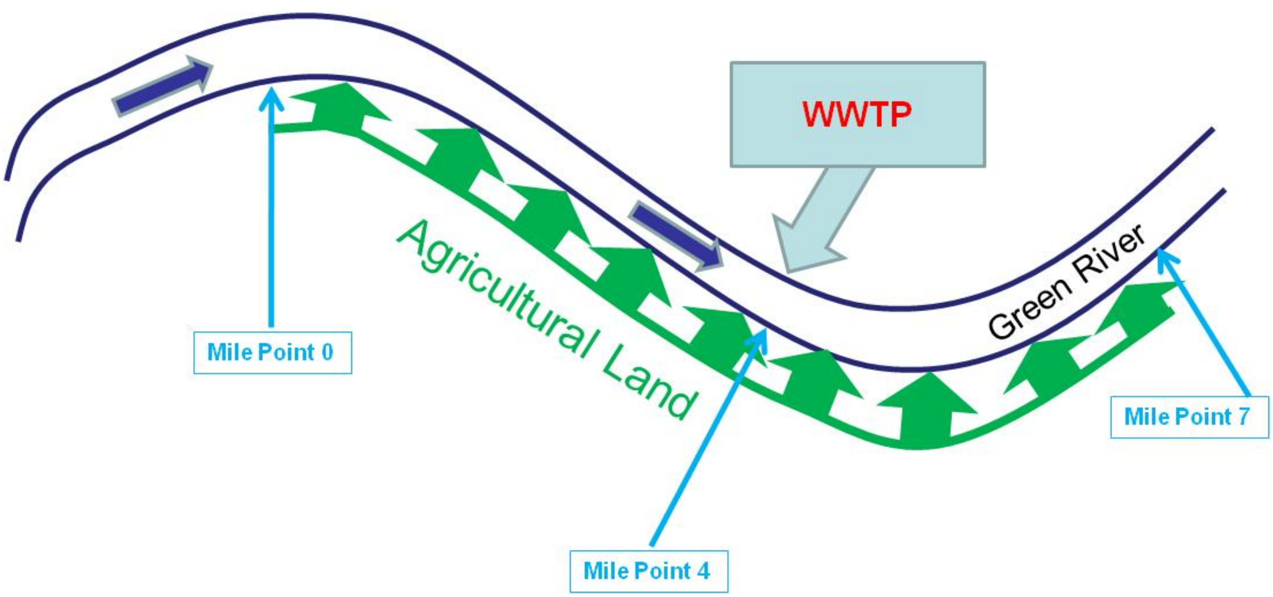
FINAL EXAM

Closed book, 2 sheets 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. Four miles into this agricultural region is a municipal wastewater discharge (from the city of Millstone). The BOD of the headwaters is 1.8 mg/L, and the dissolved oxygen is 8.2 mg/L (saturation is 9.1 mg/L for 20^{o}C). Starting at mile point zero, there is a significant non-point agricultural runoff of BOD amounting to 35 kg/mile/day. At mile point 4 is the Millstone WWTP outfall. Here a fully nitrified WW flow of 5 cfs is discharged with a CBOD of 30 mg/L and a DO of 6 mg/L. Immediately past this outfall is 3 more miles of agricultural land.

A) Calculate the dissolved oxygen concentration immediately above the WWTP outfall (i.e. at MP 3.999999)
B) Calculate the dissolved oxygen concentration immediately below the WWTP outfall (i.e. at MP 4.000001)
C) Calculate the dissolved oxygen concentration at the end of the agricultural land (i.e. at MP 7

Assume complete mixing across the stream in cross section. Assume also a temperature of 20^{o}C, a flow of 40 cfs from the headwaters and no incremental flow downstream except for flow from the Millstone WWTP. Many years if discharge has resulted in a very high SOD immediately downstream of the WWTP outfall of 5 g/m^2/d for the first mile (i.e., up to MP 5). After this, you can assume that it decreases to a fixed value of 0.5 g/m^2/d.



