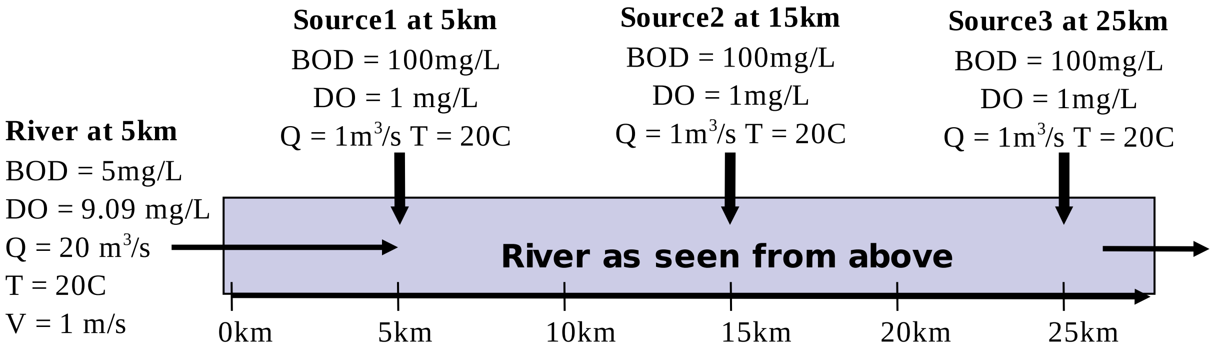
PROBLEM 1 (20 pts):



There are a great many BOD sources that affect the water quality of surface waters near urban areas. In this problem, three urban runoff sources enter a river through CSOs during a rainfall event, as illustrated above.

(a) Give the general assumptions associated with applying the Streeter-Phelps model here:

1. Are concentrations steady? *Yes*

2. Are concentrations uniform? *No (as we go downstream, BOD jumps where there are sources and decreases over stretches where there are no sources)*

3. Other assumptions? *First-order decay for BOD and first-order aeration with uniform rate constants; constant water temperature, salinity, and velocity; no other inflows/outflows, or reactions of BOD or DO*

(b) Sketch qualitatively river BOD and DO as functions of x between 0km and 25km. Do not calculate anything, but do label the curves so it is clear which is for BOD and which is for DO

BOD decreases exponentially between sources and jumps at the source locations. DO does not show such jumps; only its downward slope become steeper. DO tends to decrease when VOD is high (more deoxygenation) and increase when DO is low (more reoxygenation).

(c) Determine the concentration of BOD and DO at 10km if kd (20C)= 0.2 d-1, kr (20C)= 0.8 d-1.

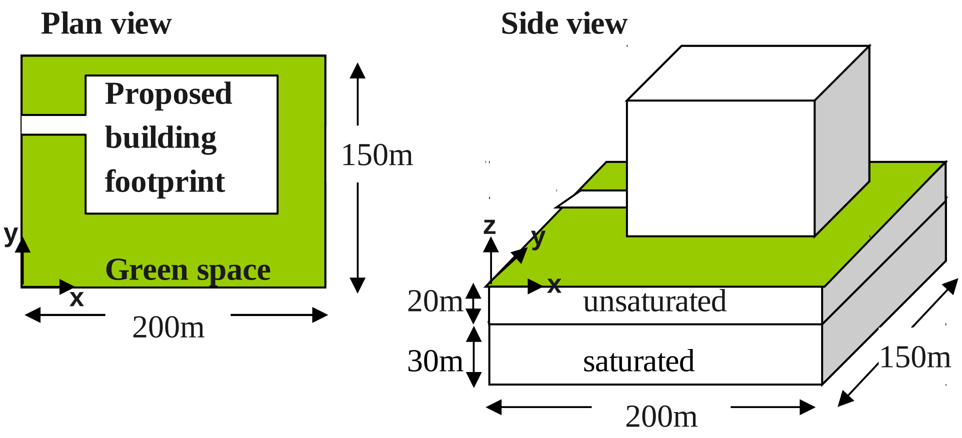
The transit time from the initial condition at x = 5km is t = Δx/v = 5000 s. The initial condition (mixing of inflow and Source 1) has Q = 21 m³/s, L = 9.5 mg/L, DO = 8.70 mg/L (D = 0.39 mg/L), T = 20C.

