of Mass (Continuity)** - closed system

   $\Sigma\ Q_{mass} = \Sigma\ Q_{In\ mass} - \Sigma\ Q_{Out\ mass} = \Delta\ Storage_{mass} / \Delta\ t$

   Inventory of sources, sinks, and storages
   = Water Budget

2. **Conservation of Momentum (Newton's 2nd Law)**

   Σ Forces $= \Sigma\ F = dM/dt$ (Δ momentum)

3. **Conservation of Energy (2nd Law of Thermodynamics)**

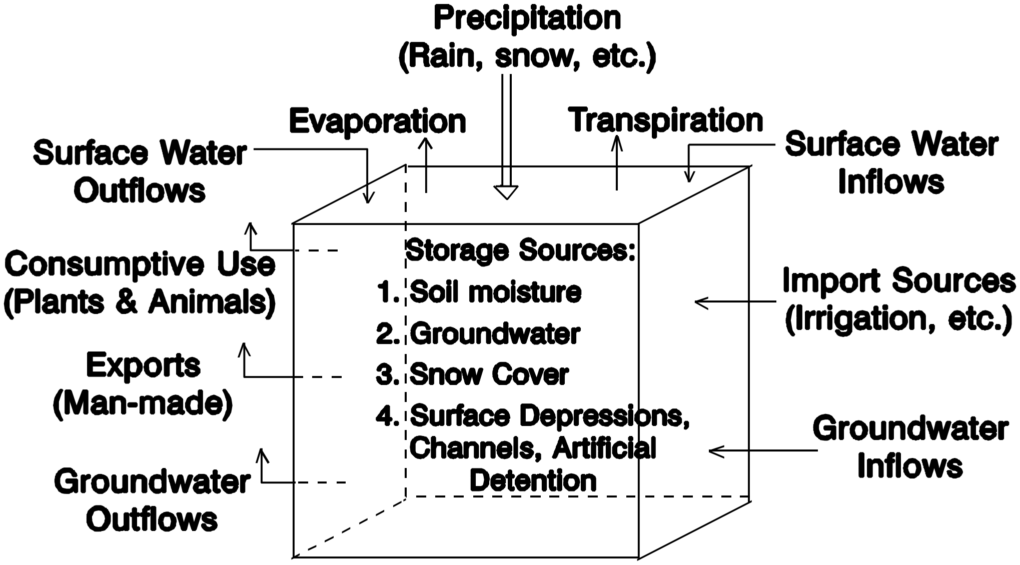
   $\Sigma\ In_{energy\ (work)} - \Sigma\ Out_{used\ energy} = \Delta\ Storage = \Delta\ E / \Delta\ t$

   Unfortunately, lack of understanding necessitates 1st Order approach.

Water Budget ("Black Box" Model)

Conservation of Mass: $\Sigma I - \Sigma O = dS/dt$

I: Inflows
O: Outflows
S: Mass Storage



Note: Work is done in the process of water transport with the primary energy source being derived from the incoming radiation from the sun (insolation). The radiation that is received by the Earth (at the edge of the atmosphere) is the so called Solar Constant which is ≈ 2.0 ly/min (1 ly = 1 cal/cm^2, 1 ly/min = 1.434 x 10^{-3} $watt/m^2$).

Transport Mechanisms - for mass, momentum, energy

Source of energy is the sun - overall driving force

Types of energy: Energy - potential, kinetic, heat

Transport - flux of some quantity

$$flux = \frac{quantity}{area\ time}$$

e.g., $$Massflux: \frac{g}{cm^2\ \mathrm{sec}}, \frac{lb}{ft^2\ hr}$$

$$Heatflux: \frac{cal}{cm^2\ \mathrm{min}}, \frac{watts}{m^2}$$

3 MECHANISMS (of energy transport):

1) Advection
2) Diffusion
3) Radiation

I. ADVECTION

- bodily transport due to motion of the fluid. Quantity moves with fluid velocity.

Advection can be in any direction, convection is only vertical transport

Flux = velocity x concentration

Mass: $$Flux = \frac{length}{time} x \frac{quantity}{volume} = \frac{quantity}{area\ time}$$

Heat: $$Flux|_x = u \cdot c = \frac{m\ mg}{s\ m^3} = \frac{mg}{m^2\ s}$$

$$Flux|_x = u \cdot T \rho C_p = \frac{cm\ °C\ g\ cal}{s\ cm^3\ g\ °C} = \frac{cal}{cm^2\ s}$$

Momentum: Flux = $u \cdot (\rho \cdot u)$ (Fickian)

II. <u>**DIFFUSION**</u>

- the process of <u>transport</u> of a quantity <u>in the direction of decreasing concentration</u> of the quantity (proportional to the concentration gradient).

