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%) All loading of para-dichlorobenzene (PDCB) to Luna Lake terminated at 7PM on November 4, 2015. Prior to this, the concentration of PDCB in the lake had been 5.7 µg/L. Assume the lake has a hydraulic residence time of 143 days, a volume of 5×10^6 m^3, and PDCB decays according to first order kinetics with a rate constant of 0.94 yr^{-1}. If Cecropia Corporation begins production on May 5, 2016 and discharges PDCB at a rate of 700 g/day, when will the PDCB concentration reach the standard of 10 µg/L?

First recognize that this problem involves "decay" and "hydraulic flushing", both simple first order processes, from Nov 4, 2015 to May 5, 2016. You should calculate the value of lambda which includes both terms (but not any settling and least that you know of). Note that Q/V is just the reciprocal of the HRT.

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

With lambda you can calculate the amount of PDCB that remains on the day that Cecropia Corp began discharging. That concentration is 0.994 µg/L.

At this point, you have a simple step load particular solution, long with the general solution (continued decay of the original PDCB)

And for a step load the particular solution is: $$c_p = \frac{\overline{W}}{\lambda V}(1 - e^{-\lambda t})$$

And the full solution is:

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

Which simplifies to:

$$c = \frac{\overline{W}}{\lambda V} + \left(c_o - \frac{\overline{W}}{\lambda V}\right) e^{-\lambda t}$$

And

$$c - \frac{\overline{W}}{\lambda V} = \left(c_o - \frac{\overline{W}}{\lambda V} \right) e^{-\lambda t}$$

luna lake					
	V =	5.00E+06	m3		
	HRT =	143	days		
	Q/V =	0.006993007	d-1 =	2.554196	yr-1
p-DCB					
	k =	0.94	yr-1		
	standard =	10	ug/L		
	lambda =	3.494195804	yr-1		
	t1/2 =	0.198371019	years =	72.45501	days
	end of loading	11/4/2015 19:00		5.7	ug/L
	start of next loading	5/5/2016 8:00		0.994	ug/L
	delta t =	182.5416667	days =	0.499772	years
	Cp =	9.006	ug/L		
	W=	700	g/d =	2.56E+08	mg/y
	W/(lambda*V)=	14.63	ug/L		
	exp(-lambda*t)=	0.339753618			
	lambda*t =	1.079534577			
	t=	0.308950796	years =	112.8443	days
ate of reaching standard =		8/26/2016 4:15			

Answer: **August 26, 2016 at 4:15 AM**

II. (50%) Buckeye Creek receives runoff from more than a dozen corn farms in a small area of central Iowa. Each results in a certain dischage of organic nitrogen and contributes to the loading of Buckeye Creek. The effective drainage area of the corn farms that impacts Buckeye Creek is 20,000 ha. Assume that prior to creation of the farms, when the drainage basin was 100% pristine prairie, the organic nitrogen level in Buckeye Creek was constant at 0.25 mg/L. Now the level is substantially higher as shown in the table below.

a. Determine the total organic nitrogen concentration for each day using the standard log-log model
b. Using this information, estimate the effective export coefficient for the corn farms during this 10-day period in units of kg-organic N/ha/yr.
c. Comment on the relationship between the organic nitrogen export coefficient for this watershed and the amount of rainfall in a given year.

Day	Flow (m^3/s)	Organic Nitrogen Concentration (mg/L)
1	1.7	
2	1.8	1.1
3	2.9	
4	4.4	
5	7.6	
6	12.1	3.7
7	11.1	
8	8.3	
9	5.4	
10	3.3	

There are several ways of solving this depending on how you interpret the "pristine concentrations of 0.25 mg/L. You could (1) view this as a baseflow value and subtract it from the two measured concentrations before solving, or (2) just subtract it from the final loading to isolate the farm runoff.

Part a.

20 points

First approach:

				a	b		Model		
				-0.258261	0.735215		c=10^a(Q)^b		
			10^x	0.5517453			log(c) = a + b[log(Q)]		
		Gross		Net					
Day	Q(cms)	Observed (mg/L)	Observed (mg/L)	Calculated (mg/L)	W(g/s)				
1	1.7			0.82	1.39		background	0.25	mg/L
2	1.8	1.1	0.85	0.85	1.53				
3	2.9			1.21	3.50				
4	4.4			1.64	7.22				
5	7.6			2.45	18.63				
6	12.1	3.7	3.45	3.45	41.75				
7	11.1			3.24	35.94				
8	8.3			2.61	21.70				
9	5.4			1.91	10.29				
10	3.3			1.33	4.38				
Sum					146.32	g/s =	12642.32	kg/d	

Second Approach:

				Coefficients from 2 data				
				a	b		Model	
				-0.121118	0.636617		c=10^a(Q)^b	
							log(c) = a + b[log(Q)]	
Day	Q(cms)	Observed (mg/L)	Calculated (mg/L)	W(g/s)				
1	1.7		1.06	1.80				
2	1.8	1.1	1.10	1.98				
3	2.9		1.49	4.32				
4	4.4		1.94	8.55				
5	7.6		2.75	20.91				
6	12.1	3.7	3.70	44.77				
7	11.1		3.50	38.88				
8	8.3		2.91	24.16				
9	5.4		2.21	11.95				
10	3.3		1.62	5.34				
Sum	58.60			162.67	g/s =	14054.35	kg/d	

Part b.

