CEE 577 12 March 2013

MID-TERM EXAM

Closed book, 1 sheet of notes allowed.
Answer 2 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

I. (50%) Husker Creek receives runoff from more than a dozen corn farms in a small area of central Nebraska. Each results in a certain dischage of organic nitrogen and contributes to the loading of Husker Creek. Assume that the drainage area for Husker Creek (10,000 ha) to its confluence with the Delmonte River is entirely made up of corn farms. Husker creek receives a baseflow from groundwater that is 1.7 m^3/s (at the confluence), and the nitrogen concentration in this baseflow is 0.25 mg/L. On July 7 the flow in Husker creek at the confluence was measured as 3.925 m^3/s.

a. Determine the basin-wide average runoff coefficient ("C") based on the single flow datum measured on Husker Creek near its confluence with the Delmonte River on July 7 of 3.925 m^3/s
b. Determine flows for each of the remaining 9 days using the rainfall data below and the rational formula
c. Calculate total organic nitrogen concentration for each day using the standard log-log model
d. 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.
e. Comment on the accuracy and usefulness of this organic nitrogen export coefficient for this watershed. Consider the average rainfall for this watershed is 3.2 inches in July and 27 inches for the entire year.

Date	Avg Rainfall (cm)	Organic Nitrogen Concentration (mg/L)
July 1	0	
July 2	0.5	0.52
July 3	0.7	
July 4	0	
July 5	1.1	
July 6	3.5	4.25
July 7	0.9	
July 8	0.2	
July 9	4.4	
July10	0.4	

There are several ways of solving this depending on how you handle the baseflow value. I believe the best way is to separate it from the runoff in all calcuations and separate the loadings of N (baseflow vs runoff). Below I present my preferred approach (#1), followed by some alternatives that are in decreasing order of rigor and logic (and therefore get somewhat less credit)>

Approach #1: complete separation of baseflow from runoff; both for flow calculations and for determination of Q vs N relationship

Part a.

I subtracted the baseflow from the July 7^{th} Q value to get the flow due to rain-induced runoff (Qrunoff) and then use the rational formula to calcuate "C", which turned out to give a value of 0.2136 or about **0.214**.

However, this presumes that the correct averaging period for the rational formula is a 24 hr day. Depending on the storm hydrograph for this watershed (information you don't have), it might make more sense to use a longer time in which to average rainfall.

Part b.

Now reversing this process and using the daily rainfall, we get the following runoff-based flow and to total flow including baseflow. This is calcuated using the runoff coefficient of 0.214 calculated in Part a.

Day	Qrunoff	Q total
1	0.0000	1.7000
2	1.2361	2.9361
3	1.7306	3.4306
4	0.0000	1.7000
5	2.7194	4.4194
6	8.6528	10.3528
7	2.2250	**3.9250**
8	0.4944	2.1944
9	10.8778	12.5778
10	0.9889	2.6889

Part c.

	Coefficients from 2 data				
	a	b		Model	
base 10	-0.131884	0.889883		c=10^a(Q)^b	
10^x	0.7381015			log(c) = a + b[log(Q)]	

			Gross	Net (from runoff)		Gross				
			Observed	Observed	Calculated	Calculated				
Day	I (cm)	Q(cms)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	W(g/s)			
1	0	1.7000			0.00	0.25	0.43			
2	0.5	2.9361	0.52	0.8913	0.89	0.52	1.53			
3	0.7	3.4306			1.20	0.73	2.51			
4	0	1.7000			0.00	0.25	0.43			
5	1.1	4.4194			1.80	1.20	5.31			
6	3.5	10.3528	4.25	5.0359	5.04	4.25	44.00			
7	**0.9**	**3.9250**			1.50	0.96	3.77			
8	0.2	2.1944			0.39	0.28	0.62			
9	4.4	12.5778			6.17	5.37	67.58			
10	0.4	2.6889			0.73	0.43	1.15			
Sum							127.31	g/s =	10999.7	kg/d

Part d.

Average load =		12.73	g/s =	1,099.97	kg/d =
				401764.2	kg/yr
		total area	10000	ha	
				40.2	**kg/ha/yr**

Part d.

There's a lot one could say here. Certainly the most notable issue is the variable nature of the export coefficient based on rainfall and runoff.

Also 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 nitrate-N washout should be seasonally-dependent. None of the simple models really take this into account.

