CEE 577 1 Apr 2009

MID-TERM EXAM

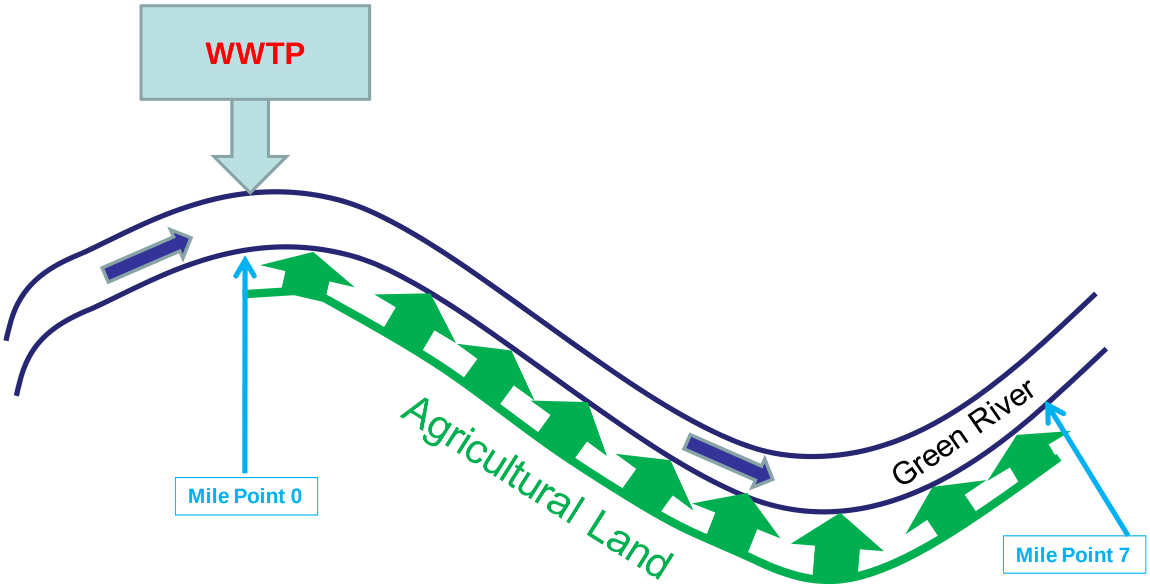
Closed book, 1 sheet of notes allowed.
Answer 2 of the following 3 questions. Please state any additional assumptions you made, and show all work.

1. (50%) The Green River emerges from pristine headwaters and runs through an agricultural region. At the start of this agricultural region is a municipal wastewater discharge (from the city of Tonawanda). The BOD of the headwaters is 6 mg/L, and the dissolved oxygen is 8.2 mg/L (saturation is 10.1 mg/L for 15°C). Starting at mile point zero, there is a significant non-point agricultural runoff of BOD amounting to 45 kg/mile/day. Also at mile point 0, is the Tonawanda WWTP outfall. Here a WW flow of 2 cfs is discharged with a CBOD of 100 mg/L, an ammonia-N concentration of 14 mg-N/L and a DO of 6 mg/L. Immediately past this outfall is 7 miles of agricultural land. **Calculate the dissolved oxygen concentration at the end of the agricultural land (i.e., 7 miles downstream of the Tonawanda WWTP outfall)** (T=15°C). Assume the flow is constant at 40 cfs from the headwaters to the end of the non-point agricultural runoff. You may also assume an SOD downstream of the WWTP outfall of 1.5 $g/m^2/d$.

Additional Information:

$U = 0.150$ ft/sec = 2.45 miles/day
DO_{sat} or $C_s = 10.1$ mg/L (at 15°C)
BOD deoxygenation rate ($k_N = k_d$) = 0.8 day^{-1} (at 15°C)
CBOD settling rate (k_s) = 0.080 day^{-1} (at 15°C)

T = 15°C
H = 8 ft = 2.44 m
for k_N and k_d, $\theta=1.047$
for reareation, $\theta=1.024$



SOLUTION:

This is a problem that can be readily solved with the full Streeter-Phelps equation:

$$D = D_o e^{-k_a t} + \frac{k_d L_o}{k_a - k_r}\left(e^{-k_r t} - e^{-k_a t}\right) + \frac{k_d L_{No}}{k_a - k_r}\left(e^{-k_r t} - e^{-k_a t}\right) + \frac{S_B' / H}{k_a}\left(1 - e^{-k_a t}\right)$$

$$+ \frac{k_d S_d}{k_r k_a}\left(1 - e^{-k_a t}\right) - \frac{k_d S_d}{k_r\left(k_a - k_r\right)}\left(e^{-k_r t} - e^{-k_a t}\right)$$

