CIVE 3331 Environmental Engineering
Spring 2005 Exam #2

Name: Solution

Problem 1 – (DO Sag-Curves)

A subdivision proposes to discharge wastewater from a package plant into a freshwater stream. The stream has a minimum flow of 4 m^3/s. The wastewater flow will not exceed 1.5m^3/s. Laboratory studies indicate that the de-aeration coefficient is k_d =0.26/day and the re-aeration constant is k_r =0.41/day (both at 25°C). The river temperature is 25°C as will be the wastewater. At the outfall, after mixing, the dissolved oxygen in the river will be 7.5 mg/L. The minimum allowable dissolved oxygen in the river is 5.5 mg/L.

Determine:

a) The saturation dissolved oxygen concentration in the river. (DO_{sat})
b) The value of dissolved oxygen in the waste stream before mixing.
c) The largest value of BOD in the waste from the table below that can be discharged and meet the minimum dissolved oxygen requirement in the river.

A)	3.15 mg/L
B)	12.8 mg/L
C)	28.8 mg/L
D)	31.5 mg/L
E)	35.5 mg/L
F)	38.8 mg/L
G)	41.2 mg/L

d) Plot the DO-Sag curve (DO versus time) for the largest candidate value from part c) (One plot)

a) DO_{sat} @25°C, assume 0 mg/L Cl^-

$= \underline{\underline{8.26 mg/L}}$ (Table 5.11, Textbook) ←

b) $DO_0 = 7.5 mg/L = \dfrac{DO_{sat} Q_R + DO_{waste} Q_W}{Q_R + Q_W}$ (solve for DO_{waste}

$$DO_W = \frac{DO_0 (Q_R+Q_W) - DO_{sat} Q_R}{Q_W} = \frac{(7.5)(5.5)-(8.26)(4)}{(1.5)}$$

$= \underline{\underline{5.47 mg/L}}$ ←

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Problem 1 (Continued) (Page is blank – show work)

$$\frac{1}{k_r - k_d} \ln\left(\frac{k_r}{k_d}\left[1 - \frac{D_0(k_r - k_d)}{k_d L_0}\right]\right)$$

$$D_{max} = \frac{k_d L_0}{k_r - k_d}\left(e^{-k_d t_c} - e^{-k_r t_c}\right) + D_0 e^{-k_r t_c}$$

L_0 is unknown, rest are given

First express L_0 in terms of L_W

$$L_0 = \frac{Q_W L_W + Q_R L_R}{Q_W + Q_R} = \frac{1.5}{5.5} L_W$$

this is value in table in part (c)

Now by trial-error / brute force find value(s) in table that meet minimum DO instream.

$D_0 = 8.26 - 7.5 = 0.76 \text{ mg/L}$

$k_r - k_d = 0.41 - 0.26 = 0.15$

$k_r / k_d = 0.41 / 0.26 = 1.577$

$k_d L_0 = k_d \frac{1.5}{5.5} L_W = 0.071 L_W$

$(k_r - k_d) D_0 = (0.15)(0.76) = 0.114$

$$\therefore t_c = \frac{1}{0.15} \ln\left[1.577\left(1 - \frac{0.114}{0.071 L_W}\right)\right]$$

$$D_{max} = \frac{0.071 L_W}{0.15}\left[e^{-k_d t_c} - e^{-k_r t_c}\right] + 0.76 e^{-k_r t_c}$$

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Problem 1 (Continued) (Page is blank – show work)

$DO_{min}(allowed) = 5.5 mg/L$
$D_{max}(allowed) = 8.26 - 5.5 = 2.76$
find L_w so $D_{max} \leq 2.76$
find biggest L_w