Approach #2: separate baseflow from runoff to determine C, but not parsing concentrations between runofff and baseflow

	A=	10000	ha =	100000000	m2					baseflow =	1.7	cms		
Q=CIA	C=	0.2136								base N =	0.25	mg/L		
					Coefficients from 2 data									
					a	b		Model				a	b	
				base 10	-1.063827	1.667114		c=10^a(Q)^b			base e	-0.30367	0.889883	
				10^x	0.0863323			log(c) = a + b[log(Q)]						
			Gross	Net (from runoff)		Gross								
			Observed	Observed	Calculated	Calculated								
Day	I (cm)	Q(cms)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	W(g/s)					Day	Qrunoff	Q total
1	0	1.7000			0.00	0.21	0.36		background	0.25	mg/L	1	0.0000	1.7000
2	0.5	2.9361	0.52	0.8913	0.89	0.52	1.53					2	1.2361	2.9361
3	0.7	3.4306			1.20	0.67	2.31					3	1.7306	3.4306
4	0	1.7000			0.00	0.21	0.36					4	0.0000	1.7000
5	1.1	4.4194			1.80	1.03	4.54					5	2.7194	4.4194
6	3.5	10.3528	4.25	5.0359	5.04	4.25	44.00					6	8.6528	10.3528
7	0.9	3.9250			1.50	0.84	3.31					7	2.2250	3.9250
8	0.2	2.1944			0.39	0.32	0.70					8	0.4944	2.1944
9	4.4	12.5778			6.17	5.88	73.95					9	10.8778	12.5778
10	0.4	2.6889			0.73	0.45	1.21					10	0.9889	2.6889
Sum							132.27	g/s =	11427.73	kg/d				
Average					Average load =	13.23	g/s =	1,142.77	kg/d =					
								417397.7	kg/yr					
						total area	10000	ha						
								41.7	kg/ha/yr					

Approach #3: ignore baseflow contribution and assume all flow is due to runoff, but subtract the baseflow nitrogen in calculating the loading and export coefficient

	A=	10000	ha =	100000000	m2					baseflow =	1.7	cms			
Q=CIA	C=	0.3768								base N =	0.25	mg/L			
					Coefficients from 2 data										
					a	b		Model				a	b		Model
				base 10	-1.037646	1.385279		c=10^a(Q)^b			base e	-0.30367	0.889883		c=e^a(Q)^b
				10^x	0.0916967			log(c) = a + b[log(Q)]							ln(c) = a +
			Gross	Net (from runoff)		Gross									
			Observed	Observed	Calculated	Calculated									
Day	I (cm)	Q(cms)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	W(g/s)					Day	Qrunoff	Q total	C
1	0	0.0000			-0.25	0.00	0.00		background	0.25	mg/L	1	-1.7000	0.0000	
2	0.5	2.1806	0.52	1.4751	0.27	0.27	0.59					2	0.4806	2.1806	0.0830
3	0.7	3.0528			0.18	0.43	1.31					3	1.3528	3.0528	0.1670
4	0	0.0000			-0.25	0.00	0.00					4	-1.7000	0.0000	
5	1.1	4.7972			0.55	0.80	3.86					5	3.0972	4.7972	0.2433
6	3.5	15.2639	4.25	4.7513	4.00	4.00	61.06					6	13.5639	15.2639	0.3348
7	0.9	3.9250			0.36	0.61	2.39					7	2.2250	3.9250	0.2136
8	0.2	0.8722			-0.17	0.08	0.07					8	-0.8278	0.8722	-0.3576
9	4.4	19.1889			5.24	5.49	105.39					9	17.4889	19.1889	0.3434
10	0.4	1.7444			-0.05	0.20	0.35					10	0.0444	1.7444	0.0096
Sum							175.01	g/s =	15120.85	kg/d					
Average					Average load =	17.50	g/s =	1,512.09	kg/d =						
								552289.2	kg/yr						
						total area	10000	ha							
								55.2	kg/ha/yr						

Approach #4: ignore baseflow contribution and assume all flow is due to runoff and ignore baseflow N content

