We will discuss three transport processes (mass transport) in water:

1) Advection: transport by the current of water
2) Dispersion: due to mixing within the water body
3) Transport of sediment particles

Dissolved chemicals move in water stream
Adsorbed chemicals move with the soil particles. These may undergo sedimentation, deposition, resuspension. These will retard the substance movement relative to water movement.

Dispersion has 3 contributing processes:

1) Molecular diffusion: random walk of molecules induced by concentration gradient as governed by Fick’s law. It is very slow: 10 days for 1 mg/L to move through 10 cm water column from a concentration of 10 mg/L

2) Turbulent diffusion: Eddy or mixing of fine particles caused by microscale turbulence. It is advection at a small scale. More than molecular diffusion by several order of magnitude.

3) Dispersion: Velocity gradient induced. It is the mechanism of transport in lakes and estuaries.

Advection:
\[ J = \bar{u}AC = QC \]
\( \bar{u} = \) avg velocity
\( A = \) area
\( Q = \) flow rate
\( VC = \) mass of substance
where \( V = \) volume, \( C = \) concentration
\[ \Delta (VC) = (Q_aC_a - Q_bC_b) \Delta t \]
\[ \frac{\Delta (VC)}{\Delta t} = Q_aC_a - Q_bC_b \]
\( V = A\Delta X \)
\[ \frac{\Delta C}{\Delta t} = -\frac{\Delta QC}{A\Delta X} \]
\[ \partial C \quad \partial = -1 \frac{\partial (QC)}{A \partial X} = -\bar{u} \partial C \]
Diffusion/Dispersion

\[ F_m = -D \frac{dC}{dx} \]  \hspace{1cm} (Fick's Law)

\[ F_m = \text{mass flux per unit area} \]
\[ D = \text{molecular diffusion coefficient} \]
\[ \frac{dC}{dx} = \text{concentration gradient} \]

Fick’s second law:
We may write Fick’s first law as a difference equation.

\[ J = -DA \frac{DC}{DX} \]
\[ V \frac{\Delta C}{\Delta t} = -DA \frac{DC}{DX} \]
\[ \Delta C \]
\[ \Delta t \]
\[ \Delta A \]
\[ \Delta C \]
\[ \Delta x \]
\[ \Delta x \]
\[ \lim_{\Delta t \rightarrow 0} \frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} \]

This is useful if the concentration is varying with time

**Advective dispersion equation:**

Based on Fick’s law and continuity equation

\[ \frac{\partial c}{\partial t} = -ui \frac{\partial c}{\partial x_i} + \frac{\partial}{\partial x_i} E_i \frac{\partial c}{\partial x_i} - R \]

Rate of change of mass in C.V.

This will be coupled with open channel flow equations.

Analytical solutions available to the advective dispersion equation.

E values are reported for various locations and conditions.

Importance of advection compared to dispersion

\[ P_e = \frac{uL}{E} \]

\[ L = \text{segment length (L)} \]
\[ U = \text{velocity LT}^{-1} \]
\[ E = \text{dispersion coefficient } L^2T^{-1} \]

\[ P_e >> 1 \text{ advection predominates} \]
\[ P_e << 1 \text{ dispersion predominates} \]

\[ E = 10^{-5} \text{ for Molecular diffusion} \]
\[ E = 10^{-7} - 10^{-5} \text{ for Compacted sediment} \]
\[ E = 10^3 - 10^7 \text{ for River in estuaries} \]
Sediment Transport

\[
C_p = \frac{K_p M}{1 + K_p M}
\]

\[C_p = \text{particulate chemical concentration } \mu g L^{-1}\]

\[C = \text{dissolved chemical concentration } \mu g L^{-1}\]

\[K_p = \text{sediment/water partition coefficient Lkg}^{-1}\]

\[M = \text{suspended solids concentration, kgL}^{-1}\]

\[
C_p = \frac{K_p M}{1 + K_p M}
\]

\[C = \frac{1}{1 + K_p M}\]

\[\text{CT = total concentration}\]

- \(\text{suspended loads} = \text{flow rate} \times \text{concentration}\)
- \(\text{sedimentation:}\)

\[W = 8.64 \left( \frac{g}{18 \mu} \right) \left( \rho_s - \rho_w \right) d_s^2\]

- \(w = \text{particle fall velocity ft/s}\)
- \(p_s = \text{density of sediment particle} 2-2.7 \text{ g/cm}^3\)
- \(p_w = \text{density of water} 1 \text{ g/cm}^3\)
- \(g = 981 \text{ cm/s}^2 \text{ gravitational constant}\)
- \(d_s = \text{sediment particle diameter}\)
- \(\mu = \text{viscosity}\)

\[K_s = \frac{W}{H} - \frac{k_u}{H}\]

- \(K_s = \text{net sedimentation rate constant T}^{-1}\)
- \(W = \text{mean particle fall velocity L/T}\)
- \(K_u = \text{scour/resuspension rate constant, T}^{-1}\)