L_w	$0.071 L_w$	$\frac{0.114}{0.071 L_w}$	$1-\frac{0.114}{0.071 L_w}$	t_c (days)	$e^{-k_d t_c}$	$e^{-k_r t_c}$	$0.76 e^{-k_r t_c}$	D_{max}	DO_{min}	
3.15	0.223	0.511	.489	1.732	0.637	0.491	0.373	1.59		
12.8	0.908	0.125	.857	2.008	.593	.438	0.333	1.271		
28.8	2.044	0.056	.944	2.65	.502	.337	0.256	2.504		
31.5	2.235	0.051	.949	2.68	.498	.333	0.253	2.711	5.549	← OK
35.5	2.519	0.045	.955	2.73	.492	.326	0.247	3.034	5.226	← Below std.
38.8	2.754	0.041	.959	2.75	.489	.324	0.246	3.270	4.99	
41.2	2.924	0.039	.961	2.77	.486	.321	0.244	3.4604	4.79	

L_w ok ↑ (rows 3.15–31.5)

L_w too big ↓ (rows 35.5–41.2)

Choose $L_{w(max)} = 31.5 mg/L$, $DO_{min} = 5.55 mg/L > 5.5 mg/L$

$D_{max} = 2.711 mg/L$

see plot

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Problem 1 (Continued) (Page is blank graph sheet – Use to plot DO-Sag Curve)

