CEE 577 11 March 2014

MID-TERM EXAM

Closed book, 1 sheet of notes allowed.
Answer all 3 of the following 3 questions. Please state any additional assumptions you made, and show all work.

Important constants & conversions:

1 ha (hectare) = 10,000 m^2

1 ft = 0.3048 m

1. (30%) Loading of para-dichlorobenzene (PDCB) to Lepidoptera Lake terminated at 7PM on March 11, 2014. Prior to this, the concentration of PDCB in the lake had been at steady state. If the lake has a hydraulic residence time of 298 days and PDCB decays according to first order kinetics with a rate constant of 0.94 yr^{-1}, when will the PDCB concentration be reduced to exactly half of its current concentration?

$$\lambda = \frac{Q}{V} + k + \frac{v}{H}$$

lepidoptera lake					
	HRT =	298	days		
	Q/V =	0.003355705	d-1 =	1.225671	yr-1
p-DCB					
	k =	0.94	yr-1		
	lambda =	2.165671141	yr-1		
	t1/2 =	0.320061143	years =	116.9023	days
	today	3/11/2014 19:00			
	half conc.	7/6/2014 16:39			

Answer: **July 6, 2014 at 4:39 PM**

2. (40%) Saginaw Bay is in the southwest quadrant of Lake Huron. It receives the flow of the Saginaw River, which has a high chloride concentration of 63.1 g m^{-3} and a discharge of 7 x 10^9 m^3 yr^{-1}. There is no reverse flow from the lake to the bay.

	Saginaw Bay (2)	Lake Huron (1)
Chloride Conc.	17.8 g m^{-3}	5.4 g m^{-3}
Volume	8 x 10^9 m^3	3,507 x 10^9 m^3
Depth	5.81 m	60.3 m
Surface Area	1,377 x 10^6 m^2	58,160 x 10^6 m^2
Outflow	7 x 10^9 m^3 yr^{-1}	161 x 10^9 m^3 yr^{-1}

a. Write the mass balance equation and determine the bulk turbulent diffusion coefficient, E' (m^3 yr^{-1}) and the turbulent diffusion coefficient, E (m^2 yr^{-1}). Assume the mixing length is approximately 10 km. Assume that the interface cross-sectional area between the bay and the lake is 170,000 m^2.

$$E' = \frac{W_2 - Q_2 s_2}{s_2 - s_1}$$

$$E' = \frac{4.42x10^{11} - \left[7x10^9(17.8)\right]}{17.8 - 5.4}$$
$$= 2.56x10^{10} m^3 / yr$$

$$E = \frac{E'\ell}{A_c} = \frac{2.56x10^{10}(10x10^3 m)}{0.17x10^6 m^2}$$
$$= 1.5x10^9 m^2 / yr$$

b. Write the mass balance equations and calculate the steady state concentration in Saginaw Bay and Lake Huron of a non-conservative parameter with a first order decay rate of 0.0014 day^{-1}. Assume that the concentration of the parameter in Saginaw River is 10 g m^{-3} ; this is the only direct loading to the system. Show your mass balance equations. **Express answer in ug/L.**

For Lake Huron:

$$V_1 \frac{dc_1}{dt} = W_1 - Q_1 c_1 - k_1 V_1 c_1 + Q_2 c_2 + E'(c_2 - c_1)$$

And for Saginaw Bay

$$V_2 \frac{dc_2}{dt} = W_2 - Q_2 c_2 - k_2 V_2 c_2 + E'(c_1 - c_2)$$

At steady state, and with no additional loading to Lake Huron (i.e., $W_1=0$), and presuming the same decay rate in both bodies of water, we get:

$$0 = -Q_1c_1 - kV_1c_1 + Q_2c_2 + E'(c_2 - c_1) \quad \text{Lake Huron}$$

$$0 = W_2 - Q_2c_2 - kV_2c_2 + E'(c_1 - c_2) \quad \text{Saginaw Bay}$$

You can then calculate the loading to Saginaw Bay:

$$W_2 = Q_2c_{SR} = 7x10^9 m^3 yr^{-1} * 10 g/m^3 = 7x10^{10} gyr^{-1}$$

Now you have 2 equations and two unknowns. There are many ways to solve this. Here's one:

