Problem Set 5

CEEG 340–Introduction to Environmental Engineering
Instructor: Deborah Sills
Fall 2019

Due Date

Friday 4 October 2019

Learning Goals

1. Apply the general mass balance equation to calculate mass fluxes and concentrations of contaminants.
2. Calculate C, t, HRT, V, Q, or k for CMFR, batch, and PFR reactors, given sufficient data.

Questions

1. *(24 pts)* As illustrated in the figure below, a river flows into a reservoir that is being used to irrigate farmland. The river inflow is 30,000 $\frac{m^3}{yr}$ and the salt concentration in the river is 300 $\frac{g}{m^3}$. The reservoir can be modeled as being *completely mixed* with a uniform salt concentration.

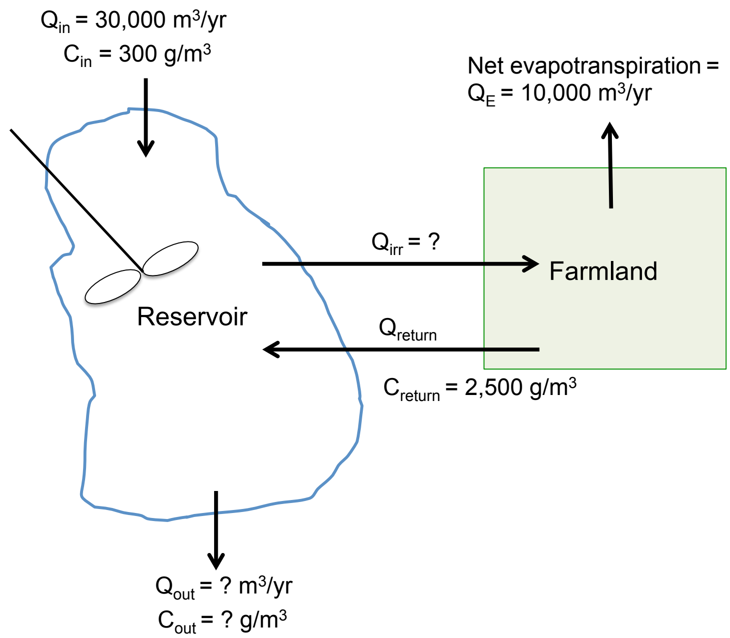
   The farmland needs irrigation water to flush salts out of the soil and for use by plants. Water used by plants is lost by evapotranspiration and the net amount of this loss over and above the water input from rainfall, Q_E, equals 10,000 $\frac{m^3}{yr}$.

   Salty water from the farm is returned to the reservoir. The salt concentration in the return flow is 2,500 $\frac{g}{m^3}$.

   You may assume that the whole system is at steady state with unchanging flows and constant salt concentrations in the river, the agricultural return flow, and the reservoir. In addition, salt is a conservative compound.

   Find:

   (a) the flow out of the reservoir, Q_{out}.
   (b) the salt concentration in the reservoir, which is the same as the concentration in the flow out of the reservoir (since the reservoir is completely mixed).
   (c) the flow rate for the irrigation water, Q_{irr}. Note that this is different from the rate of the return flow.



2. *(16 pts)* A freshwater pond has a well-mixed volume equal to 10.6 m^3. The pond is fed by a single stream and drains by another stream. There is negligible input/output other than these two streams. Flow in and out is 10.3 $\frac{\mathrm{L}}{\mathrm{day}}$. The inflow stream contains a contaminant with concentration equal to 3.4 mg/L.

   (a) Determine the steady-state concentration of the contaminant in the pond if the contaminant decays in the pond at a rate equal to 0.001 $\frac{\mathrm{mg}}{\mathrm{L}\times\mathrm{day}}$.

   (b) Determine the steady-state concentration of the contaminant in the pond if the contaminant decays in the pond at a first order rate given by:

   $$\mathrm{r} = -\mathrm{k} \times \mathrm{C}$$

   where $\mathrm{k} = 0.01 \frac{1}{\mathrm{day}}$ and C has units of $\frac{\mathrm{mg}}{\mathrm{L}}$.

3. *(16 pts)* A sewage lagoon that has a surface area of 10 ha and a depth of 1 m is receiving 8,640 $\frac{\mathrm{m}^3}{\mathrm{d}}$ of sewage containing 100 $\frac{\mathrm{mg}}{\mathrm{L}}$ of a biodegradable contaminant. At steady state, the effluent from the lagoon must not exceed 20 $\frac{\mathrm{mg}}{\mathrm{L}}$ of biodegradable contaminant.

   (a) Assuming the lagoon is well mixed and there are no losses or gains of water in the lagoon except for the sewage influent and effluent, what biodegradation reaction rate coefficient, k (d^{-1}), must be achieved for a first-order reaction?

