# Water Pollution

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# Water Pollution: Types, Effects, and Sources

- What is water pollution?
- Major types of pollutants, sources and effects

# Major Categories of Water Pollutants

- Infectious Agents
  - Bacteria, Viruses, Protozoa, Parasitic Worms
  - Source: Human and animal waste
- Oxygen-Demanding Waste
  - Organic debris & waste + aerobic bacteria
  - Source: Sewage, feedlots, paper-mills, food processing
- Inorganic Chemicals
  - Acids, Metals, Salts
  - Sources: Surface runoff, Industrial effluent, household cleansers
- Radioactive Materials
  - Iodine, radon, uranium, cesium, thorium
  - Source: Coal & Nuclear Power plants, mining, weapons production, natural
- Plant Nutrients
  - Nitrates, Phosphates,
  - Source: Sewage, manure, agricultural and landscaping runoff
- Organic Chemicals
  - Oil, Gasoline, Plastics, Pesticides, Solvents, detergents
  - Sources: Industrial effluent, Household cleansers, runoff from farms and yards
- Eroded Sediment
  - Soil, Silt
- Heat/Thermal Pollution
  - Source: Power plants, Industrial

# Pollution in Streams

# Lake Pollution

- Dilution less effective than with streams
- Stratification in lakes and relatively little flow hinder rapid dilution of pollutants
- Lakes more vulnerable to pollutants than streams
- Eutrophication: causes and effects
- Preventing or removing eutrophication

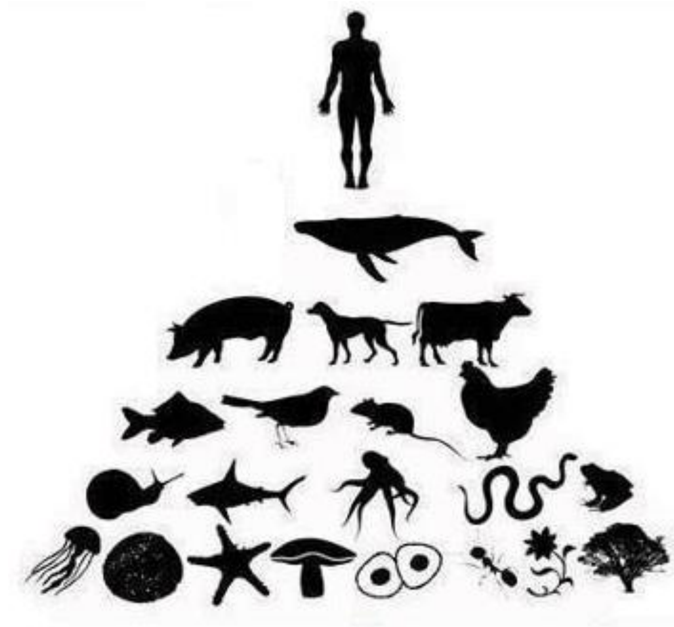
# Groundwater Pollution: Causes and Persistence

- Sources of groundwater pollution
- Slow flowing: slow dilution and dispersion
- Consequences of lower dissolved oxygen
- Fewer bacteria to decompose wastes
- Cooler temperatures: slow down chemical reactions
- “Degradable” and nondegradable wastes in groundwater

# Environmental Ethics

- Environmental ethics is the discipline that studies the moral relationship of human beings to the environment.
  - What is the value of the environment?
  - What moral responsibility do we have in dealing with the major environmental problems that result from our resource consumption?
  - Which needs should be given the highest priority in our decision making?
- Two main categories of ethics have emerged in human culture in modern history.

- Anthropocentrism literally means “human-centered”.
  - This set of ethics protects and promotes of human interests or well-being at the expense of all other factors.
  - Often places an emphasis on short-term benefits while disregarding long-term consequences.



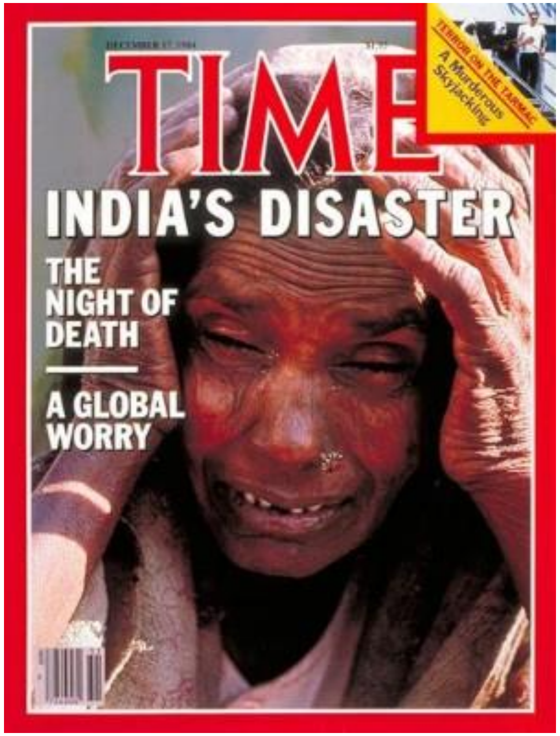
- Ecocentrists believe that nature deserves to exist for its own sake regardless of degree of usefulness to humans.
  - The preservation of ecosystems or other living things takes priority over human needs.

# Modern Environmentalism

- In 1952, the Cuyahoga river in Ohio caught fire due to all the pollution that had accumulated in it.
- Rachel Carson published a book in 1962 entitled *Silent Spring* about the effects of pesticides on large predatory birds, particularly the bald eagle.
  - This began a public awakening to threats of pollution and toxic chemicals to humans as well as other species.
  - This movement is called Modern Environmentalism.

# Case Study: Bhopal Pesticide Plant

- In December of 1984, a pesticide factory located near the town of Bhopal, India leaked a large amount of toxic chemicals into the air.
- The chemicals resulted in an immediate death toll of about 3,000 people, with 8,000 more dying of long-term health ailments.
  – A total of 558,125 injuries were reported to the Indian government.
  – A settlement of $470 million was reached by Union Carbide and the Indian government.



# The Tragedy of the Commons

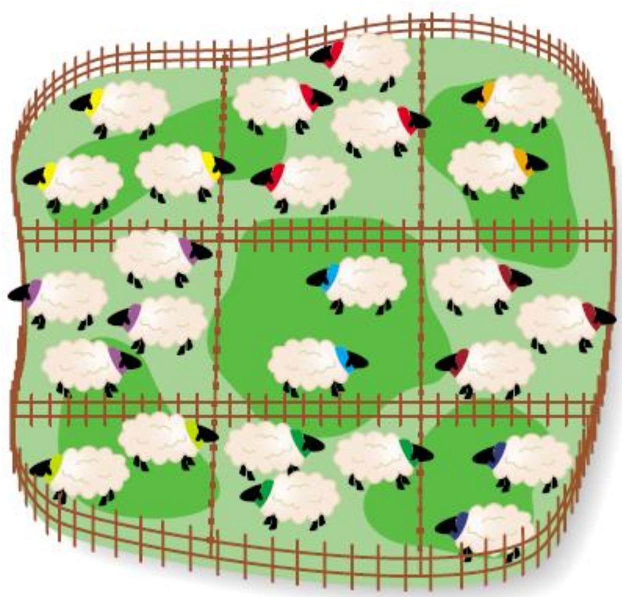
- A great deal of progress has been made since the birth of modern environmentalism, but many debates still rage on.
- An ecologist named Garrett Hardin wrote an essay called *"The Tragedy of the Commons",* describing the source of environmental problems as a conflict:
  - Short-term interests of individuals

    versus…

    Long-term interests of civilization and the Earth itself

- A small village consists mostly of farmers that raise and sell sheep at a nearby city.
- The only place for the sheep to graze is a commons in the center of the village.
  - A commons is an area that belongs to no individual; it is shared by the entire society.
- Likely outcome: Villagers obtain as many sheep as possible, allow to graze in the commons.
  - Maximize short-term financial gain.

- What if the commons was instead divided into sections that was owned by each villager?
  - Because the land is owned, individuals are much more likely to plan and use it for the long-term.