20 points

First Approach:

Average load =		14.63	g/s =	1,264.23	kg/d =
				461760.7	kg/yr
		total area	20000	ha	
				23	**kg/ha/yr**

Second Approach:

background	0.25	mg/L				
Gross Average Loading =			16.27	g/s =	1,405	kg/d =
					513335	kg/yr
Background Loading =			1.47	g/s =	127	kg/d =
					46232	kg/yr
Net Average Loading =					1279	kg/d =
					467103	kg/yr
			total area	20000	ha	
					23	**kg/ha/yr**

Part c.

10 points

Certainly based on this analysis, organic nitrogen export is positively correlated with rainfall. It seems likely that organic nitrogen is associated with particulates (soil from application of fertilizers, plant matter) which is washed into streams at higher rates during wet events. This has the unfortuante affect of changing the export coefficient based on the particular level of rainfall. Over short periods where rainfall can be quite variable, this will add a substantial amount oferror. However, over longer time periods, average rainfall becomes more uniform and export coefficients may be more accurate.

Also, it seems likely that organic-N washout should be seasonally-dependent. None of the simple models really take this into account.

2. (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 0.03 m/s. Assume the CBOD deoxygenation rate is 0.22 d^{-1}, and the CBOD settling rate is 0.05 d^{-1}.

   B. If a river is shown to have the following empirical relationships, $U=3.5\cdot Q^{0.34}$, $H=2.2\cdot Q^{0.41}$, and $B=21.4\cdot Q^{f}$. What is the value of "f"?

C. What is the concentration of nonylphenol in a lake 2 years after Trump Chemical Company (TCC) 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. Nonylphenol decays at a 1st order rate of 0.5 yr^{-1}, and assume TCC discharged 11 kg/yr to the lake on the day it opened and this discharge decreased linearly to 7.65 kg/yr by the end of year 1 and continued to decrease as the same rate during year 2. Assume there was no nonylphenol in the lake before TCC 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. Define 7Q10, and explain when it is used and when alternatives might be used instead

F. Describe what the Secchi depth is and how it is measured.

G. Explain how the dissolved oxygen level affects the rate of nitrification and the rate of CBOD deoxygenation.

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

	0.03	m/s			
	2000	m			
	travel time =	66666.67	s =	0.771605	days
	kd =	0.22	d-1		
	ks =	0.05	d-1		
	kr =	0.27	d-1		
	c/c0 =	81.2%	remaining		
	1-c/co =	**18.8%**	**lost**		

Part B.

F = 1-0.34-0.41 = **0.25**

Part C.

5 points

This is a simple lake model with both step and linear loads. Note that the linear load and the particular solution for the linear load are negative as it is due to a linear decrease in the loading

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 =	-3.35	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 =	6.28318531	radians/yr	
	phase shift =	0	yr	Theta =	0	radians	phi(om)= 0.986803

Solution

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

lambda = 0.011369 /d = 4.1525 /yr

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	-1.7596	0	0	20		11000	-1.39E+00	0	0	10999
1/1/2014	2.001369	0	0	26.48	-14.20	0	0	12.3	ug/L	11000	-6.70E+00	0	0	10993

Part D.

5 points

Nitrification begins. Ammonia is oxidized to nitrite by ammonia oxidizing bacteria such as nitrosomonas species. This consumes 1.5 moles of oxygen per mole of ammonia. Then the nitrite is oxidized to nitrate by nitrobacter species. This consumes another 0.5 mole of oxygen per mole of nitrite. In anaerobic conditions (e.g., in some sediments), denitrification can occur converting the nitrate to nitrogen gas.

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

The 7Q10 is the lowest 7-day average flow in a year that is likely to recur on only a 10-year period. This is used for design purposes when the critical conditions are low flows. In some cases high flows create the most challenging conditions.

Part F.

The Secchi disk is a circular piece of rigid material that is divided into black and white quarters. The disk can be lowered into water on a vertical rod and used to assess clarity. When it can no longer be seen, the distance from the surface is called the Secchi depth.

Part G.

As DO levels decrease, nitrifying bacteria slow down. This happens well above the DO level that normally shuts down heterotrophic metabolism. In water quality models we tend to incorporate a term with a characteristic DO level that results in attenuation of the ammonia oxidation rate constant.

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

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 B.

5 points