uOttawa

Department of Civil Engineering

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CVG2132 – Fundamental of Environmental Engineering

Fall 2015 Assignment #5 : BOD & DO Sag R.M. Narbaitz

Question 1:

For a typical laboratory of 5-day BOD experiment, explain why:

(a) Why is the BOD bottle is covered with a cap?

(b) Why are the bottles incubated in the dark (or the bottle is sometimes opaque)?

(c) Why it is typically necessary to dilute the sample?

(d) Why it is sometimes necessary to inoculation of the specimen?

(e) Why is the ultimate BOD value typically not measured?

Answer 1:

(a) the bottles are covered to prevent the reaeration.

(b) the bottles are opaque or incubated in a dark incubator to prevent the production of dissolved oxygen through photosynthesis.

(c) dilutions are almost always necessary to ensure the final DO is not zero and it is sufficiently large so that it measurable accurately (i.e., >2 mg/L).

(d) not all samples have an adequate level of microorganisms in them.

(e) the measurement of the ultimate BOD often takes too much time.

Question 2 : A waste water treatment plant releases 2.5 m^3/s of wastewater effluent with a BOD_u of 60 mg/L at 26.7 ° C and a DO concentration of 1.5 mg/L. The river where the water is released has a flowrate of 4.5 m^3/s and a flow velocity of 0.45 m/s. Its average depth is 1.5 m the temperature of the River before the mixture is 21 ° C. The River before mixing with the discharge has a DO concentration that equals 85% of the saturation level, and BOD_u concentration of 2.0 mg/L BOD value. Kinetic constants (k_r) reaeration and deoxygenation (k_d) of the River are 0.35 d^{-1} and 0.2 d^{-1} at 20 ° C, respectively.

Determine:

(a) The temperature of the River at the point of mixing.

(b) The initial concentration of DO point mix).

(c) The dissolved oxygen deficit at the point of mixture value.

(d) The value of BOD_U at the point of mixing.

(e) The distance from the point of discharge to the point where the critical DO takes place.

(f) The critical DO concentration.

Problem 2

Assume steady-state conditions so Accumulation =0

Assume the three streams are dilute and have the same density

Assume the river flow velocity downstream of the discharge equals that upstream of the discharge

Assume the mixing is instantaneous and complete. This implies the mixing volume is negligible.

So there is no DO generation or consumption in the mixing point.

Qr	4.5	m^3/s
Qw	2.5	m^3/s
Ts	21	^oC
Tww	26.7	^oC
DOr =	7.6415	mg/L
DOw	1.5	mg/L
DOsat	8.99	mg/L
BOD_U_ww =	60	mg/L
k (20°C)	0.2	d^{-1}
Ls = Upstream	2	mg/L
v (m/s) =	0.45	
H = depth (m) =	1.5	
ŋ =bed activity coefficient =		
kr	0.35	d^{-1}

Total mass balance around the mixing point

$$Accum. = (Q_r \cdot \rho_r) + (Q_w \cdot \rho_w) - (Q_o \cdot \rho_o)$$

Steady-state so Accumulation =0

All the densities are equal as these are dilute solutions

so

Q_o = 4.5 m^3/s + 2.5 m^3/s = 7 m^3/s

Dissolved Oxygen (DO) mass balance around the mixing point

$$Accum. = (Q_r \cdot DO_r) + (Q_w \cdot DO_w) - (Q_o \cdot DO_o) + \text{Generation - Consumption}$$

Accumulation =0 because of the steady-state conditions

Because of the negligible volume the generation and consumption are negligible

so

$$DO_o = \frac{(Q_r \cdot DO_r) + (Q_w \cdot DO_w)}{Q_o}$$

$$DO_o = \frac{(\ 4.5\ m^3/s\ \text{x}\ 7.6415\ mg/L\ )+(\ 2.5\ m^3/s\ \text{x}\ 1.5\ mg/L\ )}{7}$$