Diffusion of Mass: $$Flux|_x = -k\frac{dc}{dx}$$

where: k = diffusivity = area/time = length^2/time
c = concentration = quantity/time

Flux is proportional to the gradient of concentration, c, of anything.

Positive flux is in the direction of decreasing concentration.

Turbulence
Reynolds Stress

Advection	(given by the time mean products)
Diffusion	(given by the fluctuation products)

For example, c $\equiv$ Temperature, T

$\overline{U}' \cdot \overline{T}'$ is the advection of T (sometimes called convection although meteorologists use that for vertical)

$\overline{U}' \, \overline{T}'$ is diffusion of heat

Fourier's Law

$q_x = \overline{U' T'} = -k\, dT/dx$

k = diffusivity = area/time = length^2/time
T =Temperature

Diffusion of Heat:

Fourier's Law of Heat Conduction (for heat = diffusion)

$$q_x = -k' \frac{dT}{dx}$$

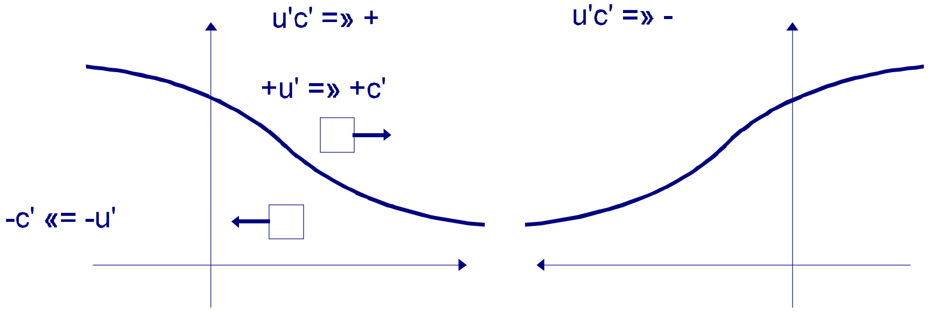
k' = thermal conductivity, cal/(°C-cm-sec)
k' = $\rho \cdot Cp \cdot \alpha$
q_x = heat flux, cal/cm^3s
ρ = density, g/cm^3
Cp = specific heat, cal/gm-°C
α = thermal diffusivity, cm^2/s
S for turbulence (eddy thermal diffusivity) (see HW#2, prob 4)

Diffusion of Momentum:
Newton's Law of Viscosity
quantity = momentum = m· u m = mass u = velocity

$$Flux = \frac{m u}{area\, time} = m \tilde{a} = \frac{force}{area} = pressure = shearstress = \tau$$

τ = coeff. (m· u/volume)d/dy

ρ = m/vol τ = coeff. ($\rho \cdot$ u)d/dy



if density constant:

τ = (coeff.)(ρ) du/dy = μ du/dy = ρ v du/dy Newton's Law of Viscosity

μ = coeff. of dynamic viscosity gm/sec-cm (fluid property)

v = kinematic viscosity

Given: Concentration gradient in a stream

Turbulent flux? (how to measure?)

U'C' = ? Measure?

From experiments we know: U'C' - gradient of average concentration

Turbulent Mass Flux: U'C' = -k di/dx

k ≡ diffusivity = -Flux/Gradient
= length^2/time = velocity fluctuation x mixing length
velocity fluctuation = mixing length/mixing time

k, in water ≈ 0.1 - 1000 cm^2/s (1 ft^2/s)
k, in atm., ≈ 1000 - 10^7 cm^2/s

In turbulent flow (heat, mass, momentum same order of magnitude)

k = f(flow conditions)

Schmidt No. = k_{mom}/ k_{mass} ≈ 0.7

Prandtt No. = k_{mom}/ k_{heat} ≈ 0.7

cm^2/sec, stoke = 10^{-4}
m^2/sec = cm^2/sec,
poise = 0.1 N· sec/m^2 = 1gm/cm· sec

III. **Radiation**

Stefan - Boltzman Law - Intensity = Emissivity x (Radiation Flux)

$I = \epsilon \cdot \sigma \cdot T^4$ T - dependent on absolute temp.