Because there is no source of BOD between 5 and 10 km, the BOD concentration is given by exponential decay: $\mathrm{L}(t) = \mathrm{L}_0 e^{-k_d t} = 9.4\ \mathrm{mg/L}.$

The DO concentration is given by

$$\mathrm{DO}(t) = \mathrm{DO}_{\mathrm{sat}}(T) - \frac{k_d L_0}{k_r - k_d}\left[e^{-k_d t} - e^{-k_r t}\right] - D_0 e^{-k_r t} = 8.62\ \mathrm{mg/L}.$$

PROBLEM 2 (20 pts):



Engineers are estimating the area of green space needed for a new housing development to meet NYC's policy to increase infiltration and reduce runoff.

Borings reveal that both the unsaturated and saturated zone soils are made up of Carnegie sandy loam, with f_c = 4.50 cm/h, f_o = 35.52 cm/h, k = 19.64/h, K = 0.4 m/day, η = 0.3, ρ = 1400 kg/m^3, f_{oc} = 0.005.

Determine the amount of exposed soil (green space), as an area and as a percentage of the lot area, needed to infiltrate 750 m^3 water over the first 30 minutes of a rainstorm.

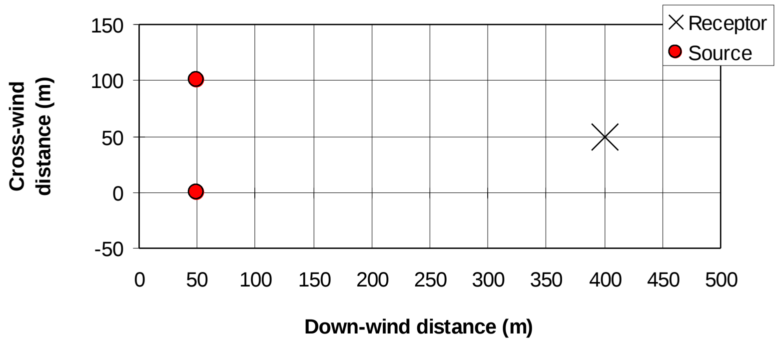
Infiltration expression over the rainstorm: $f(t) = f_c + (f_0 - f_c)e^{-kt}$

Integrated amount from time 0 to T:

$$\int_0^T \left(f_c + (f_0 - f_c)e^{-kt}\right)dt = \left[f_c t - \frac{f_o - f_c}{k}e^{-kt}\right]_0^T = f_c T + \frac{f_o - f_c}{k}(1 - e^{-kT}).$$

With the given parameter values, this works out to 3.83 cm infiltration over the first 0.5 h. With this infiltration rate, we would need 750 m^3/0.0383 m = 1.96 x 10^4 m^2 soil surface area to infiltrate the required amount of water. This corresponds to 65% of the lot area, which is 3 x 10^4 m^2.

PROBLEM 3 (20 pts):



Silica fume is often mixed into concrete for strength. It is a fine powder and can easily become suspended in the air during mixing as $PM_{2.5}$.

Wind speed at 10m is 5 m/s.

Upwind $PM_{2.5}$ concentration is 10 μg/m³.

The atmospheric stability class is B between 0 and 300m above ground, and F above 300m.

The two emission sources are identical, each with emission rate of 0.5 g/s and an effective height (h+Δh) of 10m.

Use the Gaussian Plume model to estimate the $PM_{2.5}$ concentration at the receptor (in g/m³). Be sure to determine which form of the Gaussian Plume model to use first. Specify any assumptions you are making in applying the GPM.

Plume parameters from table (x < 1 km): a = 156, c = 106.6, d = 1.149, f = 3.3

Plume dimensions (for each source, x = 0.35 km): $\sigma_y = a\, x^{0.894} = 61\,\mathrm{m}$, $\sigma_z = c\, x^d + f = 35\,\mathrm{m}$.