- The *Tragedy of the Commons* describes the likeliness of a commons area being exploited for short-term economic gain.
- Modern examples include the atmosphere and oceans.

# Economics and the Environment

- Economics has a huge influence in environmental decision-making.
- One of the most basic principles of economics is supply and demand.
  - The greater the demand for a limited resource, the higher the price.

# The Goal:  A Sustainable World

- Sustainability is when human needs are met so that the population can survive **<u>indefinitely.</u>**
  - "Meeting the needs of the present without compromising the ability of future generations to meet their own needs."
    - Brundtland Commission, 1987

Reading Assignment:

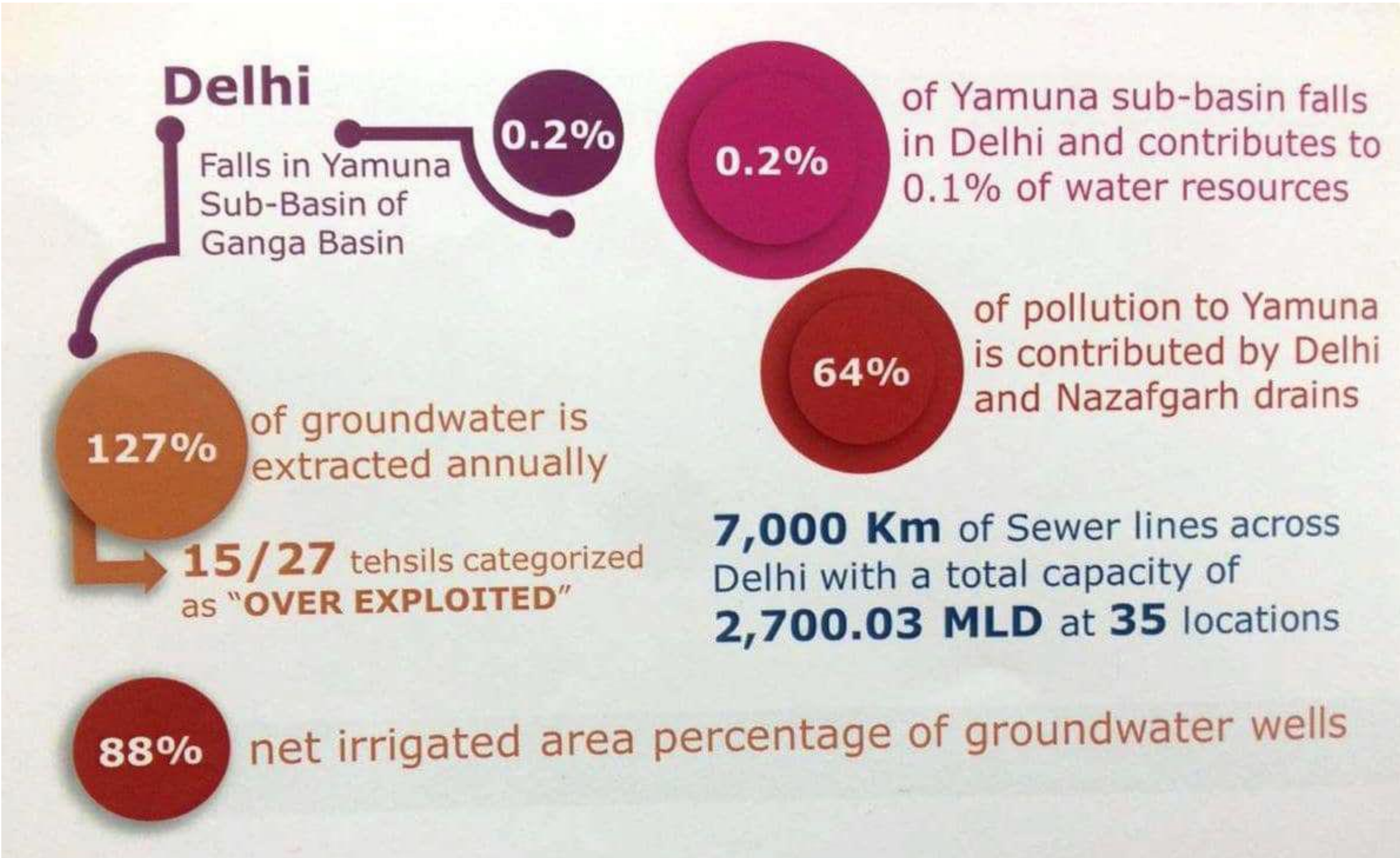
What is the Polluter pays principle ?

What is the tragedy of the anticommons?

Thank you !

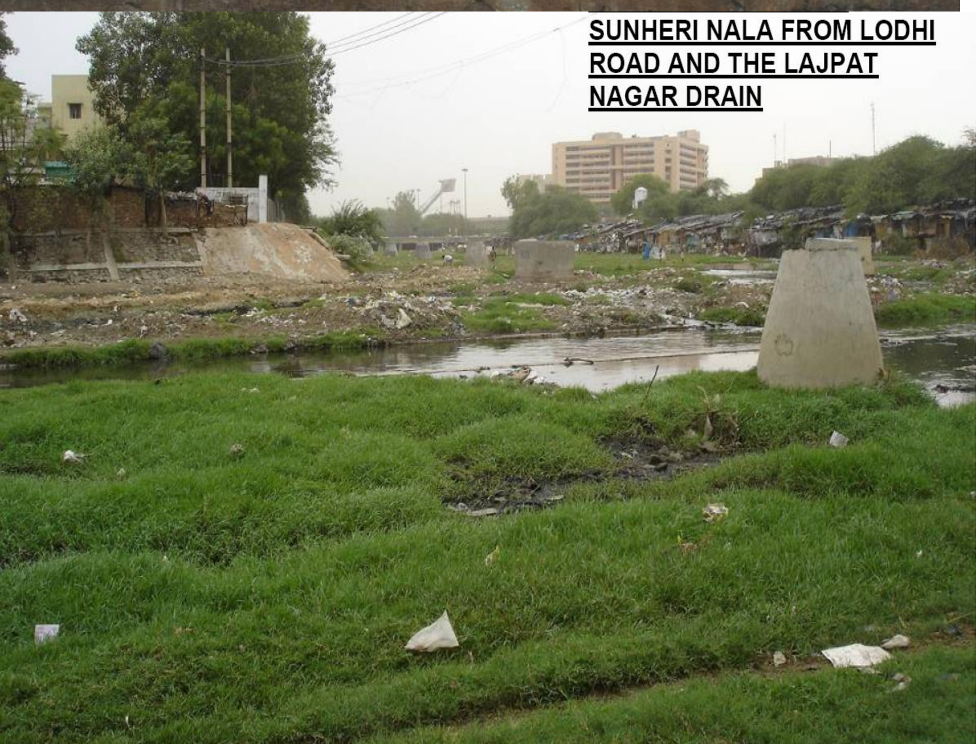
# Wastewater Management: An Alternate Approach

# Break-up of Delhi's Water & it's Pollution




About 80% of water used by community becomes wastewater, which unless properly collected, conveyed, treated and properly disposed off, may eventually pollute our precious water resources and cause environmental degradation

CONFLUENCE OF THE SUNHERI NALA WITH THE KHUSHAK NALA



SUNHERI NALA FROM LODHI ROAD AND THE LAJPAT NAGAR DRAIN

The open storm water channels or 'Nalas' as they are referred to, carry all excess storm water runoff from the city to the river.

During the non-monsoon seasons, the Nalas presently carry untreated domestic waste – which makes them foul smelling and dirty.

The city dumps some solid wastes into these uncared for wasted spaces, which further compounds the problem.

Is this siltation by any chance?

If so then what are we planning to do about it?

Is the cunnette wall increased every season or this is something else?

# Wastewater Drain as a Greenway

- Storm-water and sewage are potentially valuable resource natural resource that should be used to replenish our aquifers, rivers, streams and lakes as well as other on-site beneficial uses instead of being quickly discharged as a waste.