DO_o = 5.448107 mg/L

5.45

Ultimate BOD of the effluent

$$BOD(t) = L_w \times \left(1 - e^{-k \cdot t}\right)$$

So

$$L_w = BOD(t)/\left(1 - e^{-k \cdot t}\right)$$

Lw = 60 mg/L

Ultimate BOD remaining (L) Mass balance around the mixing point

$Accum. = (Q_r \cdot L_r) + (Q_w \cdot L_w) - (Q_o \cdot L_o)$+ Generation - Consumption

Accumulation =0 because of the steady-state conditions

Because of the negligible volume the generation and consumption are negligible

so

$$L_o = \frac{(Q_r \cdot L_r) + (Q_w \cdot L_w)}{Q_o}$$

$$L_o = \frac{(\ 4.5\ m^3/s\ \ x\ \ 2\ mg/L\ )+(\ 2.5\ m^3/s\ \ x\ \ 60\ mg/L\ )}{7}$$

L_o = 22.71429 mg/L

22.7

Pseudo heat balance around the mixing point

$$T_o = \frac{(Q_r \cdot T_r) + (Q_w \cdot T_w)}{Q_o}$$

$$T_o = \frac{(\ 4.5\ m^3/s\ \ x\ \ 21\ ^oC\ )+(\ 2.5\ m^3/s\ \ x\ \ 26.7\ ^oC\ )}{7}$$

T_o = 23.03571 ^{o}C

23

Saturation DO for T_o

From the table DOsat (23.036 ^{o}C) = 8.68

Dissolved Oxygen Deficit (D) leaving the mixing point

$$D_o = DO_{sat} - DO_o$$

D_o = 8.68 mg/L - 5.45 mg/L = 3.23 mg/L

Deoxygenation rate constant at 20^{o}C

k_d = 0.2 d^{-1}

Deoxygenation rate constant at T_o

$$k_d(T) = k_d(20) \cdot \theta^{T-20}$$

θ = 1.135

(23.0357 - 20)

$k_d\,(T_o)$ = 0.2 d^{-1} x 1.056

k_d (23.03571) = 0.235975 d^{-1}

0.236

Reaeration rate constant at 20°C k_r (20°C)

k_r = 0.35 d^{-1}

Reaeration rate constant at To k_r (To)

$$k_r(T) = k_r(20) \cdot \theta^{T-20}$$

θ = 1.024

(23.0357 - 20)

$k_r\,(T_o)$ = 0.35 d^{-1} X 1.024

k_r (23.03571) = 0.376128 d^{-1}

0.376

t_C = travel time to reach the critical deficit

$$t_c = \frac{1}{k_r - k_d} \cdot ln\left[\frac{k_r}{k_d}\left(1 - D_o \cdot \frac{k_r - k_d}{k_d \cdot L_o}\right)\right]$$

t_C = 2.699369 d

2.67

Critical DO location

$$distance = t_C \cdot flow\ velocity$$

distance = = 2.699369 d x 0.45 m/s x 86400 s/d

= 104951.4 m

= 104.9514 km

ANSWER Part A) Location of critical DO = 104.951 km downstream

DO deficit at the critical point (Dc)

$$D_c = \frac{k_d \cdot L_o}{k_r - k_d} \cdot \left(e^{-k_d \cdot t_c} \; - \; e^{-k_r \cdot t_c}\right) + \quad D_o \cdot e^{-k_r \cdot t_c}$$

D_C = 7.398319 mg/L

7.4

DO at the critical point (Dc)

$D_c = DO_{sat} - DO_C$ so $DO_C = DO_{sat} - D_c$

DO_C = 8.68 mg/L - 7.4 mg/L = 1.28 mg/L

ANSWER Part B) Critical DO = 1.28 mg/L

This is not satisfactory, it is far too low for fish

The effluent BOD concentration must be decreased by providing a greater degree of treatment is required

Question 3 : For the same conditions as problem 2.

a. The provincial regulations require that for worst conditions (high temperature and low flow summer conditions) mentioned above, the DO concentration should be at least 5 mg O_2/L. Calculate the maximum BOD_u that can be in the wastewater effluent? Use a spreadsheet to facilitate your calculations.

b. Assuming that the k of the wastewater effluent is the same as that in the river, calculate the maximum BOD_5 that can be in the wastewater effluent?

c. Assuming the wastewater in question is a municipal wastewater with raw (prior to treatment) has a BOD_5 concentration of 250 mg O_2/L, what type of wastewater treatment needs to be provided to meet the requirement in parts b) and c)? Explain in detail.

d. If a significant amount of ammonia is present in waste water, maximum oxygen deficit will be bigger or smaller? Explain clearly.

