“Movement of Pollutants in Rivers”

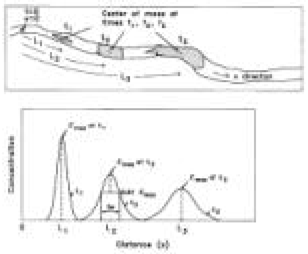
Module 2: Surface Waters, Lecture 2

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

Principles of Surface Water Quality Modeling and Control. R.V. Thomann and J.A. Mueller. Harper & Row, New York. 1987.

Example Problem 2-2

- The dye concentration profile was measured at time 2 in the dye transport plot, 5 hours after injection. What is the average river velocity if the max. concentration is occurring 1025 m down river from the injection location?



The velocity of the dye from the injection location to the time 2 location is:

$$V = \frac{L_2}{t_2} = \frac{1025m}{5hr} = 205m/hr$$

Estimate the longitudinal dispersion coefficient for this river if the standard deviation, σ_L, in the longitudinal direction is approx. 350 m when the chemical has traveled a distance of 1975 m to L_3

The travel time to this location is:

$$t_3 = \frac{L_3}{V} = \frac{1975m}{205m/hr} = 9.6hr$$

The longitudinal dispersion coefficient, D_L, can then be estimated:

$$D_L = \sigma_L^2/2t = (350m)^2/(2 \bullet 9.6hr) \approx 6400m^2/hr$$

Estimates of Fickian Transport Coefficients from Flow Data

- Turbulence is caused by velocity shear due to a nonuniform velocity profile. The shear velocity (related to the shear force per unit area) can be estimated:

$$u^* = \sqrt{gdS}$$ Where d is the stream depth and S is the slope

This shear velocity can be used to estimate the transverse dispersion coefficient, D_t:

$$D_t \approx 0.15 \bullet d \bullet u^*$$ For straight channels

$$D_t \approx 0.6 \bullet d \bullet u^*$$ For typical natural channels

The following equation can be used to predict the longitudinal dispersion coefficient, D_L:

$$D_L = \frac{0.011 \bullet V^2 \bullet w^2}{d \bullet u^*}$$

Where V is the average velocity [L/T]
w is the stream width [L]
d is the stream depth [L]

Example Design for a Dye Injection Experiment for the Cahaba River

Solve the instantaneous equation for M to determine the amount of conservative dye to be used:

$$C(x,t) = \frac{M}{2A\sqrt{4pD_L t}} e^{-(x-Vt)^2/(4D_L t)}$$

1) Estimate the average velocity (V) and travel time (t) to the location of interest (x), and determine the corresponding desired dye concentration (C) at that location.

2) Estimate the longitudinal dispersion coefficient, D_L.

3) Solve for M, the needed mass of dye to be instantaneously released.

1) Estimate the average velocity (V) and travel time (t) to the location of interest (x), and determine the corresponding desired dye concentration (C) at that location.

- The monitoring location is 4 miles from the discharge location (x = 4 miles, 21,120 ft).
- The mean flow for the Cahaba River in this area is 99 MGD, the average width is 30 ft, and the average depth is 1.7 ft.
- The average velocity in this reach is therefore expected to be 3 ft/sec (V=3 ft/sec).
- The travel time is therefore 2 hours (0.08 days)
- The desired dye concentration at the location 4 miles from the discharge location is 250 ppb (v/v).

2) Estimate the longitudinal dispersion coefficient, D_L.

$$D_L = \frac{0.011 \bullet V^2 \bullet w^2}{d \bullet u^*} \qquad u^* = \sqrt{gdS}$$

$g = 32.2$ ft/sec^2
$d = 1.7$ ft
$S = 0.01$
$V = 3$ ft/sec
$w = 30$ ft

Therefore,
$u^* = 0.74$ ft/sec
$D_L = 71$ ft^2/sec

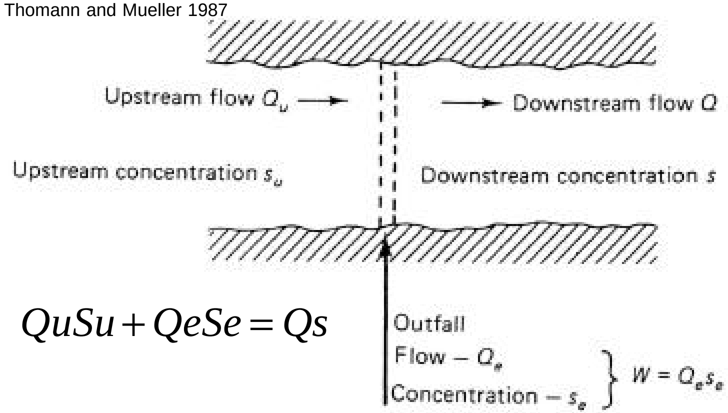
3) Solve for M, the needed mass of dye to be instantaneously released.

$$M = \frac{2AC\sqrt{4pD_L t}}{e^{-(x-Vt)^2/(4D_L t)}}$$

C = 250 ppb = 250/1,000,000,000 = 2.5×10^{-7}
$D_L = 71$ ft^2/sec
t = 7,040 sec
x = 21,120 ft
V = 3 ft/sec
A = 51 ft^2

Therefore, M = 0.032 ft^3, or 0.24 gal (about 1 L)

Thomann and Mueller 1987



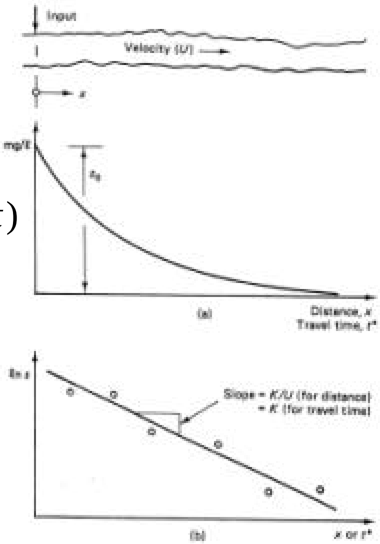
$$QuSu + QeSe = Qs$$

$$S = \frac{QuSu + QeSe}{Q}$$

Thomann and Mueller 1987

$$S = S_o \exp(-kt)$$

$$S = S_o^{-kt}$$



Example Problem

- Upstream flow is 50 cfs no background concentration of pollutant
- Discharge is 10 MGD at 100 mg/L (k = 0.1/day)
- River velocity is 5 miles/day
- What is the concentration at 10 miles downstream?
- How much reduction is needed if the 10 mi conc. must be < 15 mg/L?

$$Qe = \frac{10x10^6\, gal}{day} \times \frac{ft^3}{7.48\, gal} \times \frac{day}{86{,}400\sec} = 15.5\, ft^3/\sec$$

$$Q = 50 + 15.5cfs = 65.5cfs$$

$$So = \left(\frac{15.5cfs}{65.5cfs}\right)100mg/L = 23.66mg/L$$

$$S = S_o \exp(-kt) = (23.66mg/L)\exp\left(\frac{-(0.1/day)(10mi)}{5mi/day}\right) = 19.4mg/L$$

$$\left(\frac{19.4-15}{19.4}\right)100 = 23\%reduction$$

Thomann and Mueller 1987