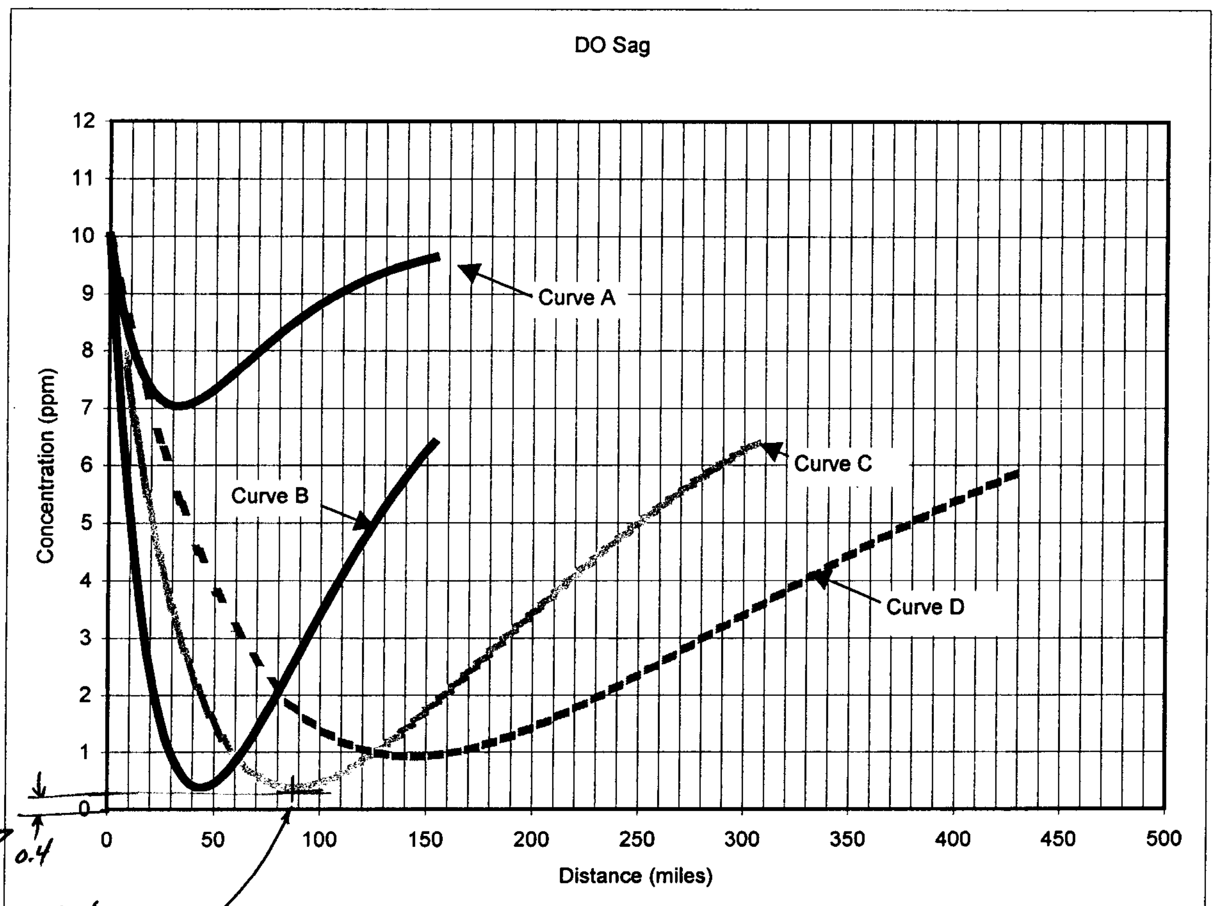
1) The ultimate BOD of a river just below a sewage outfall is 50 mg/L and the DO is at the saturation value of 10.0 mg/L. The deoxygenation coefficient k_d is 0.30/day and the reaeration coefficient k_r is 0.90/day. The river is flowing at the speed of 48.0 miles per day. The only source of BOD is the single outfall.

This information was used to produce the following dissolved oxygen sag curves, one of which is correct for this case. Select the correct and determine:

a) Select the correct dissolved oxygen profile for the situation described
b) Determine the critical distance downstream at which DO is a minimum. (Show calculations)
c) Determine the minimum DO (Show calculations)
d) If a wastewater treatment plant is to be built, what fraction of the BOD would have to be removed from the sewage to assure a minimum of 5.0 mg/L everywhere downstream?



