Instructions:

This is a 1 hour 15 minute in-class exam. You are permitted to consult two sheets of notes, and you may use a hand-held scientific/engineering calculator, pencils, and a ruler. You may also ask me any questions.

Include a sketch and clearly state assumptions and equations used on problems requiring detailed analysis. Failure to do so will result in a lower score. Problems must be worked in the unit system in which they are specified. You may turn in additional sheets as necessary.

Problems that have a “G” in the statement are for graduate students only; problems with a leading “U” are for undergraduates only.

Name: _______________________________________

I certify by my signature below that the work I am submitting is my own.

“An Aggie does not lie, cheat or steal, or tolerate those who do.”

Signature: ___________________________________
1 Combined Sewer Overflow

During a storm, raw sewage and rainfall runoff spill out of a sewer system and into a residential stream through a single sewer pipe. The spill occurs over a period of 1 hour, with a flow rate of 0.1 m$^3$/s and bacterial concentration of $6 \cdot 10^8$ #/100 ml. The river has a depth of 2.5 m, width of 350 m, average flow velocity of 0.8 m/s, and shear velocity of 0.035 m/s.

a. If you need to predict the concentration 40 km downstream at a local swimming area, can you treat the overflow as an instantaneous point source? Justify your answer quantitatively.

b. What is an estimate of the dispersion coefficient using the formula by Fischer et al. (1979)?

c. If $D_L = 1000$ m$^2$/s, what is the maximum concentration that occurs at the swimming area? Assume a bacterial decay rate of 1.3 d$^{-1}$ and that the bacteria cloud is well-mixed laterally across the river by the time it reaches the swimming area.

d. (G) The recreational swimming water quality standard for fecal coliform is $\leq 2000$ #/100 ml. Over what time period after the start of the spill should the swimming area be closed? Assume die-off is negligible just as the bacteria cloud passes the swimming area (frozen cloud assumption).

2 Combined Sewer Storage Tank

During a storm, a combined sewage storage tank (volume of 750 m$^3$) operates as a continuously stirred tank reactor. The inflow rate is 0.1 m$^3$/s and outflow occurs at the same rate as inflow whenever the tank overflows; otherwise, there is no outflow.

a. During a long storm, the tank overflows for a long period such that the tank operation reaches steady state. What is the inflow concentration if the outflow concentration is $6 \cdot 10^8$ #/100 ml and the die-off rate is 1.3 d$^{-1}$.

b. (U) At the end of the storm, the inflow and outflow stop and the tank is full with initial concentration of $6 \cdot 10^8$ #/100 ml. When is the concentration reduced to the recreational boating standard of $2 \cdot 10^4$ #/100 ml? Assume there is no inflow or outflow and the die-off rate remains 1.3 d$^{-1}$.

c. (G) At the end of the storm, the sewer company pumps out the tank at a constant flow rate of 0.005 m$^3$/s. If the initial tank concentration is $6 \cdot 10^8$ #/100 ml, solve for the concentration in the outflow over time assuming the tank remains well-mixed, starts full and the die-off rate remains 1.3 d$^{-1}$.

3 Dye Study

An engineer conducts a dye study in a local stream of width 10 m, depth 0.3 m, flow velocity 0.3 m/s, and shear velocity of 0.02 m/s. The study uses Rhodamine WT dye and a fluorometer with a measurement range of 0 to 250 ppb with detection limit of 0.01 ppb.
a. How far downstream as a minimum must the first measurement station be? Assume an injection in the center of the stream. State your assumptions and specify some kind of factor of safety.

b. (U) What mass of Rhodamine WT should be injected to achieve a good measurement at a measurement station 6 km downstream of the injection?

c. (G) What mass of Rhodamine WT should be injected to achieve good measurements at stations located 6 and 15 km downstream of the injection?
A Useful relationships

\[1 \text{ m}^3 = 1000 \text{ l}\]
\[1 \text{ cm}^3 = 1 \text{ ml}\]
\[1 \text{ mg} = 1000 \mu\text{g}\]

The dilution is defined as
\[S = \frac{C_0}{C} \quad (1)\]

The characteristic length scale of diffusion is
\[\sigma = \sqrt{2Dt} \quad (2)\]

The Peclet number is defined as
\[Pe = \frac{D}{uL} \quad (3)\]

Fick’s Law in one dimension is given by
\[q_x = -D \frac{\partial C}{\partial x} \quad (4)\]

The one-dimensional instantaneous point source solution with advection is
\[C(x, t) = \frac{M}{A \sqrt{4\pi D t}} \exp \left( -\frac{(x - ut)^2}{4Dt} \right) \quad (5)\]

The two-dimensional instantaneous point source solution with advection in the x-direction is
\[C(x, y, t) = \frac{M}{4\pi Ht \sqrt{D_x D_y}} \exp \left( -\frac{(x - ut)^2}{4D_x t} - \frac{y^2}{4D_y t} \right) \quad (6)\]

The steady-state mass flux in a continuous waste stream is
\[\dot{m} = QC \quad (7)\]

Solution to the first-order rate equation \(\frac{dC}{dt} = -kC\) with \(C(t) = C_0\)
\[C = C_0 \exp(-kt) \quad (8)\]

Well-mixed criteria for centerline discharges diffusing across a length \(L\)
\[L = 2.0 \sqrt{2Dt} \quad (9)\]

Well-mixed criteria for edge discharges diffusing across a length \(L\)
\[L = 1.1 \sqrt{2Dt} \quad (10)\]

Dispersion coefficient according to Fischer et al. (1979)
\[D_L = 0.011 \frac{u^2 B^2}{h u_*} \quad (11)\]

Dispersion coefficient according to Deng et al. (2001)
\[D_L = 0.15 \frac{B}{h} \left( \frac{B}{h} \right)^{5/3} \left( \frac{u}{u_*} \right)^2 u_* h \quad (12)\]

with
\[\epsilon_{t0} = 0.145 + \frac{1}{3520} \frac{u}{u_*} \left( \frac{B}{h} \right)^{1.38} \quad (13)\]
Figure 1: Non-dimensional solution to the 1D instantaneous point source problem.