Add the two simplified mass balance equations:

$$0 = -Q_1c_1 - kV_1c_1 - kV_2c_2 + W_2$$

Now use this to solve for C_1 as a function of C_2:

$$C_1 = \frac{W_2 - kV_2C_2}{Q_1 + kV_1} \qquad (1)$$

Next use this with the mass balance for Saginaw Bay:

$$0 = W_2 - Q_2c_2 + kV_2c_2 - E'(c_1 - c_2)$$

$$W_2 = Q_2c_2 + kV_2c_2 - E'(c_1 - c_2)$$

Now substitute for C_1

$$W_2 = Q_2c_2 + kV_2c_2 - E'\left(\frac{W_2 - kV_2C_2}{Q_1 + kV_1} - C_2\right)$$

And simplifying:

$$W_2 = Q_2c_2 + kV_2c_2 - E'\left(\frac{W_2 - kV_2C_2 - Q_1C_2 - kV_1C_2}{Q_1 + kV_1}\right)$$

Now separate variable and isolate and solve for C_2

$$W_2 + E'\left(\frac{W_2}{Q_1 + kV_1}\right) = Q_2c_2 + kV_2c_2 + \frac{E'}{Q_1 + kV}\left[kV_2c_2 - Q_1c_2 - kV_1c_2\right]$$

$$W_2 + E'\left(\frac{W_2}{Q_1 + kV_1}\right) = \left[Q_2 + kV_2 + \frac{E'}{Q_1 + kV}\left(kV_2 - Q_1 - kV_1\right)\right]c_2$$

$$W_2\left(Q_1 + kV_1\right) + E'W_2 = \left[\left(Q_2 + kV_2\right)\left(Q_1 + kV_1\right) + E'\left(kV_2 - Q_1 - kV_1\right)\right]c_2$$

$$c_2 = \frac{W_2\left(Q_1 + kV_1 + E'W_2\right)}{\left[\left(Q_2 + kV_2\right)\left(Q_1 + kV_1\right) + E'\left(kV_2 - Q_1 - kV_1\right)\right]} \qquad (2)$$

From this we calculate:

C_2 = 1931 µg/L

And now substituting into equation (1) we get

C_1 = 32 µg/L

3. (30%) On a separate sheet of paper, answer any six (6) of the following questions.

A. Calculate the % loss of CBOD as water moves 2 kilometers downstream in a river flowing at 0.01 m/s. Assume the CBOD deoxygenation rate is 0.12 d^{-1}, and the CBOD settling rate is 0.10 d^{-1}.

B. Describe the steps involved in a wasteload allocation process

C. What is the concentration of dioxane in a lake 1 year after Acme Chemical Company (ACC) initiates operation on its shore. The lake has an area of 100,000 m^2, an average depth of 1 m, and an outflow of 1000 m^3/day. Dioxane decays at a 1st order rate of 0.5 yr^{-1}, and assume ACC discharged 11 kg/yr to the lake on the day it opened and this discharge increased linearly to 14.65 kg/yr by the end of year 1. Assume there was no dioxane in the lake before ACC started operation.

D. Describe what happens when a wastewater with ammonia is discharged into a flowing river. Be specific on the chemical changes and microbial ecology.

E. Is it common to add an inhibitor to the BOD test? Why or why not?

F. Explain the difference between CBOD and NBOD.

G. Explain the difference between mechanistic modeling and stochastic modeling

H. Explain the difference between ambient and effluent standards

Most of the answers shown below are not complete; instead they make reference to sources of the correct information.

Part A.

5 points

Simple stream BOD model

	0.01	m/s			
	2000	m			
	travel time =	200000	s =	2.314815	days
	kd =	0.12	d-1		
	ks =	0.1	d-1		
	kr =	0.22	d-1		
	c/c0 =	60.1%	remaining		
	1-c/co =	**39.9%**	**lost**		

Part B.