Additional Information:

U = 0.200 ft/sec = 3.27 miles/day	T = 20°C
DO_{sat} or C_S = 9.1 mg/L (at 20°C)	H = 4 ft = 1.22 m
BOD deoxygenation rate ($k_N = k_d$) = 0.8 day^{-1} (at 20°C)	for k_N and k_d, θ=1.047
CBOD settling rate (k_S) = 0.080 day^{-1} (at 20°C)	for reareation, θ=1.024

2. (50%) It is now well established that 17α-ethynylestradiol (also known as EE2, the active ingredient in birth control pills) causes feminization of male fish even when present at very low levels. In a 2007 publication[1], Karen Kidd of the Canadian Freshwater Institute, Jim Lazorchak of the USEPA and their colleagues showed that exposure to 5 ng/L (5×10^{-9}g/L) of EE2 for 3 years resulted in the total collapse of the native fathead minnow population in an experimental lake. Other short term studies have shown impacts on fish physiology as low as 0.1 ng/L of EE2.

   Minnow Lake located near and urban center in Massachusetts will be receiving treated effluent from a small wastewater treatment plant serving a new residential development. The developers are interested in low impact development (LID) so they decided discharge the wastewater locally. Applying a factor of safety of 50x to the Kidd et al. (2007) results and considering the short-term data, you decided that the EE2 concentration should not exceed 0.1 ng/L. So your job is to **determine the % EE2 removal required of the new WWTP so that the steady state concentration of EE2 in the lake stays under 0.1 ng/L**.

Assume the lake is at a temperature of 20°C. You should assume that most loading occurs due to direct dischage from the WWTP. The average raw wastewater concentration of EE2 is 100 ng/L. You may also assume that particulate forms of this compound biodegrade aerobically at 0.02 d^{-1} as opposed to 0.005 d^{-1} for the dissolved form. (universal gas constant, R=8.206×10^{-5} atm m^3/°K mole). Assume that EE2 does not biodegrade anaerobically.

Selected Physical and Chemical Properties of Ethynylestradiol

Property	**Value**	**Special Conditions**	**Reference**
Molecular Weight	296.39		
Melting Point	145°C		
Aqueous Solubility	19.1 mg/L	20°C	Yalkowski, 1999
Log K_{ow}	3.67		Hansch et al., 1995
Henry's Law Constant	1×10^{-6} atm-m^3/mol		Estimated
Biodegradation Rate	0.005 d^{-1}	Dissolved	Estimated from Cajthaml et al., 2009
	0.02 d^{-1}	Particulate	
pKa	10.4		Hurwitz & Liu, 1977
Photolysis Rate	0.166 d^{-1}		Estimated from Leech et al., 2009
Hydrolysis Rate	0.001 d^{-1}	20°C, neutral only	Estimated

[1] PNAS, 104:21:8897-8901.

Characteristics of Minnow Lake

Characteristic	Value
Volume	1,000,000 m^3
Average Outflow	20,000 m^3/day
Mean Depth	3 m
Mean Wind Speed	0.5 m/sec
Solids Settling Rate	0.2 m/d
Solids Burial Rate	0.000007 m/d
Sediment:Water Diffusive Exchange Rate	0.001 m/d
Water Column Suspended Solids	2.2 mg/L
Mixed Sediments Suspended Solids	12,000 mg/L
Thickness of Mixed Sediments	0.2 meters
Fraction of Organic Carbon in Solids	0.2
Density of Suspended Solids	1.55 g/mL
Drainage area	2300 ha

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

A. Describe and contrast one mechanistic and one empirical approach to modeling nutrients in surface waters.

B. Describe three ways to assess algal photosynthetic production using in-situ methods (i.e., done in the water body of interest)

C. Describe the factors that determine gas transfer of toxics in rivers, and contrast this with the factors that determine gas transfer in lakes. In your description, relate micro-scale processes (molecules) to macro-scale (bulk water or air)

D. Describe the various steps involved in photolysis of toxics in surface waters. Include some discussion on how these steps are modeled.

E. Discuss the role of the octanol-water partition coefficient and the Henry's law constant in determining the fate of contaminants in natural waters. Use a graph to help your description.

F. Explain how "Black Carbon" affects sorption in natural systems

G. Why does the Streeter-Phelps equation sometimes predict negative concentrations of dissolved oxygen, despite the fact that this is physically impossible? How can one correct this problem?