Problem 3

Assume steady-state conditions so Accumulation =0

Assume the three streams are dilute and have the same density

Assume the river flow velocity downstream of the discharge equals that upstream of the discharge

Assume the mixing is instantaneous and complete. This implies the mixing volume is negligible.

So there is no DO generation or consumption in the mixing point.

Qr	4.5	m^3/s
Q_w	2.5	m^3/s
Ts	21	^oC
T_{ww}	26.7	^oC
DO_r =	7.6415	mg/L
DO_w	1.5	mg/L
DO_{sat}	8.99	mg/L
BOD_U_ww =	unknown	mg/L
k (20°C)	0.2	d^{-1}
L_r = Upstream	2	mg/L
v (m/s) =	0.45	
H = depth (m) =	1.5	
η =bed activity coefficient =		
k_r	0.35	d^{-1}

Total mass balance around the mixing point

$$Accum. = (Q_r \cdot \rho_r) + (Q_w \cdot \rho_w) - (Q_o \cdot \rho_o)$$

Steady-state so Accumulation =0

All the densities are equal as these are dilute solutions

so

Q_o = 4.5 m^3/s + 2.5 m^3/s = 7 m^3/s

Dissolved Oxygen (DO) mass balance around the mixing point

$$Accum. = (Q_r \cdot DO_r) + (Q_w \cdot DO_w) - (Q_o \cdot DO_o) + \text{Generation - Consumption}$$

Accumulation =0 because of the steady-state conditions

Because of the negligible volume the generation and consumption are negligible

so

$$DO_o = \frac{(Q_r \cdot DO_r) + (Q_w \cdot DO_w)}{Q_o}$$

$$DO_o = \frac{(4.5\ m^3/s \times 7.6415\ mg/L) + (2.5\ m^3/s \times 1.5\ mg/L)}{7}$$

DO_o = 5.448107 mg/L

Pseudo heat balance around the mixing point

$$T_o = \frac{(Q_r \cdot T_r) + (Q_w \cdot T_w)}{Q_o}$$

$$T_o = \frac{(4.5\ m^3/s \times 21\ ^oC) + (2.5\ m^3/s \times 26.7\ ^oC)}{7}$$

T_o = 23.03571 ^oC

Saturation DO for T_o

From the table DOsat (23.036 ^oC) = 8.83

Dissolved Oxygen Deficit (D) leaving the mixing point

$$D_o = DO_{sat} - DO_o$$

D_o = 8.83 mg/L - 5.448107 mg/L = 3.3819 mg/L

Deoxygenation rate constant at 20^{o}C

k_d = 0.2 d^{-1}

Deoxygenation rate constant at T_o

$$k_d(T) = k_d(20) \cdot \theta^{T-20}$$

θ = 1.135

$k_d (T_o)$ = 0.2 d^{-1} x $1.056^{(23.0357 - 20)}$

k_d (23.03571) = 0.235975 d^{-1}

Reaeration rate constant at 20°C k_r (20°C)

k_r = 0.35 d^{-1}

Reaeration rate constant at To k_r (To)

$$k_r(T) = k_r(20)\cdot\theta^{T-20}$$

θ = 1.024

$k_r(T_o)$ = 0.35 d^{-1} X $1.024^{(23.0357\ -\ 20)}$

k_r (23.03571) = 0.376128 d^{-1}

PART A) Calculate the maximum BODu that can be in the wastewater effluent?

