

MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
Department of Civil and Environmental Engineering  
1.77 Water Quality Control

Problem Set 4

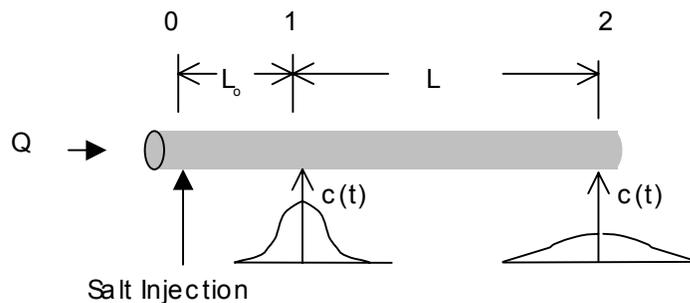
Spring 2006

Due March 21

**Problem 1**

A factory would like to measure the flow rate of water  $Q$  in their piping system sketched below. One approach involves injecting a pulse of salt water at location 0 and then using conductivity probes at locations 1 and 2 to detect peak concentrations as the salt passes by. The average velocity, and hence flow rate, are determined from the time of travel between the two peaks. Assume  $L = 60\text{m}$ ; inside diameter  $D = 2\text{ cm}$ ; Darcy-Weisbach friction factor  $f = 0.02$ .

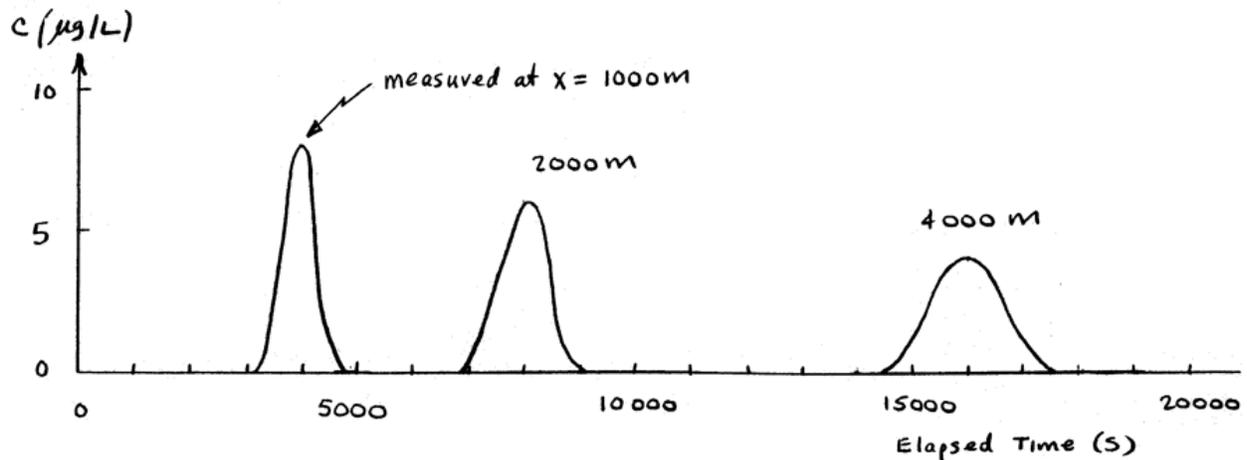
- For  $Q = 5\text{ L}\cdot\text{min}^{-1}$ , approximately how far upstream ( $L_0$ ) must the injection take place to ensure "complete mixing" at location 1?
- For the same flow, what mass of salt must be added in order to detect a peak concentration at location 2 of 0.1 parts per thousand?
- How would the answers in a) and b) change if the flow rate were  $50\text{ L}\cdot\text{min}^{-1}$ ?
- An alternative approach to flow measurement, appropriate to piping networks with variable cross section, involves *continuous* injection of salt at a rate  $\dot{m}$  (mass/time) at location 0 with observation of the steady state concentration at location 2. What is the minimum value of  $\dot{m}$  required to reliably determine flow (in the range  $5 < Q < 50\text{ L}\cdot\text{min}^{-1}$ ) assuming a peak concentration of at least 0.1 parts per thousand at location 2?