# Guiding Principles

- Reverting back to natural purification processes (e.g., wetlands)
- Reduce the velocity for removal of sediments
- Maximize aeration and engineer the symbiotic relationship between microorganisms and plants
- LOW maintenance and NO external energy processes
- Use of natural gradient/ NO pumping

# Levels of Treatment

## Primary

removal by physical separation of grit and large objects (material to landfill for disposal)

## Secondary

Mostly dead microbes

aerobic microbiological process (sludge)

organic matter + $O_2 \rightarrow CO_2 + NH_3 + H_2O$

$NH_3 \rightarrow NO_3^-$ aquatic nutrient

# Levels of Treatment continued

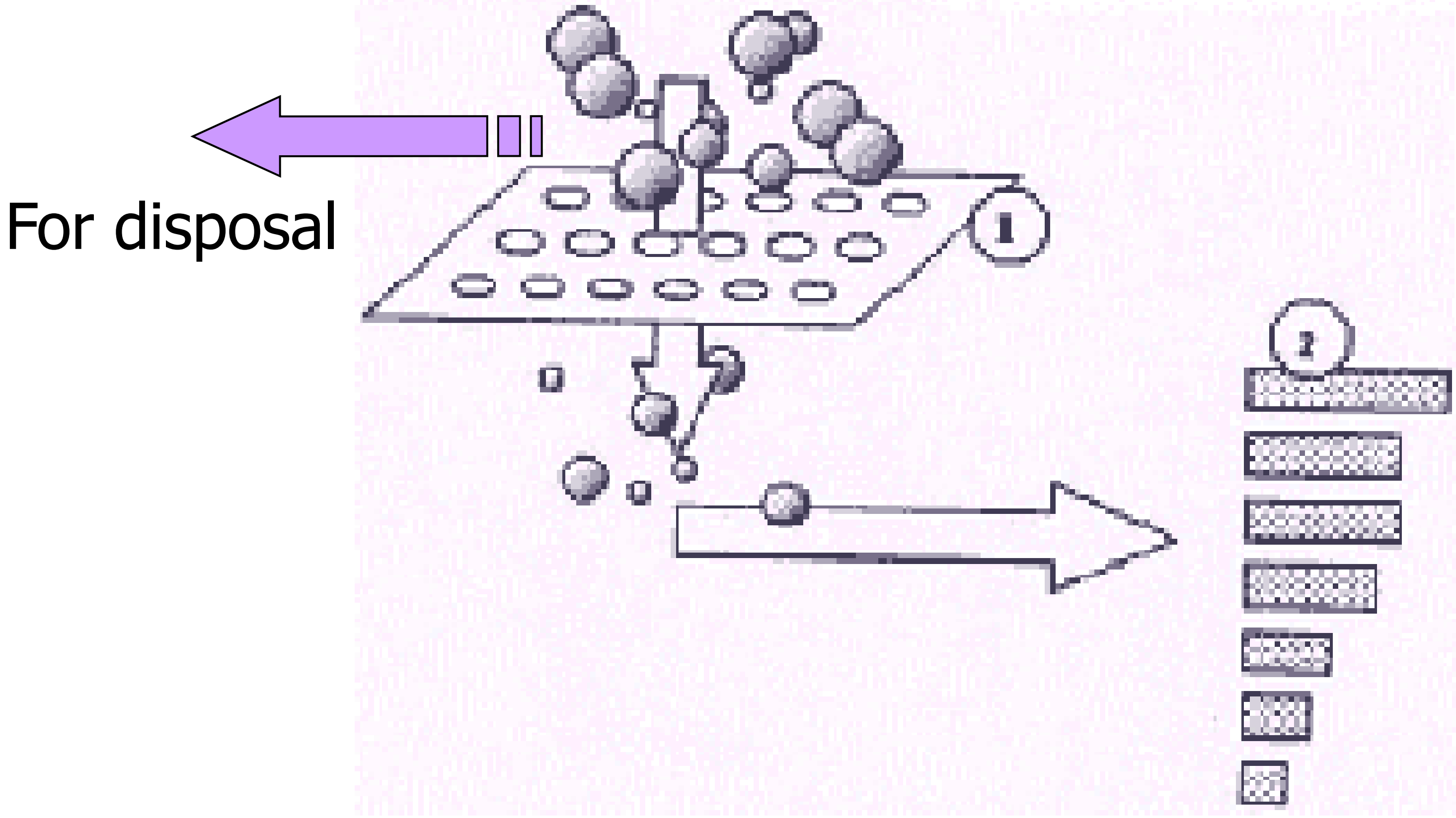
<u>Tertiary (advanced)</u>

anoxic microbiological process with a different microbe

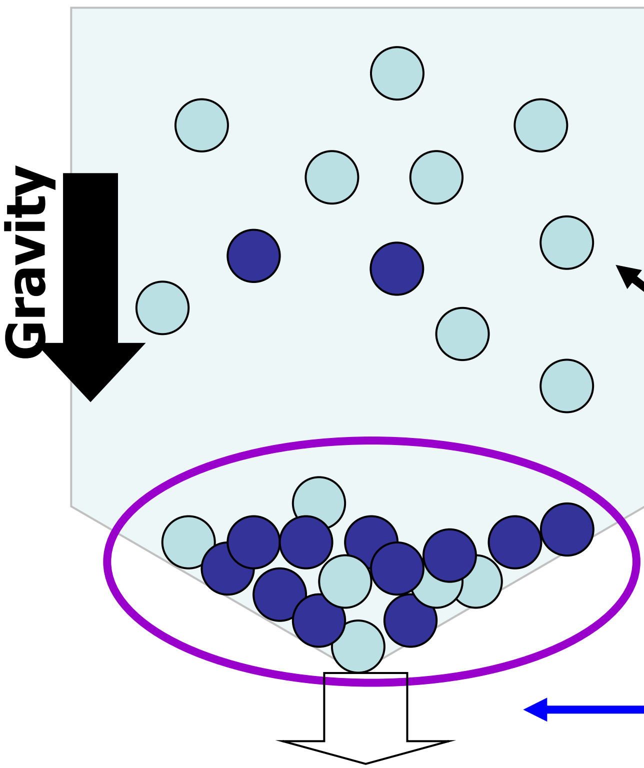
$$NO_3^- \rightarrow N_2 \text{ (escapes to atmosphere)}$$

aeration to strip $N_2$ and re-oxygenate (add DO)