DO at the critical point (Dc)

$D_c = DO_{sat} - DO_C$ so $DO_C = DO_{sat} - D_c$

DOc = 5 mg/L

D_C = 8.99 mg/L - 5 mg/L = 3.99 mg/L

Solve by a) assuming a value of L_W

b) calculate L_o, t_c, and D_c

c) If the D_c is greater than 3.99 mg/L, then try other values of LW and repeat

First assume L_w = 50 mg/L

Ultimate BOD remaining (L) Mass balance around the mixing point

$Accum. = (Q_r\cdot L_r)+(Q_w\cdot L_w)-(Q_o\cdot L_o)$+ Generation - Consumption

Accumulation =0 because of the steady-state conditions

Because of the negligible volume the generation and consumption are negligible

so

$$L_o = \frac{(Q_r\cdot L_r)+(Q_w\cdot L_w)}{Q_o}$$

$$L_o = \frac{(4.5\ \text{m}^3/\text{s} \times 2\ \text{mg/L}) + (2.5\ \text{m}^3/\text{s} \times 50\ \text{mg/L})}{7}$$

L_o = 19.14286 mg/L

t_C = travel time to reach the critical deficit

$$t_c = \frac{1}{k_r - k_d} \cdot ln\left[\frac{k_r}{k_d}\left(1 - D_o \cdot \frac{k_r - k_d}{k_d \cdot L_o}\right)\right]$$

t_C = 2.535463 d

DO deficit at the critical point (Dc)

$$D_c = \frac{k_d \cdot L_o}{k_r - k_d} \cdot \left(e^{-k_d \cdot t_c} - e^{-k_r \cdot t_c}\right) + D_o \cdot e^{-k_r \cdot t_c}$$

D_C = 6.602317 mg/L

As this is larger than our target of $D_C <$ 3.99 mg/L

Repeat these calculations in a tabular form

L_w (mg/L)	50	40	30	20	22
L_o (mg/L)	19.14	15.57	12.00	8.43	9.14
t_c (days)	2.54	2.34	2.02	1.38	1.56
D_c (mg/L)	6.60	5.62	4.67	3.81	3.97