DO min ≈ 0.4

min between 80 & 90 miles

(Page intentionally blank – use to show work for problem 1)

a) curve C (need to answer b & c to choose correct curve)

b) $t_c = \frac{1}{k_r - k_d} \ln\left(\frac{k_r}{k_d}\right) = \frac{1}{0.90 - 0.30/d} \ln\left(\frac{0.9}{0.3}\right) = 1.83$ days

$x_c = v t_c = 48 \text{ miles/day} * 1.83 \text{ days} = 87.9$ miles

c) $D_{max} = \frac{k_d L_0}{k_r - k_d}\left(e^{-k_d t} - e^{-k_r t}\right)$

$= \frac{0.3/d * 50 \text{ mg/L}}{(0.9-0.3)/d}\left(e^{-0.3*1.83} - e^{-0.9*1.83}\right) = 9.6 \text{ mg/L}$

$\therefore DO_{min} = DO_{SAT} - D_{max} = 10.0 - 9.6 \text{ mg/L} = 0.4 \text{ mg/L}$

d) $D_0 = 0$, then D is proportional to L_0

$\frac{D_{max-required}}{D_{max-current}} = \frac{5.0 \text{ mg/L}}{9.6 \text{ mg/L}} = 0.52$

$\therefore$ Need to remove $1.0 - 0.52 = 48\%$ of BOD to achieve desired in-stream standard

– curve C is chosen based on calculated values in b) & c)

Solution

2) Suppose some pond water contains 10.0 mg/L of some algae, which can be represented by the chemical formula $C_6H_{15}O_6N$. Use the following reactions:

$$C_6H_{15}O_6N + 6O_2 \Rightarrow 6CO_2 + 6H_2O + NH_3$$

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

a) Find the theoretical carbonaceous oxygen demand.
b) Find the total theoretical (carbonaceous and nitrogeneous) oxygen demand.

a) $C_6H_{15}O_6N + 6O_2 \rightarrow 6CO_2 + 6H_2O + NH_3$

1 mol $C_6H_{15}O_6N = 197$ g

6 mol O_2 oxidizes 1 mol $C_6H_{15}O_6N$

$$\frac{10\,mg\ C_6H_{15}O_6N}{L} \cdot \frac{1\,mol\ C_6H_{15}O_6N}{197\,g\ C_6H_{15}O_6N} \cdot \frac{6\,mol\ O_2}{1\,mol\ C_6H_{15}O_6N} \cdot \frac{32\,g}{/mol\ O_2} = 9.75\,mg\ L$$

ThOD carbonaceous $= 9.75$ mg/L

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

1 mol $NH_3 = 17$ g

2 mol O_2 oxidize 1 mol NH_3

$$NBOD = \frac{10\,mg\ C_6H_{15}O_6N}{L} \cdot \frac{1\,mol\ C_6H_{15}O_6N}{197\,g\ C_6H_{15}O_6N} \cdot \frac{1\,mol\ NH_3}{/mol\ C_6H_{15}O_6N} \cdot \frac{2\,mol\ O_2}{1\,mol\ NH_3} \cdot \frac{32\,g}{1\,mol\ O_2} =$$

$$= 3.25\,mg/L$$

Total $= ThOD_c + NBOD = 9.75 + 3.25 = 13.0$ mg/L

Solutions

3) A mixture consisting of 30 mL of waste and 270 mL of seeded dilution water has an initial DO of 8.55 mg/L; after five days, it has final DO of 2.40 mg/L. Another bottle containing just the seeded dilution water has an initial DO of 8.75 mg/L and a final DO of 8.53 mg/L. Find the five day BOD of the waste.