Water Surface Receiving Radiation

Long wave albedo of water = $1-\epsilon = 0.03 = R$
(0.03 = 3% reflection)

For atmospheric radiation:

$I_{cloudy} = I_{clear}\,(1 + 0.17C^2)$
Careful! Long-wave radiation

Short wave radiation measurement:
(Pyranometer)
- Thermocouple black white
voltage

For Total Radiation (all wave lengths) - Radiometer

Weather Service measures radiation of various locations around the state.

(Langleys/day) 10 to 200-800 range

Atmospheric Moisture (Ref. Viessman, Ch. 2; Eagleson & Meter Books; e.g. S. Hess)

Location	Surface Area (mile^2)	Water Volume (mile^3)	Percentage of Total Water
Surface water			
Freshwater lakes	330,000	30,000	0.009
Saline lakes	270,000	25,000	0.008
Stream Channels	-	300	0.0001
Subsurface water			
Groundwater < ½ mi. deep	50,000,000	1,000,000	0.31
Groundwater > ½ mi. deep	50,000,000	1,000,000	0.31
Soil moisture, etc.	50,000,000	16,000	0.005
Icecaps and glaciers	6,900,000	7,000,000	2.15
Atmosphere (at sea level)	197,000,000	3,100	0.001
Oceans	139,500,000	317,000,000	97.2
approx. totals		326,000,000	100

Equation of State (Gas Law)

$$pV = f(T) \text{ - Boyle's Law}$$

$$PV = nR^*T = \frac{M}{m}R^*T \qquad \textit{Universal Gas Law}$$

- equation which governs gases in the atmosphere

- applies to the constituents as well as the total

R^* = Universal Gas Constant = 8.31×10^7 erg/mole· °K

erg - unit of energy = F x L = g· cm/s^2 x cm

$$P\frac{V}{M} = P\alpha = \frac{P}{\rho} = \frac{R^*}{m}T \qquad P = \rho RT$$

α = specific volume = vol/mass = $1/\rho$
R^*/m = gas constant for individual gases

For water:

$M_W = 2H + \frac{1}{2}O_2 = 2 + 16 = 18$ gm. molecular wt.

$R_{vapor} = \frac{8.31}{18} \times 10^7 = 4.62 \times 10^6$ erg/gm· °K

Energy: 1 erg = 1 dyne· cm

1 mb = 1000 dyne/cm^2

1 dyne = 1 gm· cm/s^2

$$\mathbf{M_T = M_W + M_d}$$

For Dry Air: (Mixture of Nitrogen, Oxygen, etc.)

$M_d = 20\%(O_2) + 80\%(N) = (0.2) \cdot 32 + (0.8) \cdot 28$

= 28.8 gm.molecular wt.

By "Harmonic Mean": $\mathbf{M_d = 28.97}$ for dry air

$R_d = \frac{8.31}{28.97} \times 10^7 = 2.87 \times 10^6$ erg/gm· °K

$= 2.87 \times 10^3$ mb· cm^3/gm· °K

= gas constant for dry air

Gas Law for Water Vapor $Pv = e = \rho_v R_v T$

e = vapor pressure
ρ_v = vapor density or absolute humidity

Dry Pressure $P_d = \rho_d RT$

<u>Total Pressure</u> = <u>Sum of Partial Pressures</u>

$$P_{atm} = P_d + e$$

$$\rho_v = \frac{e}{R_v T} = \frac{e}{T\frac{R^*}{m_v}} = \frac{e}{T\frac{R_d m_d}{m_v}} = \frac{e}{TR_d}\frac{m_v}{m_d}$$

$$\rho_v = 0.622\frac{e}{TR}$$

Pressure Measurement Conversions:

Avg. atm. pressure = 1013.2 mb = 760 mm Hg = 29.92 in Hg = 1 atm = 14.7 psi

$\rho_v \approx \Theta(10^{-5}\ \mathrm{g/cm^3})$ $\rho_d \approx \Theta(10^{-3}\ \mathrm{g/cm^3})$

Atmospheric density

$$\rho_{atm} = \rho_d + \rho_v = \left(\frac{P_{atm} - e}{RT}\right) + 0.622\frac{e}{RT} = \frac{P_{atm}}{RT}\left(1 - 0.378\frac{e}{P_{atm}}\right)$$

Define T^* = Virtual Temperature

Virtual temperature of moist air = Temperature at which dry air would have same density

$$T^* = \frac{T}{1 - 0.378\frac{e}{P_{atm}}}$$