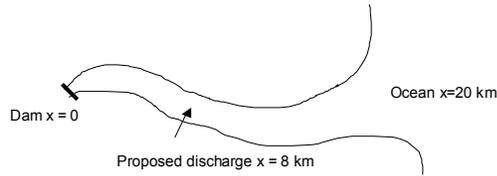
## Problem 2

A long channel with rectangular cross section (width  $B = 2$  m, depth  $H = 0.5$  m) and slope  $S = 3 \times 10^{-5}$  carries irrigation return water at a constant flow rate of unknown magnitude  $Q$  ( $\text{m}^3 \text{s}^{-1}$ ). To help understand the fate of fertilizers and pesticides that enter the system, a tracer experiment was performed. In the experiment a conservative fluorescent dye was injected instantaneously and three fluorimeters were used to measure longitudinal concentration distributions as the dye passed stations located 1000, 2000 and 4000 m downstream from the injection. The (smoothed) measured concentrations are plotted in the following figure as a function of elapsed time following the release. At each station, the tracer was well mixed over the cross section. Use the data in the figure to answer the following questions. For parts a) through c) you should only make "eyeball" estimates; do not attempt formal calculations.

- What is the flow rate of the canal  $Q$ ?
- Estimate the quantity of dye that was released.
- Estimate the standard deviation of the dye distribution at each station and calculate an approximate value for the longitudinal dispersion coefficient.
- Compare your longitudinal dispersion coefficient with the value you would compute based on theory.
- Do you think that the dispersion is produced more by lateral or vertical variations in longitudinal velocity?



### Problem 3



The above figure illustrates schematically a New England estuary. The estuary follows a sinuous 20-km course from an upstream dam ( $x = 0$ ) to the ocean ( $x = L = 20$  km). Tides are semi-diurnal with an average range (mean high tide elevation minus mean low tide elevation) of 2m throughout the estuary. During dry weather (critical condition for water quality) nearly all of the freshwater flow enters the estuary upstream, through a controlled release at the dam of  $10 \text{ m}^3 \text{ s}^{-1}$ . Salinity measurements show that the estuary is both laterally and vertically well-mixed (less than 1 % variation over the cross section), but indicate a substantial longitudinal gradient. Temperature gradients are negligible in all three directions. Salinity measurements taken during a period of dry weather are included in the following table.

x (km)	Width (m)	Ave depth (m)	Tidal average salinity (PSU)
0	100	2.0	6.5
4	200	3.0	14.2
8	300	4.0	20.1
12	400	5.0	24.7
16	500	6.0	27.5
20	600	8.0	29.5
Ocean			30.0

An electric power plant is to be located on the estuary at  $x = 8$  km. The plant will use evaporative cooling towers, withdrawing make-up water from the estuary at a rate of  $1.5 \text{ m}^3 \text{ s}^{-1}$ , evaporating  $1.0 \text{ m}^3 \text{ s}^{-1}$  and returning the remaining  $0.5 \text{ m}^3 \text{ s}^{-1}$  to the estuary as blowdown. Environmental authorities are concerned about the concentrations in the estuary of trace metals introduced with the blowdown, and about the entrainment of fish larvae that spawn in the river upstream and may die from physical, chemical or thermal stress if they enter the plant intake.

- As a first step, use the salinity data to compute and plot the tidal-average longitudinal distribution of copper concentration, assuming copper is introduced at the rate of  $1 \text{ kgd}^{-1}$  (and that it behaves conservatively) over the interval  $0 < x < 20$  km. Also compute the fraction of larvae that are entrained due to plant operation (assuming that the larvae act as passive tracers in the water column). How would the computed concentration distribution and entrainment percentage differ if the plant were moved downstream to  $x = 12$  km?
- Estimate the mean residence time corresponding to each discharge location.
- Use the salinity and bathymetric data provided to calibrate a tidal-average longitudinal dispersion coefficient for the dry weather period analyzed in (a). What do you think are the primary causes of dispersion in this estuary?