# Screening



# Primary Sedimentation



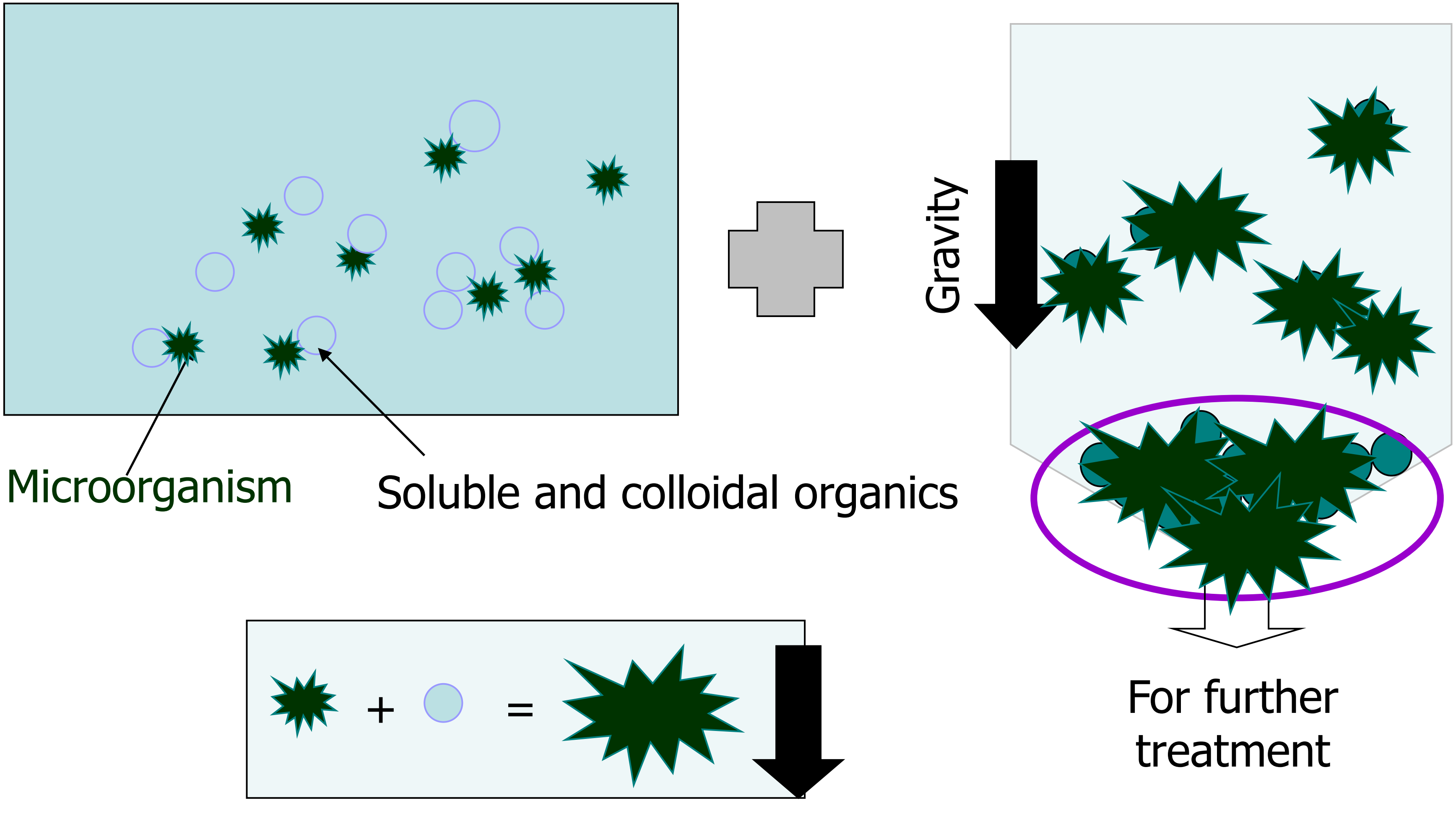

Collected and removed

**Sedimentation** is the gravity setting, and thus removal, of materials more dense than a suspending fluid.

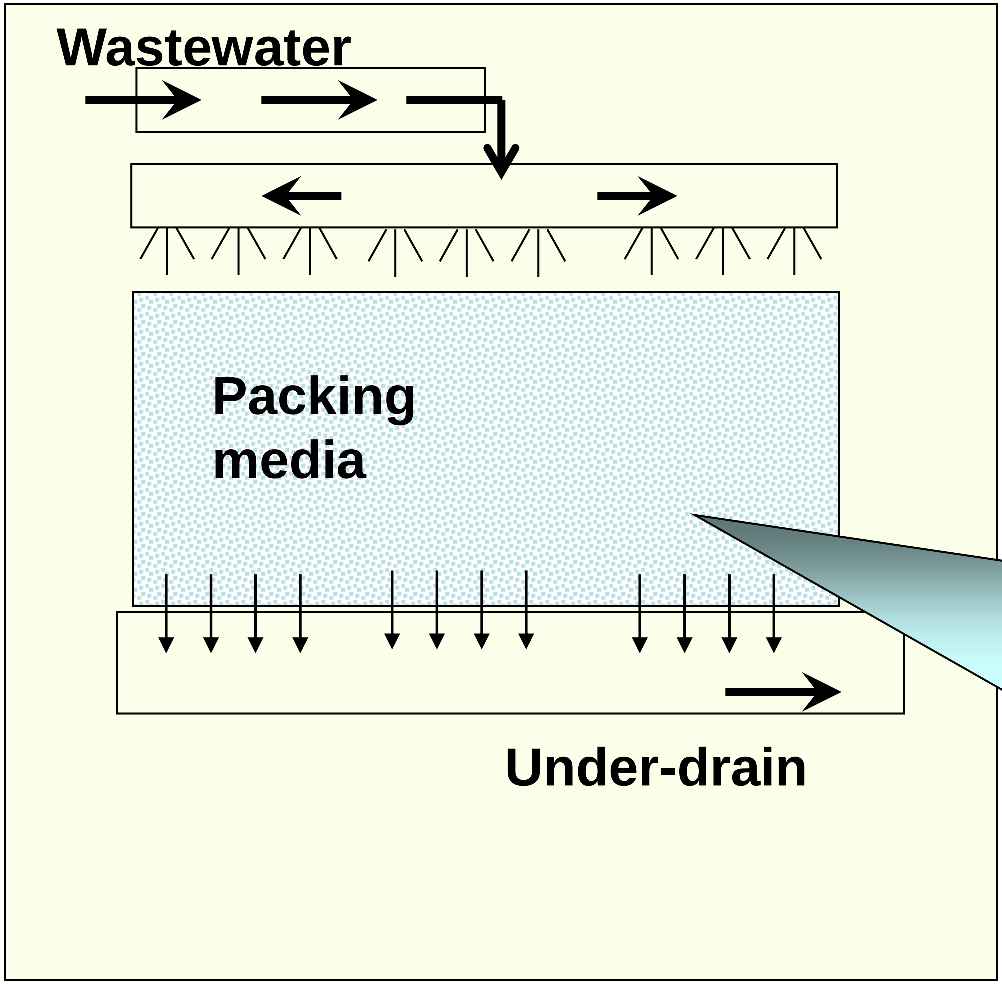
Organic matter, grit, clay, sand, and bacteria

