Water Quality: Oxygen Demanding Waste

What happens when wastewater is discharged in a river?

- Why are we concerned about DO?
  - Important for aquatic species - need some minimum level of DO
  - Lack of DO can result in development of anaerobic conditions which can be result in anaerobic breakdown leading to generation of methane and carbon dioxide
- How to track trend of important parameter with time and distance along the movement of driver?

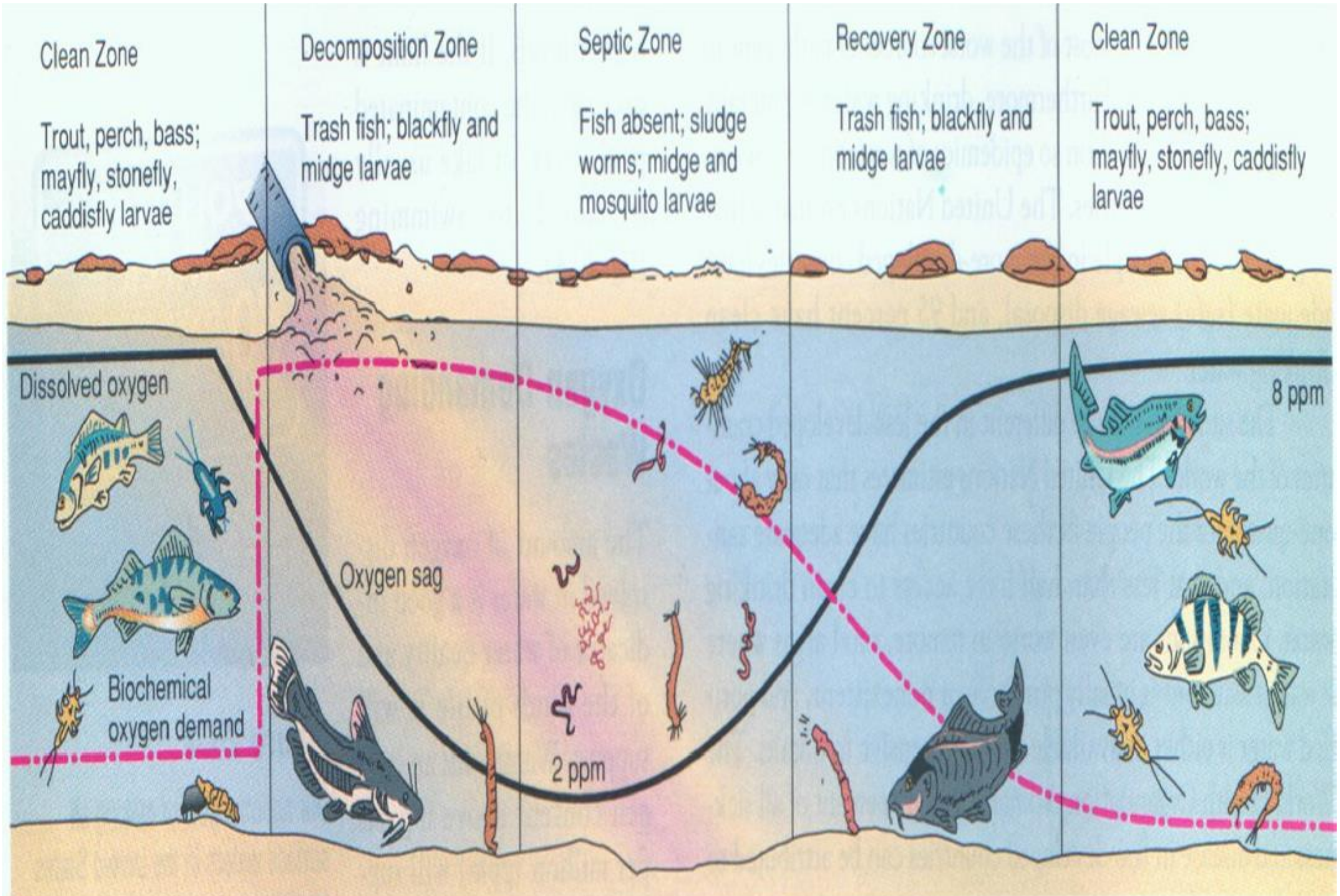
Dissolved oxygen (DO)

- Amount of DO in water is one of the most commonly used indicator of a river's health. Why?
  - What are the factors that affect the amount of DO concentration in a river?
  - What is the approximate DO concentration in a healthy natural water body?
  - If there was no change in the waste addition in a stream throughout the year, will the DO be higher in winter or summer?

Dissolved oxygen (DO)…

- The solubility of oxygen depends on temperature, pressure, and salinity and the dissolved oxygen. Concentration of DO ranges from 8 - 10 mg/L in a healthy stream.
- As DO drops below 4 or 5 mg/L the forms of life that can survive begin to reduce.
- In an extreme case, when anaerobic conditions exist, most higher forms of life can not survive.

