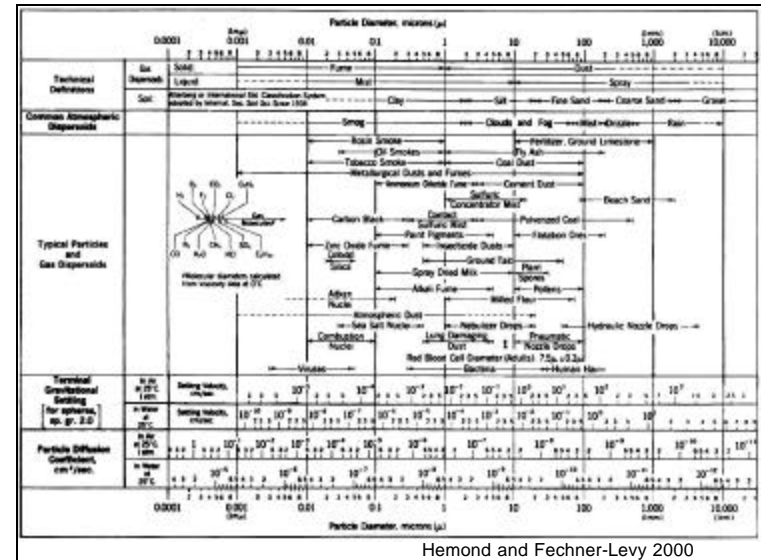# "Movement of Particulates (and Air-Water Exchange)"

Module 2: Surface Waters, Lecture 4

Chemical Fate and Transport in the Environment, 2nd edition. H.F. Hemond and E.J. Fechner-Levy. Academic Press. London. 2000.

Hemond and Fechner-Levy 2000

Stoke's Law to predict settling of particles (type 1, discrete, non-interacting):

$$w_f = \frac{(2/9) \bullet g \bullet (r_s / r_f - 1) \bullet r^2}{h_f}$$

With the sediment and fluid densities, particle size, and kinematic viscosity.
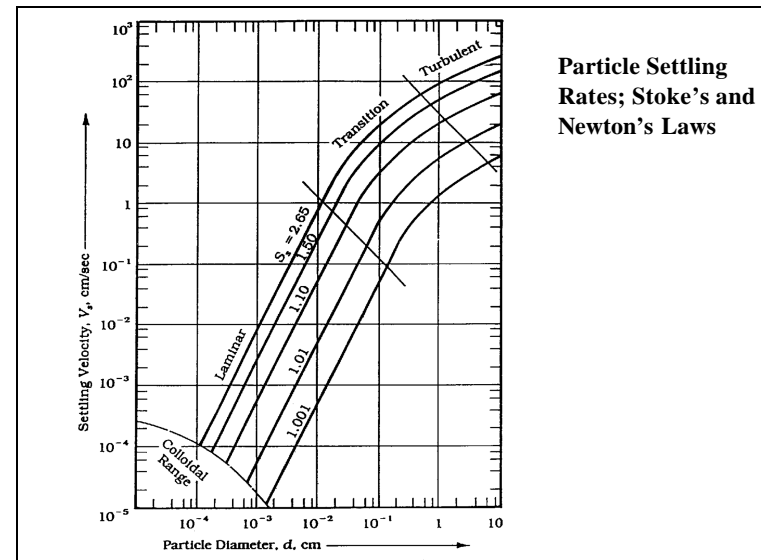
Downward flux due to settling [M/L^{2}T] is therefore:

$$J_{Stokes} = C \bullet w_f$$

Corresponding upward flux density:

$$J_{Fickian} = D \bullet dC / dx$$

Vertical concentration profile of particles at steady state:

$$C = C_o \bullet e^{-(w_f / D) \bullet x}$$

Particle Settling Rates; Stoke's and Newton's Laws

Example 2-3

Describe the steady-state distribution of 1 μm clay particles in still water. Assume kinematic viscosity of water at 50°F is 0.013 cm^2/sec and a solid density of 2.6 g/cm^3. Also calculate the depth when the concentration is halved.