A L_W of 22 mg/L meets the $D_c <$ 3.99mg/L

ANSWER PART a) Lw = **22 mg/L**

Critical DO location

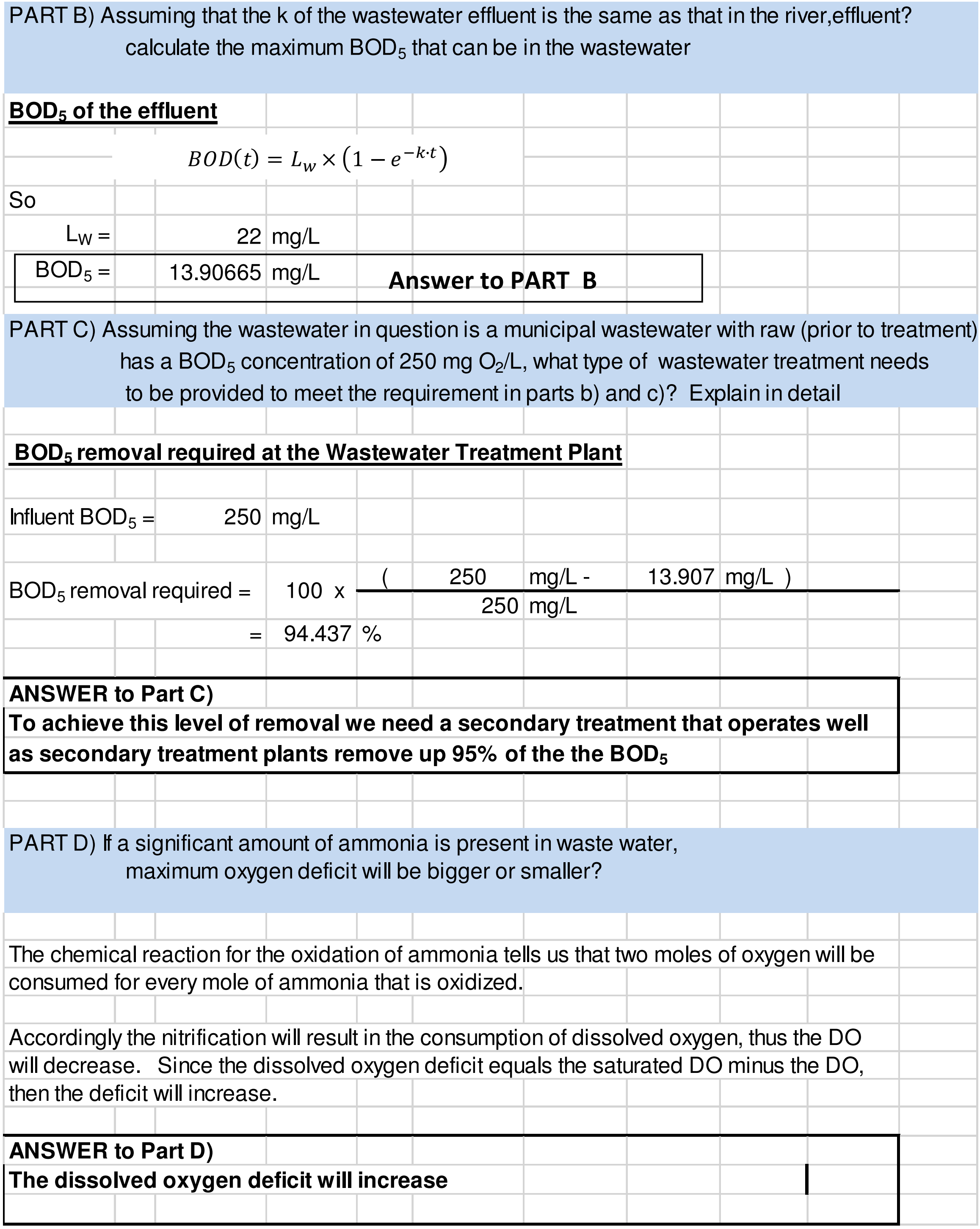
$$distance = t_C \cdot flow\ velocity$$

distance = = 1.56 d x 0.45 m/s x 86400 s/d

= 60513.68 m

= 60.51368 km

Location of critical DO = 60.5137 km downstream



PART B) Assuming that the k of the wastewater effluent is the same as that in the river,effluent? calculate the maximum BOD_5 that can be in the wastewater

BOD_5 of the effluent

$$BOD(t) = L_w \times (1 - e^{-k \cdot t})$$

So

L_W = 22 mg/L

BOD_5 = 13.90665 mg/L **Answer to PART B**

PART C) Assuming the wastewater in question is a municipal wastewater with raw (prior to treatment) has a BOD_5 concentration of 250 mg O_2/L, what type of wastewater treatment needs to be provided to meet the requirement in parts b) and c)? Explain in detail

BOD_5 removal required at the Wastewater Treatment Plant

Influent BOD_5 = 250 mg/L

$$BOD_5 \text{ removal required} = 100 \times \frac{(250 \text{ mg/L} - 13.907 \text{ mg/L})}{250 \text{ mg/L}}$$

$$= 94.437\ \%$$

ANSWER to Part C)
To achieve this level of removal we need a secondary treatment that operates well as secondary treatment plants remove up 95% of the the BOD_5

PART D) If a significant amount of ammonia is present in waste water, maximum oxygen deficit will be bigger or smaller?

The chemical reaction for the oxidation of ammonia tells us that two moles of oxygen will be consumed for every mole of ammonia that is oxidized.

Accordingly the nitrification will result in the consumption of dissolved oxygen, thus the DO will decrease. Since the dissolved oxygen deficit equals the saturated DO minus the DO, then the deficit will increase.

ANSWER to Part D)
The dissolved oxygen deficit will increase

If the wastewater effluent has an ammonia concentration of 2.8 mg/L as N.

- Given that the molecular weight of N is 14, then the molar concentration of ammonia is 0.2 mmole /L or 0.2 mole/m^3

- Assume that the upstream ammonia concentration is zero

  Ammonia mass balance around the mixing point

  $$Accum. = \ (Q_r \times Ammonia_r) + \ (Q_W \times Ammonia_W) - (Q_o \times Ammonia_o)$$

  As steady-state condition prevail, Accum. =0.