5 points

Points to make here are:

- Beneficial use for the water body is specified
- This is translated into a ambient water quality standards for parameters of critical concern
- A model is developed for the water body
- Design conditions are established (usually 7Q10 flow)
- Using this model under the design condition, reductions waste loading are simulated and a set of feasible options are determined that are predicted to lead to compliance with the ambient standard
- At various points there will be model validation tests and sensitivity tests for key parameters

Part C.

5 points

This is a simple lake model with step and linear loads.

Lake Model						t zero =	1/1/2012				
Lake Data											
	Q =	1.00E+03	m3/day		Co =	0	mg/L		tau =	0.27	yr
	A =	1.00E+05	m2						depth =	1.00E+00	m
	V =	1.00E+05	m3		k =	0.0013689	/day =	0.5	"/yr		
Loading Functions											
	Impulse		m =	0.00E+00	kg						
	Step		W=m/T=	11	kg/yr =	11000000	mg/yr =	30116.36	mg/d		
	Linear		Wl			bl =	3.65	kg/y/y			
	Exponential		We=	0	kg/d =	0	g/yr				
			be=	0	/yr	0					
	Sinusoidal		W=	0	kg						
			Wa=	0	kg						
			Tp=	1	yr	Omega =	6.2831853	radians/yr			
			phase shift	0	yr	Theta =	0	radians	phi(om)=	0.986803	
Solution											
				lambda =	0.011369 /d	=	4.1525 /yr				

$$\lambda = \frac{Q}{V} + k$$

Initial

$$c_g = c_o e^{-\lambda t}$$

Step

$$c_p = \frac{\overline{W}}{\lambda V}(1 - e^{-\lambda t})$$

Linear

$$C_p = \frac{\beta_\ell}{\lambda^2 V}(e^{-\lambda t} + \lambda t - 1)$$

Exponential

$$c_p = \frac{W_e}{V(\lambda + \beta_e)}(e^{\beta_e t} - e^{-\lambda t})$$

		Concentration in ug/L								Loading (kg/yr)				
Date	years	Initial C	Impulse	Step	Linear	Exponen	Sinusoid	Total		Step	Linear	Expon	Sinusoid	Total
1/1/2012	0	0	0	0	0	0	0	0		11000	0.00E+00	0	0	11000
6/1/2012	0.4162	0	0	21.78	1.9172	0	0	24		11000	1.52E+00	0	0	11002
1/1/2013	1.002053	0	0	26.08	6.72	0	0	32.8	ug/L	11000	3.66E+00	0	0	11004

Part D.

5 points

Key points:

- Overall oxidation of ammonia is called nitrification
- Oxidation of ammonia to nitrite by nitrosomonas
- Oxidation of nitrite to nitrate by nitrobacter.
- This creates a nitrogenous oxygen demand of 2 moles of oxygen per mole of ammonia (~4.6 mg O_2/mg-ammonia-N)

Part E.

5 points

Yes it is common. An inhibitor is used to stop nitrification. The BOD test is intended to measure carbonaceous BOD only. NBOD can be easily measured using the TKN analysis.

Part F.

5 points

Key points

- CBOD is carbonaceous, resulting from oxidation of compounds containing carbon, but not from oxidation of any nitrogen – this must be assessed using a biological test (the BOD test)
- NBOD is nitrogenous, resulting from oxidation of any nitrogen, whether inorganic (ammonia, nitrite) or organic-N (amines, nucleic acids, etc) – this can be assessed by measuring Total Kjeldahl Nitrogen (TKN).

Part G.

5 points

Key points:

- Mechanistic is based on physical, biological and chemical theory; based on deductive reasoning
- Stochastic is based on observations and statistical relationships; inductive

Part H.

5 points

Key points:

- Ambient standards and for actual waters as they exist in the environment. They are not directly enforceable and are used to determined TMDLs or allowable point loads
- Effluent standard are for point loads (e.g., municipal WWTPs). These are enforceable and used in writing discharge permits