The settling rate for the 1 μm particle is therefore:

$$w_f = \frac{(2/9) \bullet g \bullet (r_s / r_f - 1) \bullet r^2}{h_f} = \frac{(2/9) \bullet 981 cm/\sec^2 \bullet ((2.6 g/cm^3)/(1g/cm^3)-1) \bullet (5 X 10^{-5} cm)^2}{0.013 cm^2/\sec}$$

$$= 6.7 X 10^{-5} cm/\sec$$

The diffusion coefficient for this particle is about 5x10^{-9} cm^2/sec (from fig 2-11). The first-order decay coefficient for the large particle is therefore:

$$w_f / D = \frac{6.7 x 10^{-5} cm/\sec}{5 x 10^{-9} cm^2/\sec} = 1.3 x 10^4 / cm$$

The distance at which the concentration is halved is:

$$\frac{1}{2} = e^{-(1.3 x 10^4 / cm) \bullet x}$$

x = 5x10^{-5} cm or 0.5 μm

Example 2-4

What is the minimum distance the particles will travel before settling to the river bottom? Assume a 2-m river depth and 200 μm particles, 2.6 g/cm^3 particle density and 1.3x10^{-2} cm^2/sec kinematic viscosity.
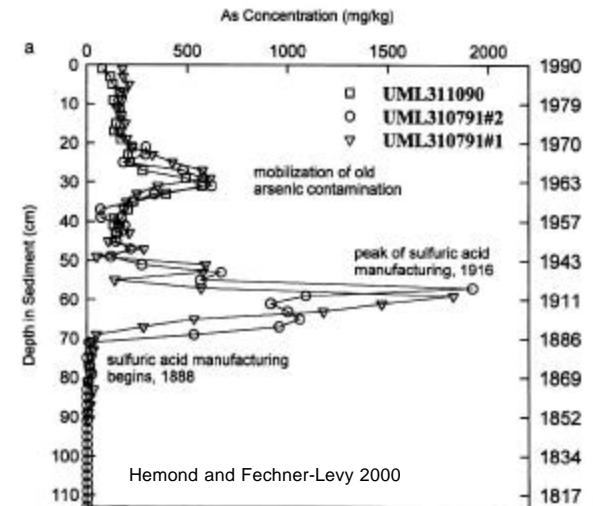
Settling rate:

$$w_f = \frac{(2/9) \bullet 981 cm/\sec^2 \bullet ((2.6 g/cm^3)/(1g/cm^3)-1) \bullet (10^{-2} cm)^2}{0.013 cm^2/\sec}$$

$$w_f = 2.7 cm/\sec$$

The time required to settle 2 m is therefore 75 sec, and the particle will travel:

$$75 \sec \bullet 0.2 m/\sec = 15 m$$

Sediment accumulations:

Hemond and Fechner-Levy 2000

Example 2-5

Sediment from a 10 cm depth of a lake has a ^{210}Pb activity
Of 2.5 disintegrations per minute (DPM), while surface sediment
Has a DPM of 4. How rapidly does sediment accumulate in this lake?

Using the basic equation for radioactive decay:

$$t = \frac{-1}{\lambda} \bullet \ln\left(\frac{A_d}{A_o}\right) = \frac{-1}{0.03/year} \ln\left(\frac{2.5DPM}{4DPM}\right) = 16/year$$

$$\frac{10cm}{16\,year} = 0.6cm/year$$

Air-Water Exchange

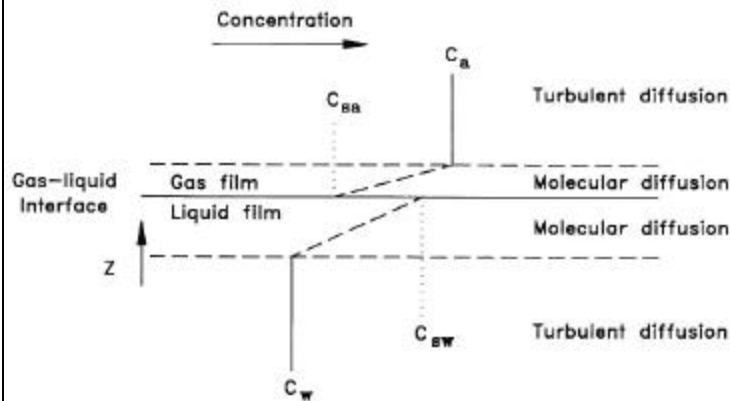The concentration of a dissolved gas in water at equilibrium
with the atmosphere is:

$$C_{equil} = C_a / H$$

Where Ca is the concentration in air, and H is the Henry's
law constant.