  Substituting the known values we get

  $$0 = \ \left(4.5\frac{m^3}{s} \times 0\right) + \ \left(2.5\frac{m^3}{s} \times 0.2\frac{mole\ Amm}{m^3}\right) - \left(7\frac{m^3}{s} \times Ammonia_o\right)$$

  $$so\ Ammonia_o = \ 0.0714\frac{mole\ Amm}{m^3}$$

  Based on the nitrification equation 2 moles of O_2 are consumed per mole of ammonia oxidized. This reaction is slow, slower than that caused by the BOD, so the O_2 reduction will take longer. But eventually it result in the consumption of 0.143 moles O_2 / m^3. Since each mole of O_2 weighs 32 g, then the ammonia will eventually cause a reduction of 4.58 g O_2 /m^3. So it could consume practically all of the DO available. Fortunately the maximum NOD will occur downstream of the critical point so DO should be a bit higher than at the critical point.

Question 4: (from the 2014 final exam)

The only source of BOD in a river is from the untreated wastewater discharge of an industry. The DO sag curve in the resulting river has a minimum DO value of 2.0 mg/L at some distance downstream of the point of discharge. The DO of the waste from the plant is high enough and therefore the DO of the river water after the discharge mixes with the river water is still saturated. The mixed stream temperature is 10 ° C. Reaeration coefficient equal to 0.65 day^{-1} at 20 ° C and deoxygenation coefficient of 0.12 day^{-1} at 20 ° C. The average flow velocity of the stream is 25,000 m/day. $\theta_d = 1.135$ and $\theta_r = 1.024$.

TASKS:

A) Calculate the distance (km) downstream from the discharge to where the DO level is critical.

B) Calculate the BOD_U in the river at the point immediately after the wastewater discharge mixes with the river.

C) Calculate the BOD_U at the point of mixing (between the discharge and river) which is necessary to maintain the DO above 6 mg/L and therefore that let stand an aquatic community in 'health' through the system whole?

D) Based on the value of BOD_U at the point of mixing between the discharge and the river that is necessary to maintain an aquatic community in 'health' (part c) and the BOD_u value when the untreated wastewater is discharged (part b), calculate the level of wastewater treatment (primary, secondary or tertiary) which is necessary to treat such waste. Explain in detail.

Problem 4

Assume steady-state conditions so Accumulation =0
Assume the three streams are dilute and have the same density
Assume the river flow velocity downstream of the discharge equals that upstream of the discharge
Assume the mixing is instantaneous and complete. This implies the mixing volume is negligible.
So there is no DO generation or consumption in the mixing point.

Velocity r	25000	m/d
To	10	°C
DO_{sat}	11.33	mg/L
DO_o =	11.33	mg/L
DO_w	1.5	mg/L
BOD_{U_ww} =	unknown	mg/L
k_d (20°C)	0.12	d^{-1}
k_r	0.65	d^{-1}

Dissolved Oxygen Deficit (D) leaving the mixing point

$$D_o = DO_{sat} - DO_o$$

D_o = 11.33 mg/L - 11.33 mg/L = 0 mg/L

D_o = 0 mg/L

Deoxygenation rate constant at 20°C

k_d = 0.12 d^{-1}

Deoxygenation rate constant at T_o

$$k_d(T) = k_d(20) \cdot \theta^{T-20}$$

θ = 1.135

k_d (T_o) = 0.12 d^{-1} x $1.135^{(10 - 20)}$

k_d (10) = 0.033824 d^{-1}

k_d = 0.0338 d^{-1}

Reaeration rate constant at 20°C k_r (20°C)

k_r = 0.65 d^{-1}

Reaeration rate constant at To k_r (To)

$$k_r(T) = k_r(20) \cdot \theta^{T-20}$$

θ = 1.024

k_r (T_o) = 0.65 d^{-1} X $1.024^{(10 - 20)}$

k_r (10) = 0.51276 d^{-1}

k_r = 0.513 d^{-1}

*

PART A) Calculate the distance (km) downstream from the discharge to where the DO level is critical.