DO depletion due to waste discharge



(Source: Environmental Science: A Global Concern, 3rd ed. by W.P Cunningham and B.W. Saigo, WC Brown Publishers, © 1995)

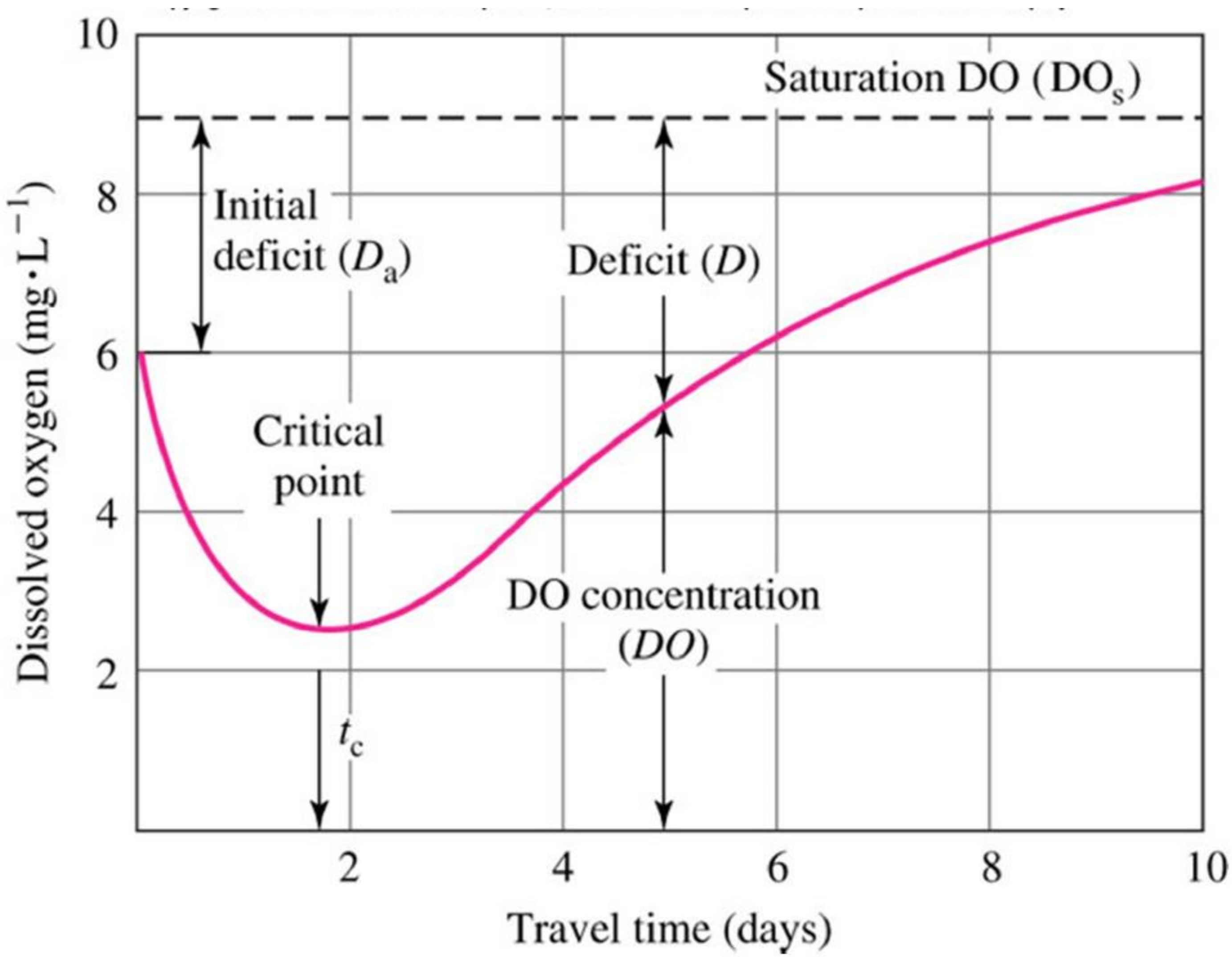
Factors Affecting DO

- Oxygen demanding wastes affect available DO
- Tributaries bring their own oxygen supply
- Photosynthesis adds DO during the day, but the same plants consume oxygen at night
- Respiration of organisms living in water as well as in sediments remove oxygen
- In the summer rising temperatures reduce solubility of oxygen
- In the winter oxygen solubility increases, but ice may
- form blocking access to new atmospheric oxygen