Check for effect of the inversion starting at L = 300 m: $x_L = \left(\dfrac{0.47(L-H)-f}{c}\right)^{1/d} = 1.21\,\mathrm{km}$ *(1.22 km if we redo with the x > 1 km plume parameter values), so plumes are not affected at receptor.*

Because the 2 sources are effectively the same distance and direction from the receptor (x = 0.35 km, |y| = 50 m), the concentration due to each one will be the same. This is (assuming that all of the emitted silica fume is $PM_{2.5}$)

$$C(x,y,0) = \frac{E}{\pi u_H \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] = 1.02 \times 10^{-5}\,\mathrm{g\ m^{-3}}.$$

Doubling this and adding the background concentration, and assuming that the $PM_{2.5}$ concentration doesn't change due to reaction, we get $C^{\text{total}}_{\text{x, y, 0}} = C_u + 2\mathrm{C}^{\text{plume}}_{\text{x, y, 0}} = 3.03 \times 10^{-5}\,\mathrm{g\ m^{-3}}$.

PROBLEM 4 (20 pts):
When traffic gets rerouted around a project site, some communities can experience more traffic than usual. In this problem, you will estimate the impact of formic acid, HCOOH(g), emissions from rerouted vehicles on water quality at a nearby lake.

The ONLY two relevant reactions are:

$$1)\ HCOOH(\mathrm{aq}) \Leftrightarrow HCOOH(\mathrm{g}),\ \ K_1 = 0.00028\ \frac{atm}{M} = 1.17\times10^{-5}\frac{M_g}{M}$$

$$2)\ HCOOH(\mathrm{aq}) \Leftrightarrow HCOO^-(\mathrm{aq}) + H^+(\mathrm{aq}),\ \ K_2 = 1.78\times10^{-4}\,M$$

a) Write the equilibrium rate expression for the two reactions that are given above, using "*" to show concentrations at equilibrium.

Products over reactants:

$$\frac{[\mathrm{HCOOH(g)}]^*}{[\mathrm{HCOOH(aq)}]^*} = K_1 = 0.00028\ \frac{atm}{M} = 1.17\times10^{-5}\frac{M_g}{M}$$

$$\frac{[\mathrm{HCOO^-(aq)}]^*[H^+(\mathrm{aq})]^*}{[\mathrm{HCOOH(aq)}^*]} = K_2 = 1.78\times10^{-4}\,M$$

b) If the equilibrium pH is 5 and the equilibrium concentration of $HCOOH_g$ in the air is $4.16 \times 10^{-11}\ M_g = 10^{-9}$ atm, determine the equilibrium concentrations of $HCOOH_{aq}$ and $HCOO^-_{aq}$ in the lake in M. Assume that the air CV is 85,000,000 m^3 and the water CV is 125,000 m^3.

$$[\mathrm{HCOOH(aq)}]^* = \frac{[\mathrm{HCOOH(g)}]^*}{K_1} = 3.56\times10^{-6}\,M$$

$$[\mathrm{HCOO^-(aq)}]^* = \frac{[\mathrm{HCOOH(aq)}]^* K_2}{[\mathrm{H^+(aq)}]^*} = 6.33\times10^{-5}\,M$$

PROBLEM 5 (20 pts):
Below are extracts from the EIS for the Cape Wind offshore wind energy project, completed by the US Department of the Interior in 2009. Based on the information given as well as on what you learned in class and in your group project,

(a) Concisely describe the project alternatives that were analyzed, and explain how these relate to EQR requirements.
Alternatives included the proposed project; No-Action (as required); changing the wind farm location (partly suggested by public and agency comments); and reducing the size of the project, doing it in two phases, or concentrating the turbines over a smaller area.

(b) Concisely describe the main potential impacts of the project (which may be negative and/or positive) on the attributes of (1) Natural Resources, (2) Transportation, (3) Air Quality, (4) Greenhouse Gas Emissions.
Natural resources: disturbance of aquatic life, particularly organisms living on the seabed, by laying down the turbine foundations and power lines
Transportation: Possible traffic delays in the construction phase from bringing heavy equipment and components to the project port; commutes of the construction and maintenance crews may bring more traffic to small towns.
Air quality: Emission-free power source that would eliminate pollution associated with displaced fossil fuel electricity generation, but some emissions from diesel engines for construction and maintenance equipment and barges.
GHG emissions: Similar to air quality: eliminate pollution associated with displaced fossil fuel electricity generation, but some (probably much lesser) emissions from diesel engines for construction and maintenance equipment and barges.