Primary sedimentation – Remove about 1/3 $BOD_5$ and 2/3 Suspended Solids

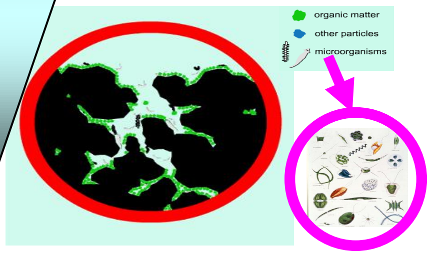
# Biological Treatment

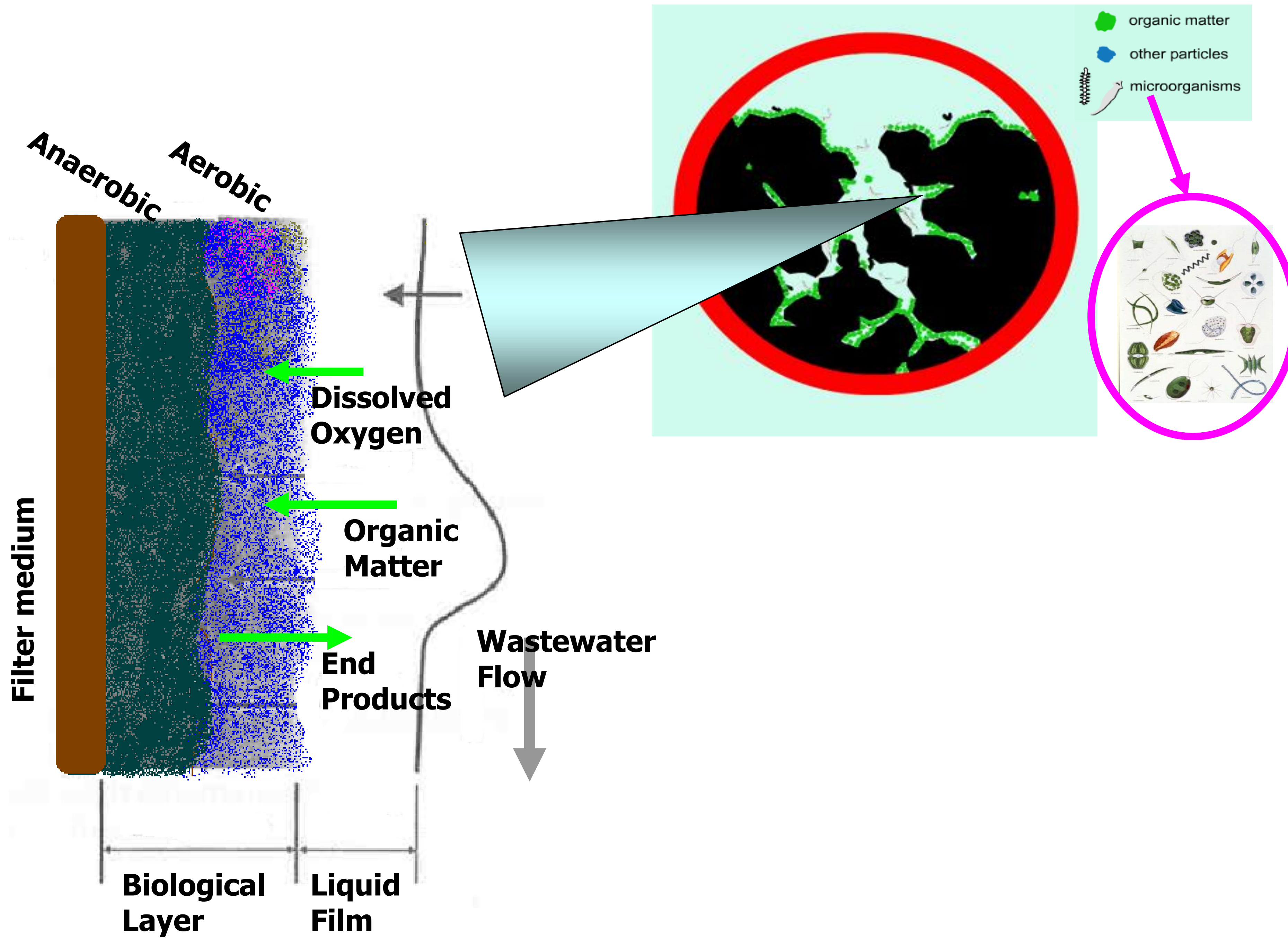


# Trickling Filter

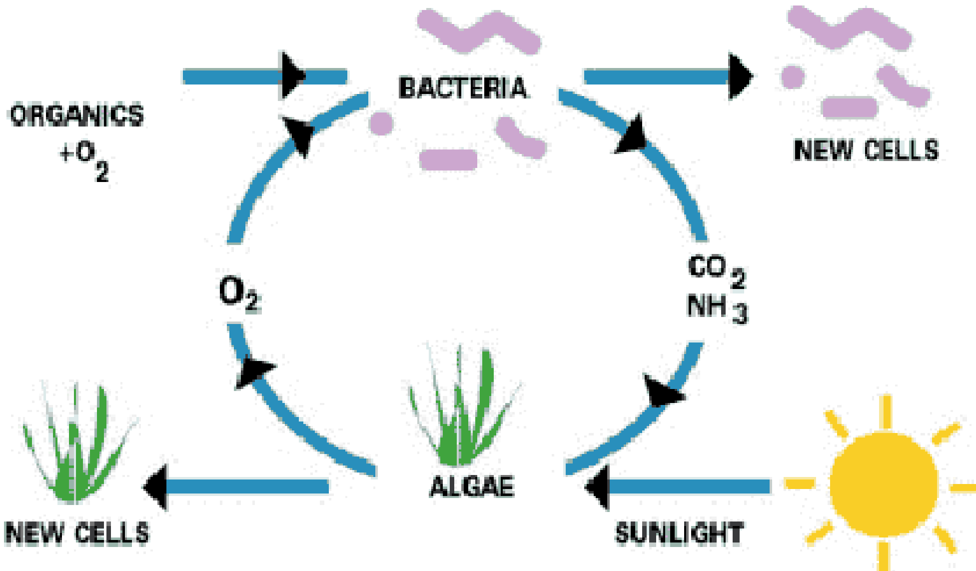



- TF consists of:
  - An arrangement that sprays wastewater over a filter medium.
  - Filter medium: rocks, plastic, or other material.
- The water is collected at the bottom of the filter for further treatment.

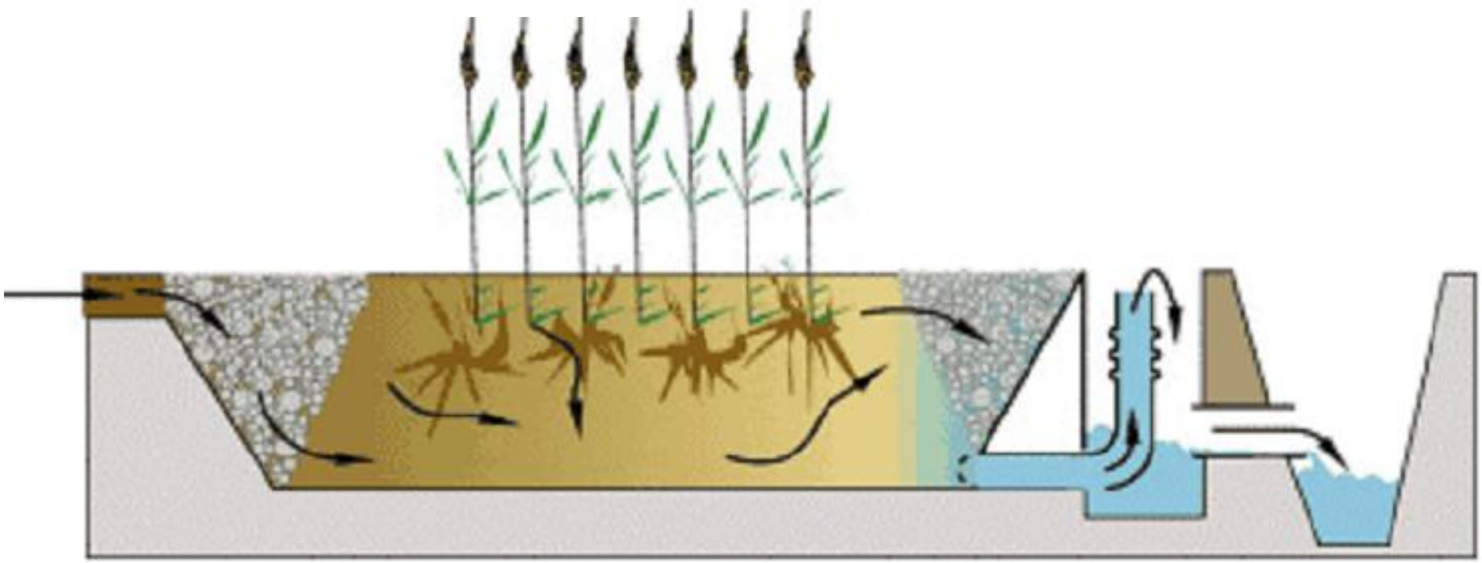



Anaerobic
Aerobic
Filter medium
Dissolved Oxygen
Organic Matter
End Products
Wastewater Flow
Biological Layer
Liquid Film
organic matter
other particles
microorganisms