	A=	10000	ha =	100000000	m2					baseflow =	1.7	cms	
Q=CIA	C=	0.3768								base N =	0.25	mg/L	
					Coefficients from 2 data								
					a	b		Model				a	b
				base 10	-0.649521	1.079621		c=10^a(Q)^b			base e	-0.30367	0.889883
				10^x	0.2241192			log(c) = a + b[log(Q)]					
			Gross	Net (from runoff)		Gross							
			Observed	Observed	Calculated	Calculated							
Day	I (cm)	Q(cms)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	W(g/s)					Day	Qrunoff
1	0	0.0000			#NUM!	0.00	0.00		background	0.25	mg/L	1	-1.7000
2	0.5	2.1806	0.52	1.4751	0.38	0.52	1.13					2	0.4806
3	0.7	3.0528			0.97	0.75	2.28					3	1.3528
4	0	0.0000			#NUM!	0.00	0.00					4	-1.7000
5	1.1	4.7972			2.02	1.22	5.84					5	3.0972
6	3.5	15.2639	4.25	4.7513	7.51	4.25	64.87					6	13.5639
7	0.9	3.9250			1.50	0.98	3.85					7	2.2250
8	0.2	0.8722			#NUM!	0.19	0.17					8	-0.8278
9	4.4	19.1889			9.42	5.44	104.41					9	17.4889
10	0.4	1.7444			0.05	0.41	0.71					10	0.0444
Sum							183.27	g/s =	15834.68	kg/d			
Average					Average load =	18.33	g/s =	1,583.47	kg/d =				
								578361.9	kg/yr				
						total area	10000	ha					
								57.8	kg/ha/yr				

II. (50%) Pleasantville is a rapidly growing community in an exclusive area of California. Starting on January 1, 1988, half of the population of Pleasantville began taking 20 mg/day of the newly released drug, fluoxetine (trade name: Prozac). Studies have shown that 80% of ingested fluoxetine is excreted. Furthermore the removal efficiency of the Pleasantville wastewater treatment plant (serving the entire population of Pleasantville) for fluoxetine is only 60% prior to discharge into nearby Tranquil Lake. This lake as a total volume of $9\text{x}10^6$ m^3 and an outflow of 8000 m^3/d. Fluoxetine decays in the lake at a rate of 0.10 yr^{-1} due to direct photolysis. No other losses are known.

Pleasantville, CA

Year	Population on Jan 1
1988	300,000
1993	350,000
1998	400,000
2003	450,000
2008	500,000
2013	Data not yet available

A. Calculate the expected fluoxetine concentration at the beginning of the year 2015.
B. If a new WWTP capable of completely removing fluoxetine is placed on line at the beginning of 2015, when will the lake fluoxetine level finally drop below 2.0 µg/L?

Part A.

30 points

Note that this includes both a step load and a linear load:

Lake Model						t zero =	1/1/1988				
Lake Data											
	Q =	8.00E+03	m3/day		Co =	0	mg/L		tau =	3.08	yr
	A =	3.00E+06	m2						depth =	3.00E+00	m
	V =	9.00E+06	m3		k =	0.0002738	/day =	0.1	"/yr		
Loading Information											
		300000	people	10	mg/d/cap	80%	excreted	40%	discharged		
		10000	people/yr								
Loading Functions											
	Impulse		m =	0.00E+00	kg						
	Step		W=m/T=	350.64	kg/yr =	350640000	mg/yr =	960000	mg/d		
	Linear		Wl			bl =	11.688	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	0.25	yr	Theta =	1.5707963	radians	phi(om)=	1.50331116	
Solution											

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

lambda = 0.001163 /d = 0.4246667 /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
1/1/1988	0	0	0	0	0	0	0	0		350640	0.00E+00	0	0	350640
1/28/1988	0.0739	0	0	2.84	0.0035	0	0	3		350640	8.64E-01	0	0	350641
1/1/2015	27.00068	0	0	91.74	75.37	0	0	**167**		350640	3.16E+02	0	0	350956

Part B.

20 points

Note that this is a simple decay without any loading. The lambda is the same as above.

Years	Target Conc					
37.422	2				Dates	
		years	days		starting	ending
		30	2710.82		1/1/1988	**6/3/2025**

III. (50%) On a separate sheet of paper, answer any five (5) 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 1^{st} 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.

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

Part A.

10 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.

10 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.

10 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

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

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

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

Date	years	Concentration in ug/L: Initial C	Impulse	Step	Linear	Exponen	Sinusoid	Total		Loading (kg/yr): 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.

10 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.

10 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.

10 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).