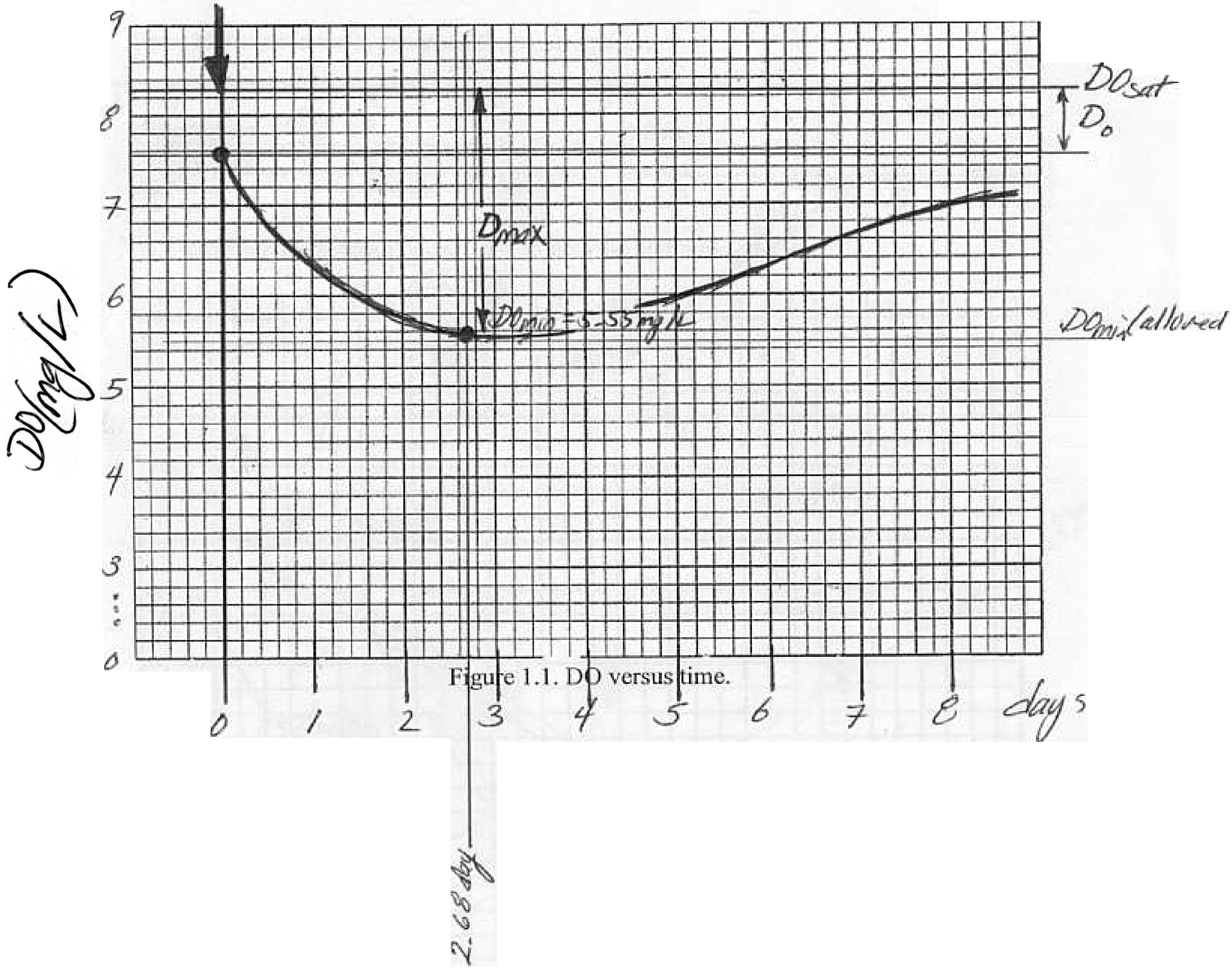

Figure 1.1. DO versus time.

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Problem 2 – (Gradients and Flowlines)

Three observation wells penetrate the same aquifer.

Well	A	B	C
x-coordinate	0	+ 300 m	0
y-coordinate	0	0	+ 200 m
head	+10 m	+ 11.5 m	+8.4 m

(a) Determine the magnitude and direction of the hydraulic gradient.