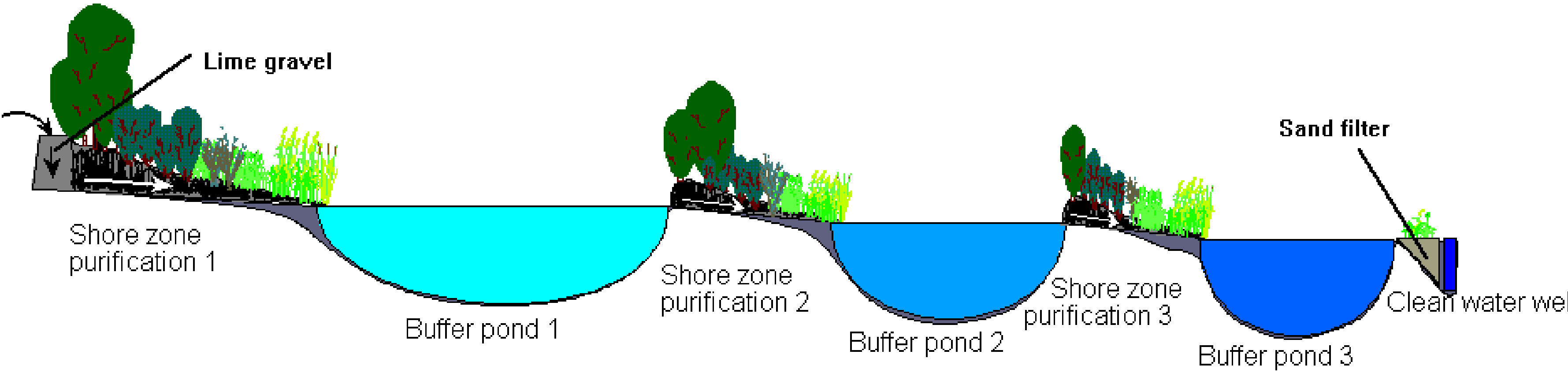
# Wetland systems

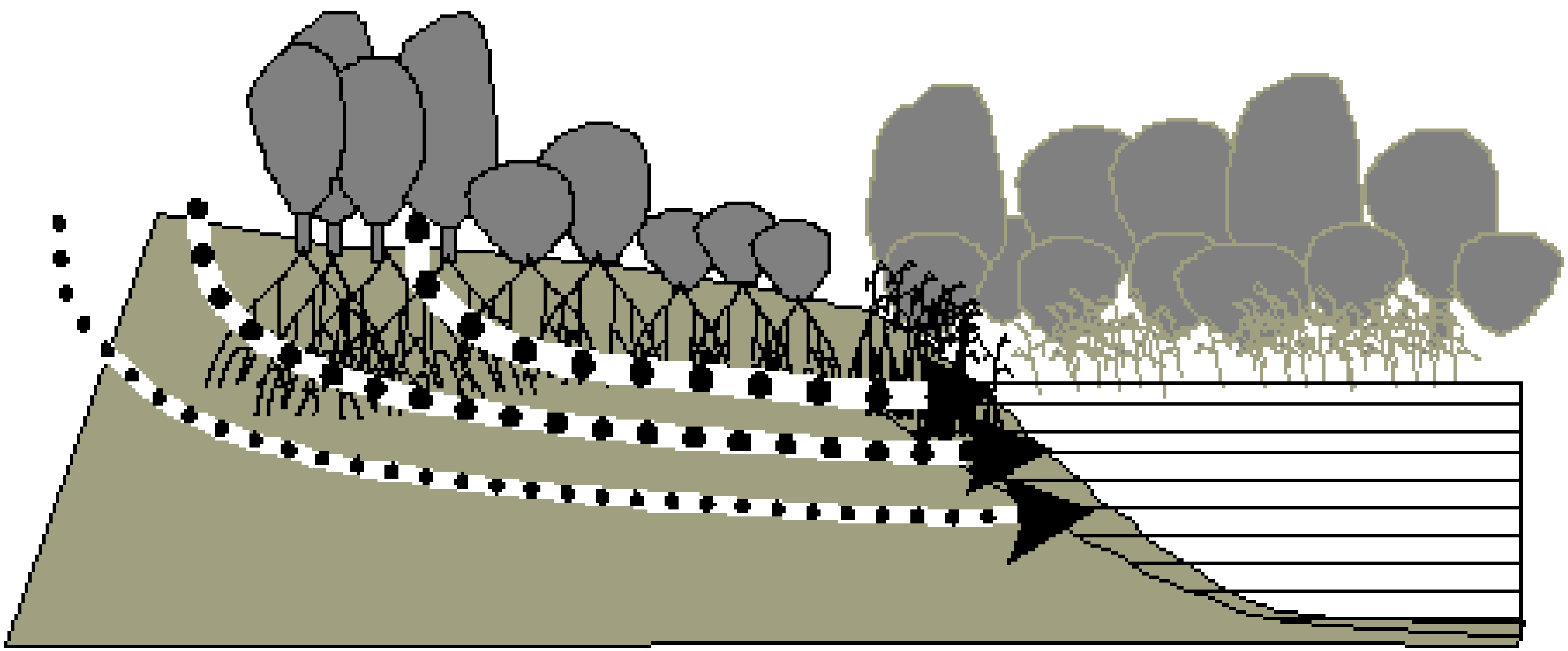



Symbiotic relationship between bacteria and algae in a wastewater

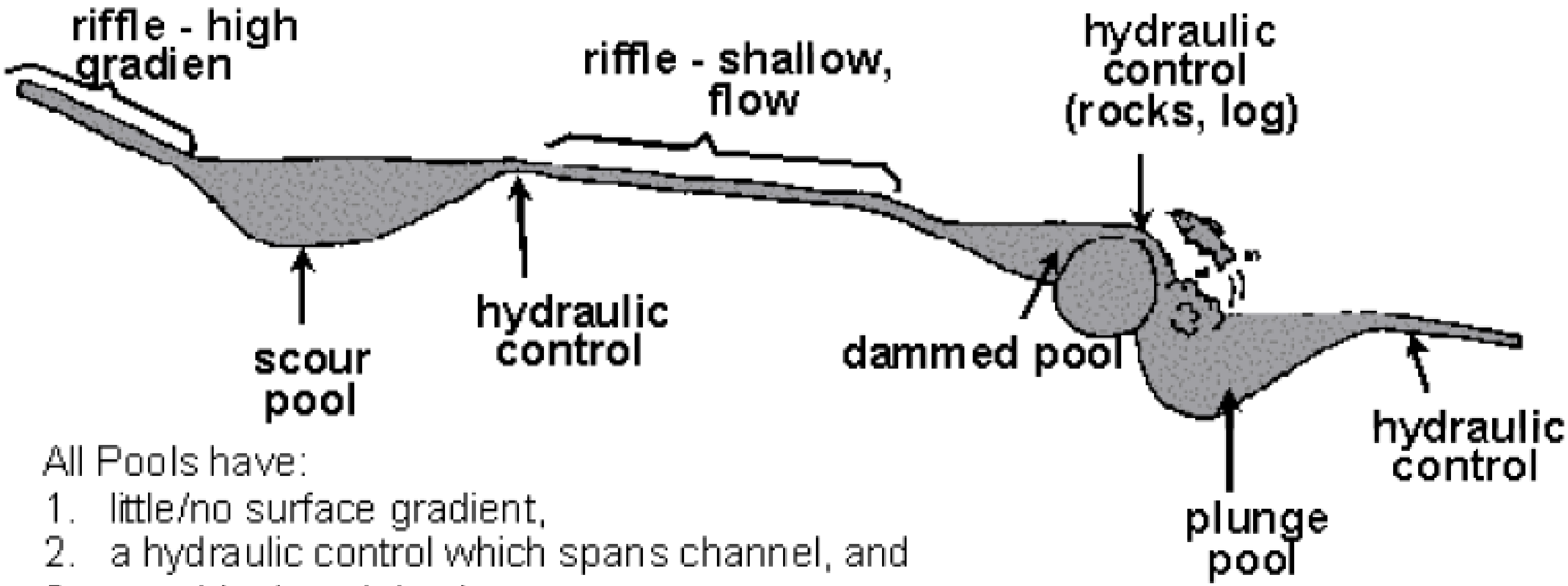


# Continuous Pool and Filtration System



## Basic characteristics of a pool/riffle system

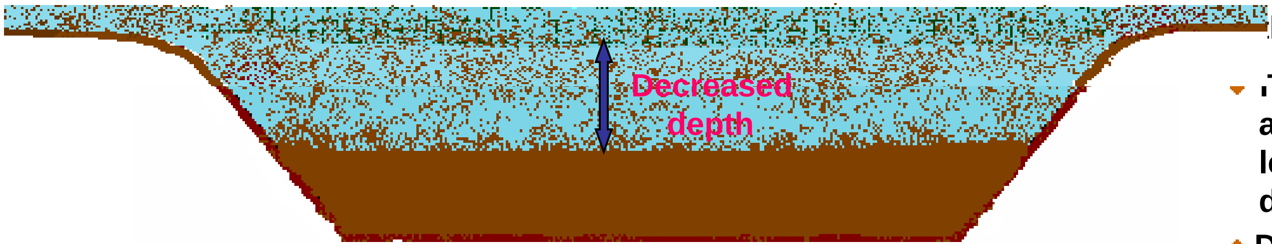



All Pools have:

1. little/no surface gradient,
2. a hydraulic control which spans channel, and
3. a residual pool depth.