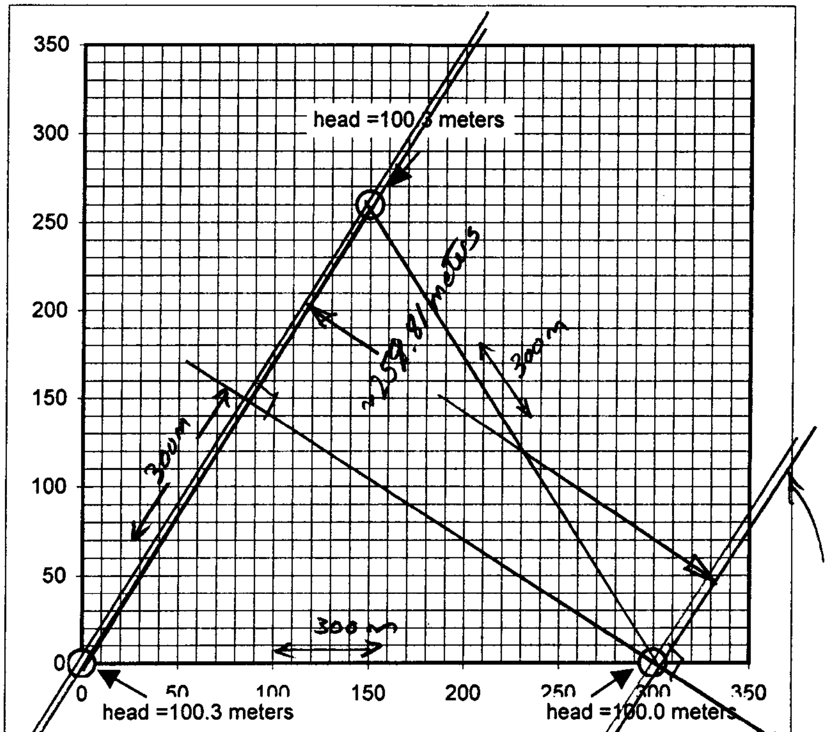
$$BOD_W = \frac{(DO_i - DO_f) - (B_i - B_f)(1-P)}{P}$$

$$P = \frac{mL\ waste}{mL\ total} = \frac{30}{300} = \frac{1}{10}$$

$$\therefore \quad \frac{8.55 - 2.40 - (8.75 - 8.53)(1 - 1/10)}{\frac{1}{10}} = 59.5\ mg/L$$

3) Consider three monitoring wells located as shown. The head in each well is noted next to the well (it is also listed in the table at the bottom of the picture. The aquifer has a porosity of 0.23 and a hydraulic conductivity of 1000m/d.

   a) Determine the magnitude and direction of the hydraulic gradient in this aquifer.
   b) Determine the average linear velocity of the groundwater
   c) If the front edge of a straight plume arrives simultaneously at wells 1 and 2, how long will it take the plume to arrive at well 3 if the retardation factor is 2?



x (meters)	y (meters)	head (meters)
0	0	100.3
150	259.81	100.3
300	0	100

a) $\frac{\Delta h}{\Delta l} = \frac{100.3 - 100}{259.81} = 0.0011$ in direction shown.

(This page intentionally blank – use to show work for problem 4)

b) $v = \frac{K}{n}\frac{\Delta h}{\Delta l} = \frac{1000 \, m/d}{0.23} \cdot 0.0011 = 5.02 \, m/d$

c) $x = vt$ solve for t

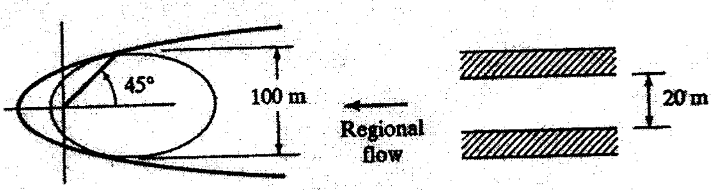
$$t = \frac{x}{v} = \frac{259.81}{5.02} = 51.75 \text{ days}$$

but $R = 2.0$

$\therefore$ travel time of plume is

$(2.0)(51.75 \text{ day}) = 103.5$ days

5) A single well is to be used to remove a symmetrical oblong plume of contaminated groundwater in an aquifer 20.0 m thick, porosity 0.30, hydraulic conductivity 1.0 x 10^{-4} m/sec, and hydraulic gradient 0.0015. With the plume and well oriented as shown, the angle from the well to the edge of the plume at the widest part of the plume is 45°. The plume is 100 meters wide at this point. What pumping rate is required to achieve these conditions?



$$y = \frac{Q}{2Bv}\left[1 - \frac{\phi}{\pi}\right] = \frac{Q}{2Bv}\left[1 - \frac{\pi/4}{\pi}\right] = \frac{3Q}{8Bv} = 50\text{m (plume } \tfrac{1}{2} \text{ widths)}$$

$$v = K \cdot \text{gradient} = 1 \cdot 10^{-4} \cdot 0.0015$$

$$B = 20 \text{ m}$$

Solve for Q

$$Q = \frac{8Bvy}{3} = \frac{8(20\text{m})(1\cdot 10^{-4}\text{ m/sec})(0.0015)(50\text{m})}{3} = 0.0004\text{ m}^3/\text{s}$$

Note: porosity is not used in this problem.