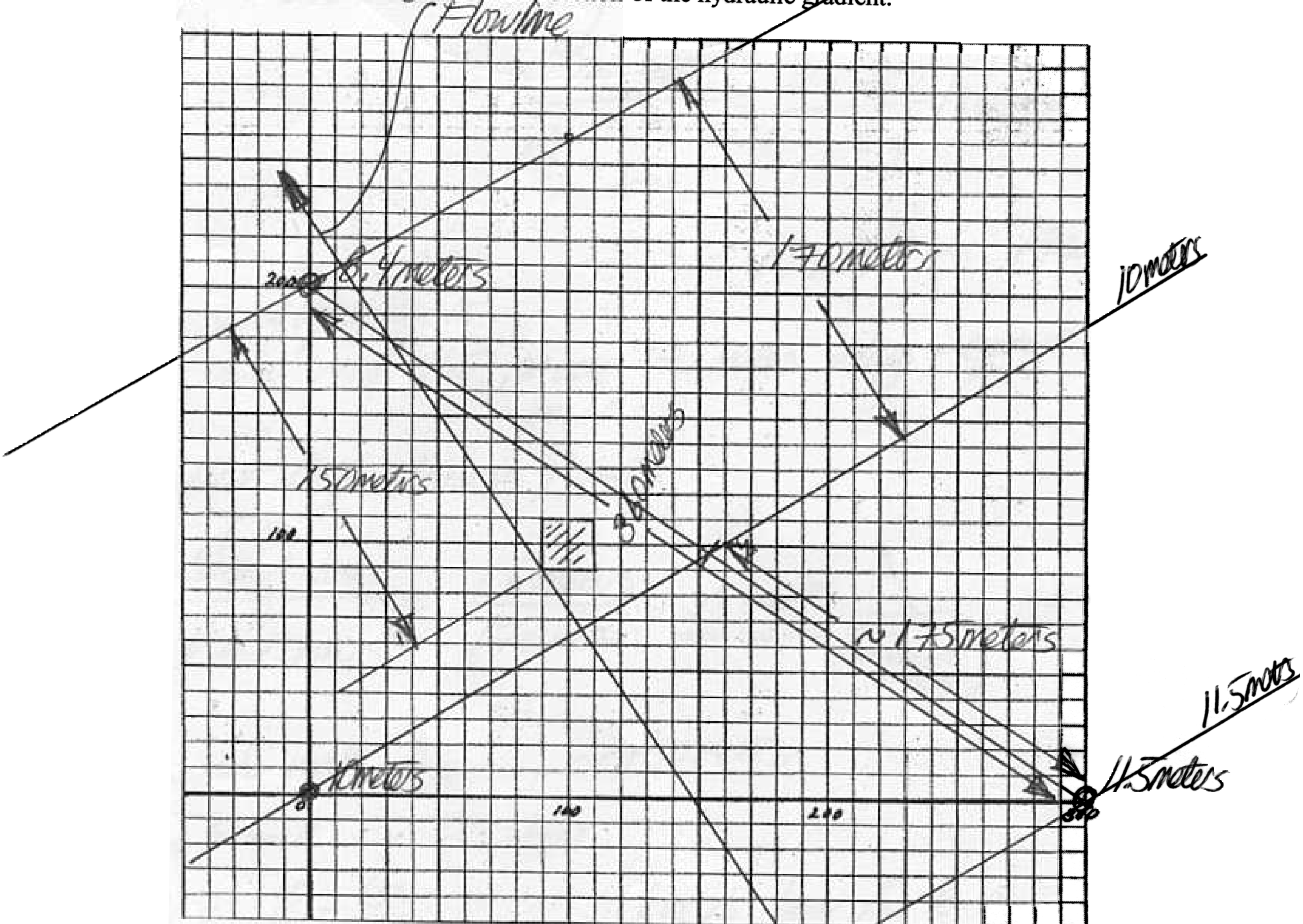

Figure 2.1 Well Field Sketch

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Problem 2 – (Continued)

(b) The rectangular pond centered at (100,100) leaks a chemical into the aquifer. The chemical moves as an ideal tracer (R=1). The time from the first entry of the chemical into the aquifer until detected at well C is 500 days. Determine the hydraulic conductivity of the aquifer if the porosity is 35%.

a) $dist_{Hi-low} \simeq 360$ meters

$dist_{hi-med} = ?$

$$\frac{\Delta h_{hi-med}}{\Delta h_{hi-lo}} = \frac{11.5-10.0}{11.5-8.4}(360\text{meter}) = dist_{hi-med}$$

$$= 174.19 \sim 175 \text{meters}$$

– draw equipotentials from well 11.5, move 175 meters along segment to 10.0 point

gradient (see drawing)

$$\frac{\Delta h_{med-low}}{l_{med-low}} = \frac{1.6 \text{ meters}}{170 \text{ meters}} = \underline{\underline{0.009}}$$

(direction on map)

b) $x_{pond\ to\ well}$ (approx) ~ 150 meters

$t_{pond\ to\ well}$ ~ 500 days

$$\therefore V = \frac{x}{t} = \frac{150}{500}$$

darcys law for R=1

$$V = \frac{K}{n}\frac{dh}{dl}\ ; \quad K = \frac{nV}{\frac{dh}{dl}}$$

$$K = \frac{(0.35)(150/500)}{} = \underline{\underline{11.6 \text{ m/day}}}$$

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Problem 3 – (BOD,ThOD)

A sample contains 200mg/L of casein ($C_8H_{12}O_3N_2$).

a) Calculate the theoretical CBOD.
b) Calculate the theoretical NBOD.
c) Calculate the theoretical total BOD.
d) If none of the NBOD is exerted in the first five days and k=0.25/day, estimate the 5-day BOD for the sample.

$C_8H_{12}O_3N_2$

$$MW = (8 \cdot 12) + (12 \cdot 1) + (3 \cdot 16) + (2 \cdot 14) = 184 g/mol$$

a) $$C_8H_{12}O_3N_2 + 8O_2 \Rightarrow 8CO_2 + 3H_2O + 2NH_3$$

$$CBOD = \frac{8O_2}{mol\ Cas.} \cdot \frac{32 g O_2/mol}{184 g\ Cas/mol} \cdot \frac{200 mg\ Cas}{L} = \underline{\underline{278 mg/L}}$$

) $$NH_3 + 2O_2 \Rightarrow NO_3^- + H^+ + H_2O$$

$$NBOD = \frac{2O_2}{1NH_3} \cdot \frac{2NH_3}{1 mol\ Cas.} \cdot \frac{32 g\ O_2/mol}{184 g\ Cas/mol} \cdot \frac{200 mg\ Cas}{L} = \underline{\underline{139 mg/L}}$$

$$TBOD = 278 mg/L + 139 mg/L = \underline{\underline{417 mg/L}}$$

d) $$BOD_5 = CBOD(1 - e^{-kt}) = 278(1 - e^{-\frac{0.25}{d}(5d)}) = \underline{\underline{198 mg/L}}$$