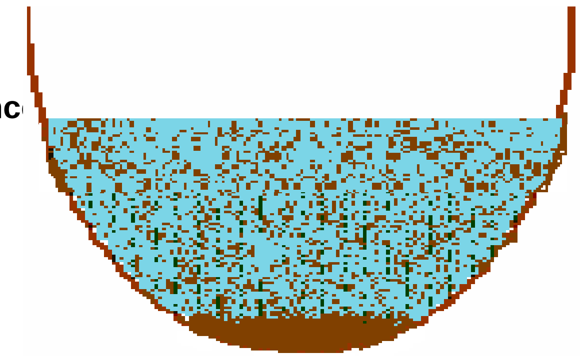
# CHOOSING DRAIN CROSS-SECTIONAL SHAPE

## Trapezoidal Section



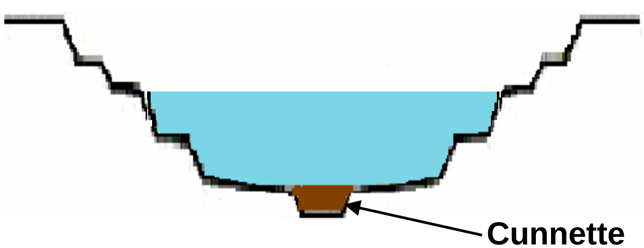

- With time the incoming sediment load in the drain starts settling at the bottom.
- The settled sediments obstruct the flow and causes further settling which in turn leads to decreased depth and hence decreased cross-section of the drain
- Drain bank gets eroded and leads to overflow and hence flooding conditions

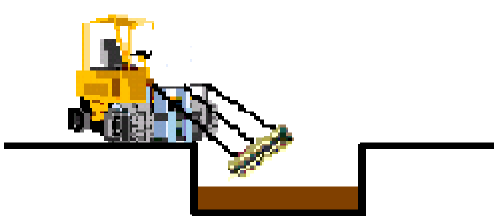
## Parabolic Section



- The sediment load settles at the bottom but does not obstruct the flow and hence the desired self cleansing velocity is maintained in the drain
- Hence, an ‘IDEAL SECTION’ but will be modified for practical purpose

## Stepped Section

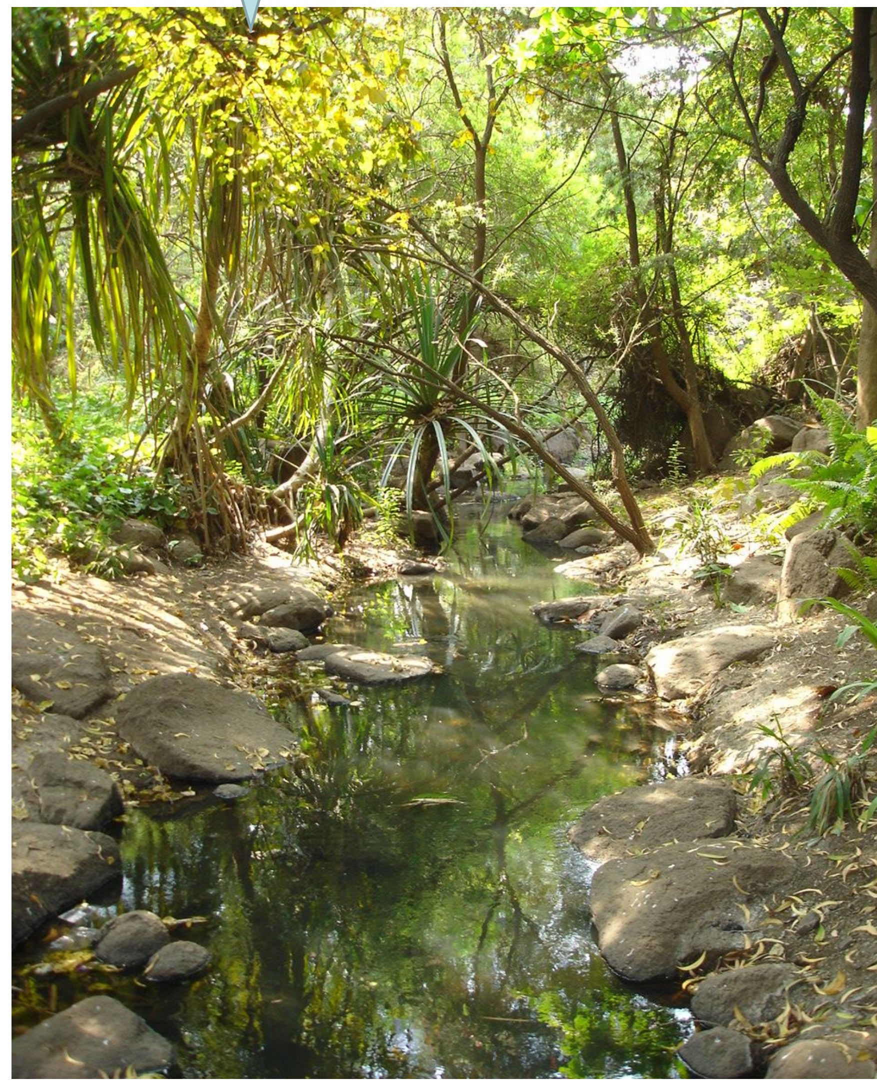


- Parabolic section is modified by introducing some steps and will be used in-situ
- The silting occurs in the cunnette of the drain. The stepped portions of the drain accommodate the resultant increased level of flow
- It can also carry the excess or the flood flows very efficiently minimizing the flood occurring probability
- Desilting basins will be provided at every 1 km length of the drain and manual/mechanical cleaning of the silt settled will be done frequently

Can we revert back to natural purification systems?


- Reverting back to natural purification processes
- Reduce the velocity for removal of sediments
- Maximize aeration and engineer the symbiotic relationship between microorganisms and plants



Thank You!

# Water Quality: Oxygen Demanding Waste

# What happens when wastewater is discharged in a river?

- Why are we concerned about DO?
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# Dissolved oxygen (DO)

- Amount of DO in water is one of the most commonly used indicator of a river's health. Why?
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# Dissolved oxygen (DO)…