t_C = travel time to reach the critical deficit

$$t_c = \frac{1}{k_r - k_d} \cdot ln\left[\frac{k_r}{k_d}\left(1 - D_o \cdot \frac{k_r - k_d}{k_d \cdot L_o}\right)\right]$$

but since Do= 0 $t_c = \frac{1}{k_r - k_d} \cdot ln\left[\frac{k_r}{k_d}\right]$

t_c = 5.675741 d

t_c = 5.676 d

Critical DO location

$$distance = t_C \cdot flow\ velocity$$

distance = 5.676 d x 25000 m/d

= 141900 m

= 141.9 km

Answer to Part A) distance to critical location = 141.9 km

PART B) Calculate the BOD$_U$ in the river at the point immediately after the wastewater discharge mixes with the river.

DO at the critical point (Dc)

$D_c = DO_{sat} - DO_C$ so $DO_C = DO_{sat} - D_c$

DOc = 2 mg/L

D$_C$ = 11.33 mg/L - 2 mg/L = 9.33 mg/L

DO deficit equation at the critical point (Dc) is

$$D_c = \frac{k_d \cdot L_o}{k_r - k_d} \cdot \left(e^{-k_d \cdot t_c} - e^{-k_r \cdot t_c}\right) + D_o \cdot e^{-k_r \cdot t_c}$$

So for this case

$$D_c = \frac{k_d \cdot L_o}{k_r - k_d} \cdot \left(e^{-k_d \cdot t_c} - e^{-k_r \cdot t_c}\right)$$

so

$$L_o = D_c \times \frac{k_r - k_d}{k_d \times (e^{-k_d \cdot t_c} - e^{-k_r \cdot t_c})}$$

$$L_o = 9.33 \times \frac{0.513 - 0.0338}{0.0338 \times (e^{-0.0338 \times 5.676d} - e^{-0.513 \times 5.676d})}$$

L$_o$ = 171.5526 mg/L

Answer to Part B) BOD$_u$ at the point of mixing = 171.553 mg/L

PART C) Calculate the BOD$_U$ at the point of mixing (between the discharge and river) which is necessary to maintain the DO above 6 mg/L and therefore that let stand an aquatic community in 'health' through the system whole?

As in this case t_c is not impacted by L_o, t_c is the same

so resolve

$$L_o = D_c \times \frac{k_r - k_d}{k_d \times (e^{-k_d \cdot t_c} - e^{-k_r \cdot t_c})}$$

for the new value of Dc

DO at the critical point (Dc)

$D_c = DO_{sat} - DO_C$ so $DO_C = DO_{sat} - D_c$

DOc = 6 mg/L

D_C = 11.33 mg/L - 6 mg/L = 5.33 mg/L

so

L_o = 98.00381 mg/L

Answer to Part C) for a critical DO of 6 mg/L the BODu at the point of mixing will be 98.0038 mg/L

PART D)

Based on the value of BOD$_U$ at the point of mixing between the discharge and the river that is necessary to maintain an aquatic community in 'health' (part c) and the BOD$_u$ value when the untreated wastewater is discharged (part b), calculate the level of wastewater treatment (primary, secondary or tertiary) which is necessary to treat such waste. Explain in detail.

For a critical DO of 2 mg/L, Lo = 171.5526 mg/L

For a critical DO of 6mg/L, Lo = 98.00381 mg/L

The required percent removal is

$$\text{BOD}_U \text{ removal required} = 100 \times \frac{(171.5526 \text{ mg/L} - 98.004 \text{ mg/L})}{171.5526 \text{ mg/L}}$$

= 42.872 %

Answer to Part D)
Primary treatment can aachieve a maximum BOD removal of 40%
So a higher level of treatment will be required.
The necessary level of treatment will be achived by secondary treatment (85-95% rem.)
And it would probably be achieved by enhanced primary treatment