A Simple Model for DO in a River

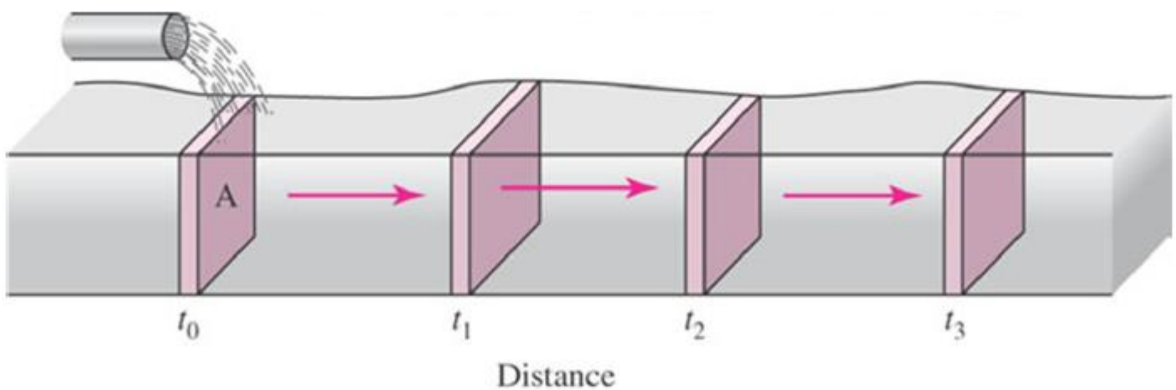
- To model all the effects and their interaction is a difficult task
- The simplest model focuses on two processes:
  - The removal of oxygen by microorganisms during biodegradation (de-oxygenation)
  - The replenishment of oxygen at the interface between the river and the atmosphere (re-aeration)

Dissolved Oxygen Sag Curve



Mass Balance Approach

- River described as "plug-flow reactor"

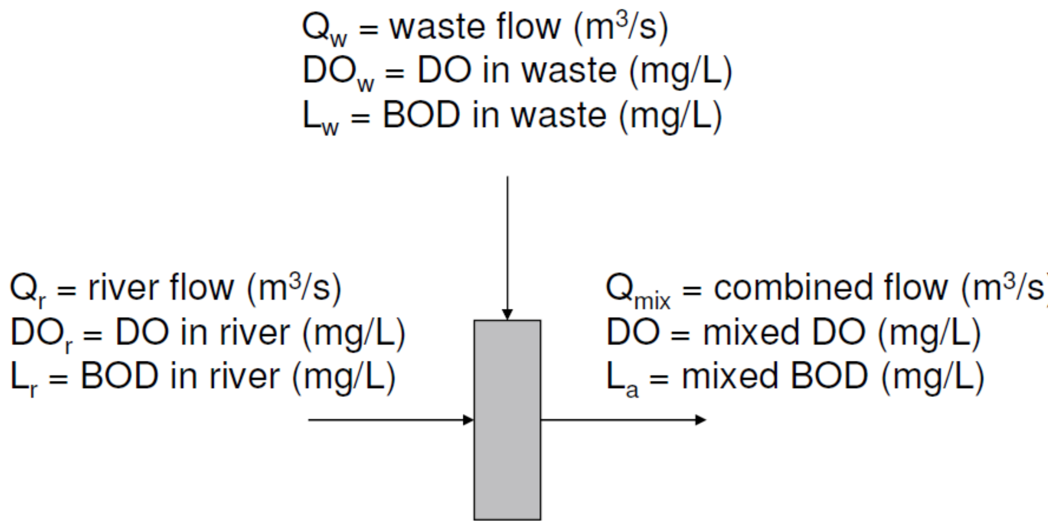


- Mass balance
  - Oxygen is depleted by BOD exertion (deoxygenation)
  - Oxygen is gained through re-aeration

DO Sag Curve…

- Determine the initial conditions
- Determine the de-oxygenation rate from BOD test and stream geometry
- Determine the re-aeration rate from stream geometry
- Calculate the DO deficit as a function of time
- Calculate the time and deficit at the critical point (worst conditions)

Mass Balance for Initial Mixing



a. Initial dissolved oxygen concentration:

$$DO = \frac{Q_w DO_w + Q_r DO_r}{Q_w + Q_r}$$

b. Initial DO deficit:

$$D_a = DO_s - DO$$

where:
D_a=initial DO deficit (mg/L)
DO_s=saturation DO conc.(mg/L)

Therefore, the initial deficit after mixing is

$$D_a = DO_s - \frac{Q_w DO_w + Q_r DO_r}{Q_{mix}}$$

where D_a is the initial deficit (mg/L)

Note: DO_s is a function of temperature, atmospheric pressure, and salinity. Values of DO_s are found in tables.