The flux density is proportional to the product of the difference
Between the actual and the equilibrium concentrations :

$$J = -k_w(C_w - C_a / H)$$

Thin Film Model:

Hemond and Fechner-Levy 2000

For water-side control, the flux of the chemical out/in water is:

$$J = -\frac{D_w}{d_w}C_w = -k_w C_w$$

Which considers the molecular diffusion coefficient, the film thickness,
and the concentration in the water. The thickness cannot be directly
measured, but the k_w factor can, and with an estimate of the diffusion
coefficient, the film thickness can also be estimated

The general case (needed when H is on the order of 0.01)
and both air and water affect the gas transfer:

$$J = -\left[\frac{1}{d_w / D_w + d_a /(D_a \bullet H)}\right]\left[C_w - \frac{C_a}{H}\right]$$

Estimation of gas exchange coefficients can be made based on the relative molecular weights of a gas tracer and the gas of interest:

$$\frac{k_A}{k_B} = \frac{D_A}{D_B} \approx \frac{\sqrt{MW_B}}{\sqrt{MW_A}}$$

The gas exchange coefficients can also be estimated based on wind speed (measured 10 m above the water). For water side control:

$$k_w(cm/\sec) \approx 4X10^{-4} + 4X10^{-5} \bullet u_{10}{}^2$$

For air-side control (and cm/hr units for k_a):

$$k_a(cm/hr) \approx 1100 \bullet u(m/\sec)$$

Example 2-6

The dissolved concentration of trichloroethylene (TCE) (C_2Cl_3H) is 1 µ/L. H is 0.4 and the measured gas exchange rate coefficient for propane (C_3H_8) in water is 3x10^{-3} cm/sec . What is the flux density for TCE from the lake?

MW TCE = 131 g/mol and MW propane = 44 g/mol. Assuming C_a is almost 0. Diffusion through air is not a bottleneck due to Fairly high H. Dw for TCE is estimated by the Dw
For propane multiplied by the roots of the ratios of the MW:

$$\frac{D_{TCE}}{d_w} = 3X10^{-3}cm/\sec \bullet \frac{\sqrt{44}}{\sqrt{131}} = 1.7X10^{-3}cm/\sec$$

$$J = -\frac{D_w}{d_w}C_w = -k_w C_w$$

$$J_{TCE} = (1.7X10^{-3}cm/\sec)\left(\frac{1mg}{liter}\right)\left(\frac{1liter}{1,000cm^3}\right) = 1.7X10^{-6}\frac{mg}{cm^2 \bullet \sec}$$

Volatilization from Pure Phase Liquids

The concentration at he base of a stagnant air layer, just above The surface of a NAPL, is determined by:

$$C_a = \frac{P}{RT}(MW)$$

Where P is the vapor pressure of the chemical, R is the universal gas constant, T is the absolute temperature, and MW is the molecular weight of the chemical (g/mol).

The volatilization rate from the NAPL surface is:

$$J = \frac{-D_a}{d_a} \bullet C_a$$

Example 2-6

Benzene is spilled in a lake from an overturned tanker truck. The 10m high wind speed is 3 m/sec. What is the flux density from the slick?

The concentration of benzene at the air-NAPL interface is:

$$C_a = \frac{P}{RT}(MW) = \frac{(0.12atm)}{(293K)\left(0.082\frac{atm \bullet liter}{mol \bullet K}\right)} \bullet \frac{78g}{mol} = 0.4\,g/liter$$

The flux density is therefore:

$$J = \left(\frac{3300cm}{hr}\right)\left(\frac{0.4g}{liter}\right)\left(\frac{1liter}{1,000cm^3}\right) = \frac{1.3g}{cm^2 \bullet hr} \Rightarrow \frac{360mg}{cm^2 \bullet \sec}$$