You already have some of the coefficients needed. Here's what you need to do to get them all:

1. Calculate k_a and adjust for temperature:

Given the depth and velocity, use the O'Connor-Dobbins formula

$$k_a = 12.9\frac{U^{0.5}}{H^{1.5}} = 12.9\frac{0.15^{0.5}}{8^{1.5}} = \boxed{0.2208 d^{-1}} \text{ at 20C}$$

Then correct for temperature of 15C

$$(k_a)_{15} = (k_a)_{20}\theta^{(15-20)} = 0.2208(1.024)^{-5} = \boxed{0.196 d^{-1}}$$

2. Calculate the non-point volumetric CBOD load:

$$S_D = \frac{1000 L/m^3 (45 kg/mi/d) 0.15 ft/s (3.2808 ft/m)^3}{5280 ft/mi(40cfs + 2cfs)} = \boxed{1.075 mg/L/d}$$

3. Calculate the initial Deficit (D_o) from a simple mass balance at MP 0.

$$D_o = C_s - \frac{Q_u C_u + Q_{ww} c_{ww}}{Q_u + Q_{ww}} = 10.1 - \frac{40x8.2 + 2x6}{40 + 2} = 2.0\ mg/L$$

4. Calculate the initial CBOD concentration from a simple mass balance at MP 0

$$L_o = \frac{Q_u L_u + Q_{ww} L_{ww}}{Q_u + Q_{ww}} = \frac{40x6 + 2x100}{40 + 2} = \boxed{10.48\ mg/L}$$

5. Calculate the initial NBOD concentration from a simple mass balance at MP 0

$$L_{No} = \frac{Q_u L_{Nu} + Q_{ww} L_{Nww}}{Q_u + Q_{ww}} = \frac{40x0 + 2x(14x4.57)}{40 + 2} = \boxed{3.047\ mg/L}$$

6. Determine the sediment oxygen deman volumetric demand rate:

$$SOD = \frac{S_B'}{H} = \frac{1.5\frac{g}{m^2 d}}{8ft\frac{1m}{3.2808ft}} = \boxed{0.61\frac{mg}{L-d}}$$

Then determine the BOD and deficit at MP 7:

Overall deficit = terms incorporating (CBOD point deficit + point BOD + distributed deficit + distributed BOD)

$$D = D_o e^{-k_a t} + \frac{k_d L_o}{k_a - k_r}\left(e^{-k_r t} - e^{-k_a t}\right) + \frac{k_d L_{No}}{k_a - k_r}\left(e^{-k_r t} - e^{-k_a t}\right) + \frac{S_B' / H}{k_a}\left(1 - e^{-k_a t}\right)$$

$$+ \frac{k_d S_d}{k_r k_a}\left(1 - e^{-k_a t}\right) - \frac{k_d S_d}{k_r\left(k_a - k_r\right)}\left(e^{-k_r t} - e^{-k_a t}\right)$$

$$D = 2.0e^{-0.196(2.85)} + \frac{0.8(10.48)}{0.196 - 0.88}\left(e^{-0.88(2.85)} - e^{-0.196(2.85)}\right)$$

$$+ \frac{0.8(3.047)}{0.196 - 0.88}\left(e^{-0.88(2.85)} - e^{-0.196(2.85)}\right) + \frac{0.61}{0.196}\left(1 - e^{-0.196(2.85)}\right)$$

$$+ \frac{0.8(1.075)}{0.88(0.196)}\left(1 - e^{-0.196(2.85)}\right) - \frac{0.196(1.075)}{0.88\left(0.196 - 0.8\right)}\left(e^{-0.88(2.85)} - e^{-0.196(2.85)}\right)$$

D = 1.146 + 6.009 + 1.80 + 0.981 + 2.134 – 0.701
D = 11.732

C = 10.1 – 11.73 = -1.63 mg/L

The stream is anaerobic at MP 7

2. (50%) Lake Colvin is a suburban surface water that has received inputs of monosodium methane arsenate (MSMA) for many years. Efforts to clean up the lake resulted in the termination of all known loads of this compound by the beginning of 1997. At that point, the concentration of MSMA was 0.15 µg/L. By January 1, 2002, the MSMA level in the lake had dropped to 0.08 µg/L due to decay ($k = 0.00015\ d^{-1}$) and hydraulic flushing. However, on January 1, 2002 construction of a new golf course was completed on the shore of the lake. The export coefficient for MSMA from a golf course is 200 µg/acre/d. In 2002, the golf course consisted of 9 holes and 115 acres. Two years later (January 1, 2004 they completed addition of an additional 9 holes and thereby doubled the size of the golf course. The lake outflow is 100 m^3/day.