Solubility of Oxygen in Water ($DO_s = DO_{saturation}$)

DO_s is a function of temperature, atmospheric pressure and salinity

	Chloride concentration in water (mg/L)			
Temperature (°C)	0	5000	10,000	15,000
0	14.62	13.73	12.89	12.10
5	12.77	12.02	11.32	10.66
10	11.29	10.66	10.06	9.49
15	10.08	9.54	9.03	8.54
20	9.09	8.62	8.17	7.75
25	8.26	7.85	7.46	7.08
30	7.56	7.19	6.85	6.51

Source: Thomann and Mueller (1987).

DO sag curve....

c. Initial ultimate BOD concentration:

If, the BOD data for the waste or river are in terms of BOD_5, calculate L for each

$$L = \frac{BOD_t}{1 - e^{-kt}}$$

Therefore, initial *ultimate* BOD concentration

$$L_a = \frac{Q_w L_w + Q_r L_r}{Q_w + Q_r}$$

2. Determine De-oxygenation Rate

rate of de-oxygenation = $k_d L_t$

where: k_d = de-oxygenation rate coefficient (day^{-1})

L_t = ultimate BOD remaining at time (of travel down-stream) t

If k_d (stream) = k (BOD test) and $L_t = L_0 e^{-k_d t}$

$$\text{rate of de-oxygentation} = k_d L_0 e^{-k_d t}$$

3. Determine Re-aeration Rate

rate of re-aeration = $k_r D$

k_r = re-aeration constant (time $^{-1}$)
D = dissolved oxygen deficit (DO_s-DO)
DO_s = saturated value of oxygen
DO = actual dissolved oxygen at a given location downstream

- O'Connor-Dobbins correlation:

$$k_r = \frac{3.9u^{1/2}}{h^{3/2}}$$

where k_r = re-aeration coefficient @ 20ºC (day^{-1})
u = average stream velocity (m/s)
h = average stream depth (m)

- Correct rate coefficient for stream temperature

$$k_r = k_{r,20}\Theta^{T-20}$$

where Θ = 1.024

4. DO as function of time (Streeter-Phelps equation or oxygen sag curve)

- Rate of increase of DO deficit = rate of deoxygenation – rate of reaeration

$$\frac{dD}{dt} = k_d L_t - k_r D$$

- Solution is:

$$D_t = \frac{k_d L_o}{k_r - k_d}\left(e^{-k_d t} - e^{-k_r t}\right) + D_a\left(e^{-k_r t}\right)$$

5. Calculate Critical time and DO

Critical Point = point where steam conditions are at their worst

$$t_c = \frac{1}{k_r - k_d} \ln\left[\frac{k_r}{k_d}\left(1 - D_a \frac{k_r - k_d}{k_d L_a}\right)\right]$$

$$D_c = \frac{k_d L_a}{k_r - k_a}\left(e^{-k_d t_c} - e^{-k_r t_c}\right) + D_a e^{-k_r t_c}$$

D = dissolved oxygen deficit

Q. A wastewater treatment plant discharges its treated effluent in a stream. Characteristics of the stream and effluent are shown below.

Parameter	wastewater	stream
flow (m^3/s)	0.2	5
Dissolved oxygen, mg/L	1	8
Temperature, °C	15	20.2
BOD_5 at 20°C, mg/L	100	2
Oxygen consumption rate (K1 at 20°C) (1/day)	0.2	-
Oxygen reaeration rate (K2 at 20°C) (1/day)	-	0.3

(a) What will be the dissolved oxygen conc. in the stream after 2 days?
(b) What will be the lowest dissolved oxygen concentration as a result of the waste discharge?
(c) Also calculate the maximum BOD_5 (20°C) that can be discharged if a minimum of 4.0 mg/L of oxygen must be maintained in the stream?

Answer:

Parameter	wastewater (given)	stream (given)	Wastewater and stream water mixture
flow (m^3/s)	0.2	5	$=Q_{mixture}=5+0.2=5.2$ m/s
Dissolved oxygen, mg/L	1	8	$DO_{mixture}=(0.2*1+8*5)/(5+0.2)$ =7.73 mg/L
Temperature, °C	15	20.2	$Temp_{mixture}=(0.2*15+20.2*5)/(5+0.2)$ =20 deg C (No temp. correction required)
BOD_5 at 20°C, mg/L	100	2	$BOD_{mixture}=(0.2*100+2*5)/(5+0.2)$ =5.77 mg/L
Oxygen consumption rate (K1 at °C) (1/day)	0.2		0.23 (No temp. correction required) (assumed for stream water)
Oxygen reaeration rate (K2 at °C) (1/day)	-	0.3	0.3 (No temp. correction required)

Answers

- DO (after 2 days) = 6.10 mg/L
- D_c = 3.28 mg/L
- $DO_{critical}$ = 5.89 mg/L

- Is any modifications required in WWTP?

Thank you !