Name: solution

Problem 3 – (Page Blank, Show work)

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Problem 4- (Clarifier Design)

A clarifier for a 2 million-gallon-per-day (2mgd) activated-sludge treatment plant is to have an average overflow rate of 800 gal./day /ft^2. The tank must have a hydraulic retention time of 2.0 hours and be at least 11-feet deep. If the tank is circular, which of the following specifications produces the smallest volume tank that meets the design criteria?
(Hint: (1) Look at page 290 in the text, then THINK before you start the design problem).

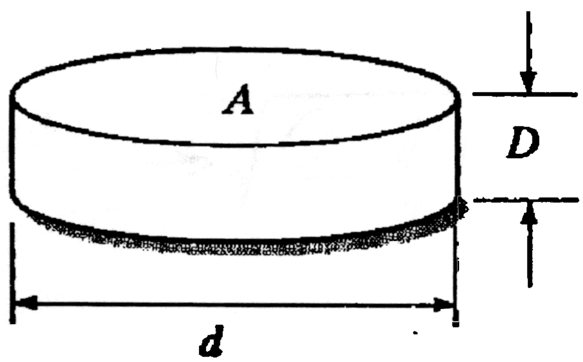

Figure 4.1 Sketch of circular clarifier.

A = area
d = diameter
D = depth

Two criteria

① $\frac{Q}{A} \leq 800 \text{ gal/day/ft}^2$

② $\frac{V}{Q} \geq 2 \text{ hrs} = 0.083 \text{ day}$

d too small — ~~A) $d = 56.2$ ft. ; $D = 8.9$ ft.~~
D too small — ~~B) $d = 56.4$ ft. ; $D = 8.9$ ft.~~
D too small — ~~C) $d = 56.8$ ft. ; $D = 8.9$ ft.~~
d too small — ~~D) $d = 56.2$ ft. ; $D = 11$ ft.~~
E) $d = 56.4$ ft. ; $D = 11$ ft.
~~F) $d = 56.8$ ft.~~ ; $D = 11$ ft.
d too small — ~~G) $d = 56.2$ ft. ; $D = 12.2$ ft.~~
H) $d = 56.4$ ft. ; $D = 12.2$ ft.
I) $d = 56.8$ ft. ; $D = 12.2$ ft.

Smallest volume tank meets criteria

Name: Solution

Problem 4- (Page Blank – Use to show work)

$$\frac{Q}{A} \leq 800\,gal/day/ft^2$$

$$\frac{Q}{A} = \frac{2\cdot 10^6\,gal/day}{\frac{\pi d^2}{4}} \leq 800\,gal/day/ft^2$$

$$\frac{2\cdot 10^6}{800} \leq \frac{\pi d^2}{4} \rightarrow \sqrt{\frac{(2.5\cdot 10^3\,ft^2)(4)}{\pi}} \leq d$$

$$56.4 \leq d$$

$\therefore$ d must be larger than 56.4 ft or overflow load will be too big. Eliminates A, D, G

(2) $$\frac{V}{Q} \geq 0.083\,day$$

$$\frac{\left(\frac{\pi d^2}{4}\right)D}{(2\cdot 10^6\,gal/day)\left(\frac{1\,ft^3}{7.48\,gal}\right)} \geq 0.083\,day$$

$$D \geq \frac{(0.083\,day)(2\cdot 10^6\,gal/day)\left(\frac{1\,ft^3}{7.48\,gal}\right)}{\left(\frac{2\cdot 10^6\,gal/day}{800\,gal/day/ft^2}\right)}$$

$$D \geq 8.91\,ft$$

$\therefore$ Depths must be at least 8.9 ft, but told min depth is 11 ft. Eliminates B & C

Min volume tank has smallest possible d & D in this case
E is smallest volume that meets design criteria