A. Determine the volume of Lake Colvin

Loss of MSMA is a first order reaction, incorporating decay (k) and hydraulic flushing.

$$C = C_o e^{-\lambda t}$$

Where:

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

So

$$\lambda = \frac{1}{t} ln\left(\frac{C}{C_o}\right) = \frac{1}{5yr} ln\left(\frac{0.08}{0.15}\right) = 0.1257yr^{-1} = 0.000344d^{-1}$$

And, rearranging the eigenvalue equation

$$V = \frac{Q}{\lambda + k} = \frac{100\frac{m^3}{d}}{0.000344d^{-1} - 0.00015d^{-1}} = \boxed{5.15x10^5 m^3}$$

B. Calculate the expected MSMA concentration in Lake Colvin at the beginning of the year 2020.

There are many ways to do this, but the easiest might be to break up the model into two time segments, one for the first two years with just a 9-hole golf course. And then a second for the remaining 16 years when the full 18-hole golf course was in operation.

Both would require general and particular solutions, the latter being for a step load:

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

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

And the loading is calculated from a simple export function:

$$W = 200\frac{\mu g}{acre{-}d}115acres = 23{,}000\frac{\mu g}{d}$$

At the end of 2 years (2004), the solution would be:

$$C = C_g + C_p = 0.0622 + 0.0289 = 0.0911 \ \mu g/L$$

At the end of the full 18 years, the solution would be:

$C = C_g + C_p = 0.0083 + 0.2287 =$ **0.2370 μg/L**

In summary:

		Concentration (ug/L)				
Date	years	Initial C		Step #1	Step #2	Total
2002	0	0.08		0		0.08
2004	2	0.0622		0.0289	0	0.0911
2020	18	0.0083		0.1163	0.1124	**0.2370**

3. (50%) On a separate sheet of paper, answer any five (5) of the following questions.

A. Describe the difference between mechanistic and empirical modeling

- Mechanistic is based on a some mechanism grounded in first principles or theory; a deductive approach
- Empirical is based on a statistical analysis of real environmental data. The model need not resemble actual fundamental relationships; an inductive approach

B. Discuss errors on model predictions. What is the origin of model error and what are the various types.

Some examples of errors

- Model errors
- Errors in parameter estimation
- Data errors
- Numerical dispersion and related “rounding” errors
- Error from application of models to conditions outside of the predictive space

Model error arise from sources of variability in the predicted variability that not adequately described by the model itself. These are normally independent of measurement or analytical errors.

C. List and briefly explain the various options for controlling or reversing cultural eutrophication

Options

- Reduce nutrient loading from the watershed (especially P)
- Add algicide like copper sulfate (kill agae directly)
- Remove macrophytes (reduce nutrient cycling)
- Dredge sediments (remove a source of nutrients)

In-lake treatment vs watershed

D. Describe 3 different methods for determining stream velocity.

a. Dye: inject it and follow concentration versus time at a point downstream
b. Current Meter: hand-held or suspended meter to measure velocity at various depths and cross-sections
c. Surface floating device: (oranges), only get surface velocity that way, look at different locations across stream width
d. Drogue: follow movement of device, sail can be set to different depths
e. Theoretical relationship based on roughness, slope, etc: e.g., Manning’s equation

E. Explain various options for design conditions in waste load allocations

- High flow (e.g., 7Q10) when contaminant concentrations are positively correlated with flow
- Low flow: when contaminants are diluted by runoff
- Ice cover: when volatilization is a major sink

F. Describe the factors that determine re-aeration in rivers, and contrast this with the factors that determine re-aeration in lakes. In your description, relate micro-scale processes (molecules) to macro-scale (bulk water or air)

a. Mixing is drives it. 2-film model interprets this as reducing the stagnant film thickness
b. Water side mixing is most important, and it is determined by turbulence and water depth
c. Water side turbulence is high with high velocity flow and roughness of stream channel. High flow and turbulence is cause by elevation drop (slope, free fall over a weir), and by wind turbulence on the surface
d. Air side mixing is less important but affected by wind speed also