   (b) Solve the same problem, but assume that instead of one lagoon, there are two well-mixed lagoons in series. Each lagoon has a surface area of 5 ha and a depth of 1 m. For this scenario find k that will result in an effluent (from the second lagoon) of 20 mg/L.

(c) Assume that the process that produces sewage suddenly stops and clean water begins to flow into the single pond (from Part a). Use Excel (or any software you like) and plot the effluent concentration as a function of time at 1 day intervals for 10 days.

4. *(12 pts)* **FE Formatted Question: Multiple Choice**
The next topic covered in this course is design of water (for drinking) treatment plants. The decay of chlorine in a distribution system follows first-order decay with a rate constant of 0.360 d^{-1}. If the concentration of chlorine in a well-mixed storage tank is 1.00 mg/L at time zero, what will the concentration be one day later? Assume no water flows in or out of the tank while the reaction takes place (i.e., batch reactor).

   (a) 0.360 $\frac{mg}{L}$
   (b) 0.500 $\frac{mg}{L}$
   (c) 0.368 $\frac{mg}{L}$
   (d) 0.698 $\frac{mg}{L}$

   Show your work even though you wouldn't have to for the FE.

5. *(16 pts)* Derive an equation for steady state C_{out} for

   (a) A completely mixed flow reactor (CMFR) with a zero order reaction. The equation for C_{out} should be a function of the influent concentration: C_{in}, the zero-order rate coefficient: k, and the hydraulic retention time (HRT): θ.

   (b) A plug flow reactor (PFR) with a zero order reaction. The equation for C_{out} should be a function of the influent concentration: C_{in}, the zero-order rate coefficient: k, and the hydraulic retention time (HRT): θ.

6. *(20 pts)* **Adapted from a previous midterm:** *For this problem, only use your calculator for the final steps of parts (c) and (e).*
The coal company—*Freedom Enterprise*— hired you to design a reactor with a first-order biological reaction rate, that will remove 99 percent of the chemical 4-methylcyclohexane methanol (MCHM), at steady state. You are considering a completely-mixed flow reactor (CMFR) and a plug-flow reactor (PFR). The design volumetric flow rate (Q), and the biological reaction rate coefficient (k) are known.

   (a) For the CMFR, draw a schematic that includes an appropriate reactor, control volume, and all known and unknown variables.

   (b) Write the *complete* mass balance equation, including all variables. Then, clearly indicate which terms (if any) should not be considered for this problem. Clearly state all assumptions made to simplify the mass balance equation.

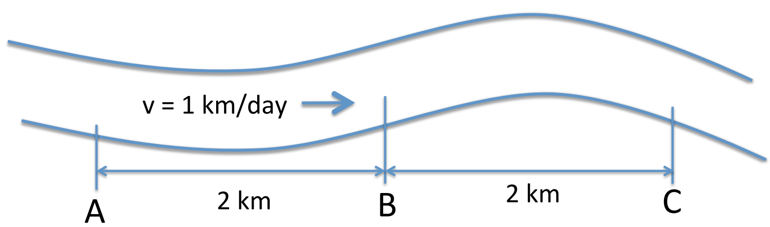
   (c) Solve the mass balance equation for the CMFR volume needed to achieve 99% removal of MCHM in terms of volumetric flow rate and the reaction rate coefficient.

   (d) For the PFR, draw a schematic that includes an appropriate reactor, control volume, and all known and unknown variables.

   (e) Write a complete mass balance equation, and solve for the volume needed to achieve 99% removal of MCHM (at steady state) in terms of volumetric flow rate and the reaction rate coefficient.

(f) Provide a **brief** statement regarding the relative sizes of the reactors. Should the volumes be the same or different? Why?

7. *(20 pts)* **From a previous midterm(note that we haven't covered BOD, but you can still solve this problem—all you need to know is that BOD is a pollutant that is biodegraded according to first-order kinetics:** *(20 pts)* Consider the following stream, which can be modeled as a plug-flow reactor (stream flows from Point A to Point B to Point C).



At time=0, assume that the stream has a uniform (ultimate biological demand) BOD concentration of 2 mg/L at all points. Also, at time=0, a continuous wastewater discharge begins at point A, immediately resulting in a steady-state, mixed concentration of 20 mg/L BOD_u. The first-order decay rate for BOD in the stream is 0.25 day^{-1}, and the stream's velocity is 1 km/day.

(a) At time=3 days, what is the BOD concentration at point C? Assume plug-flow behavior.

(b) At time=3 days, what is the BOD concentration at point B? Assume plug-flow behavior.