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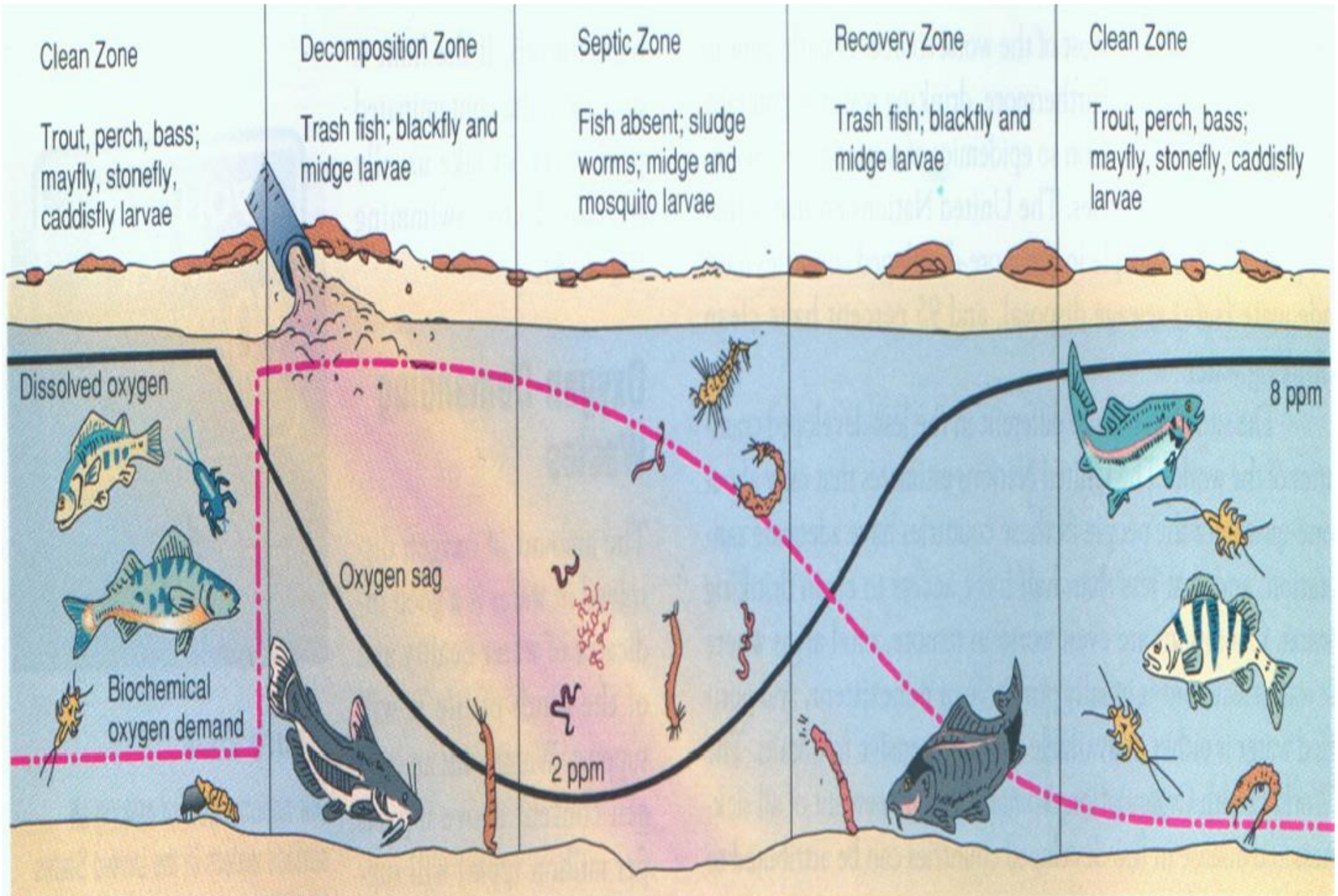
# DO depletion due to waste discharge




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

# Factors Affecting DO

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- Photosynthesis adds DO during the day, but the same plants consume oxygen at night
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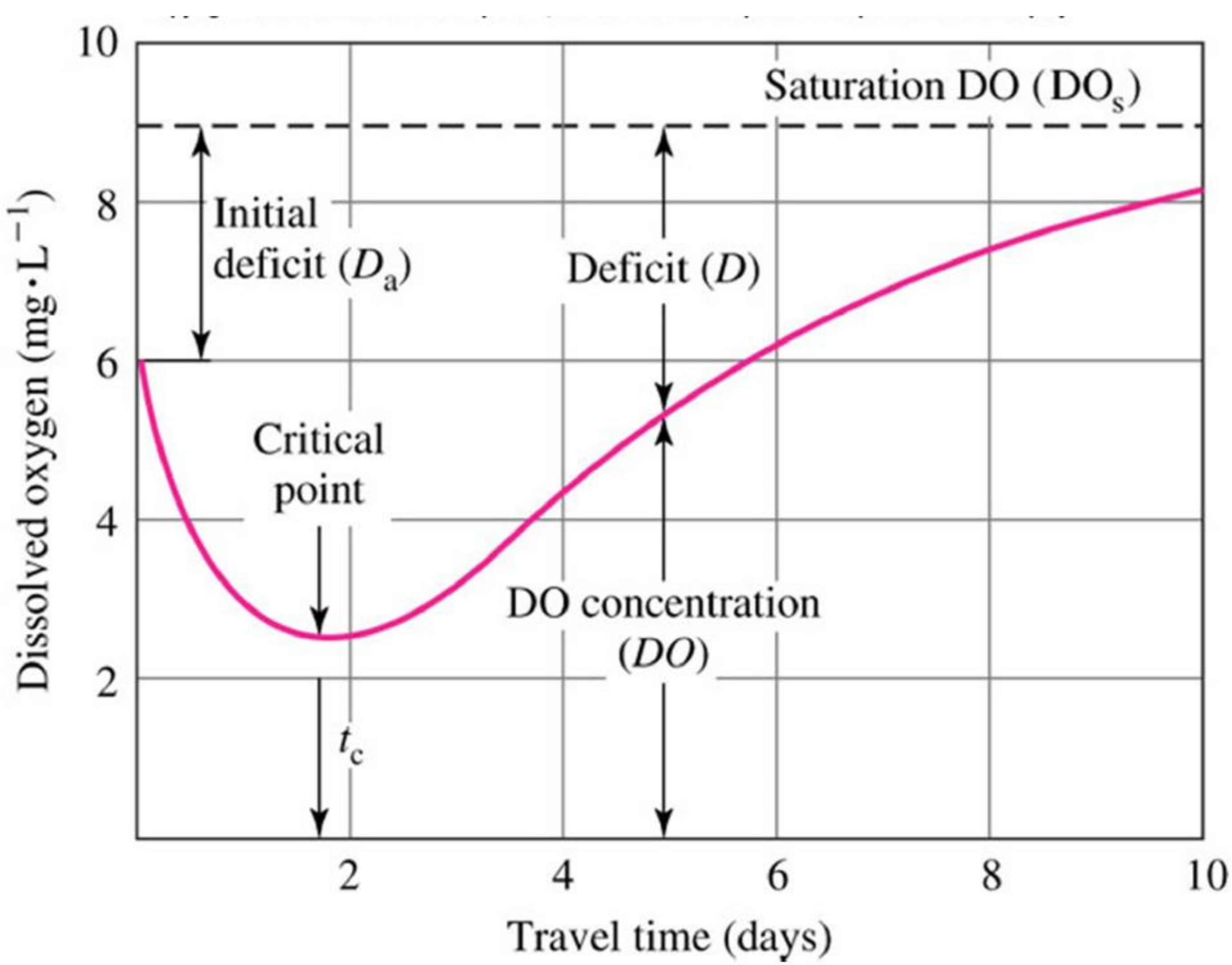
# A Simple Model for DO in a River

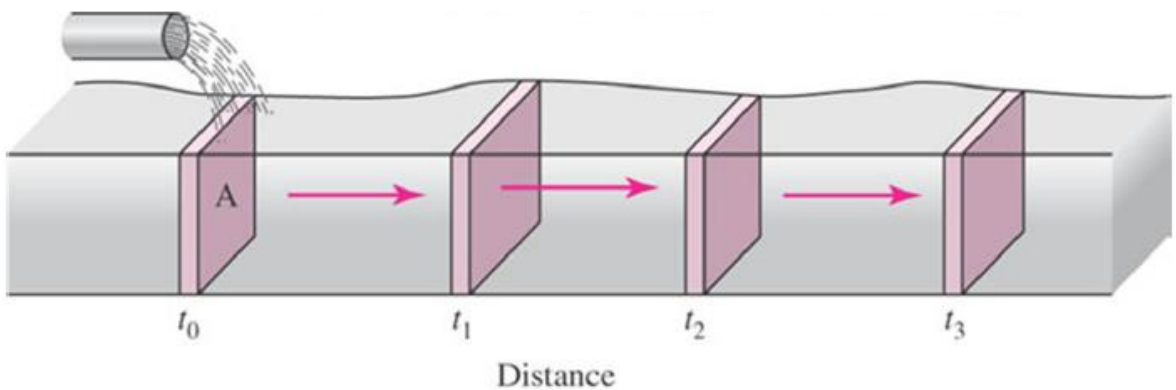
- To model all the effects and their interaction is a difficult task
- The simplest model focuses on two processes:
  - The removal of oxygen by microorganisms during biodegradation (de-oxygenation)
  - The replenishment of oxygen at the interface between the river and the atmosphere (re-aeration)

# Dissolved Oxygen Sag Curve



# Mass Balance Approach

- River described as "plug-flow reactor"

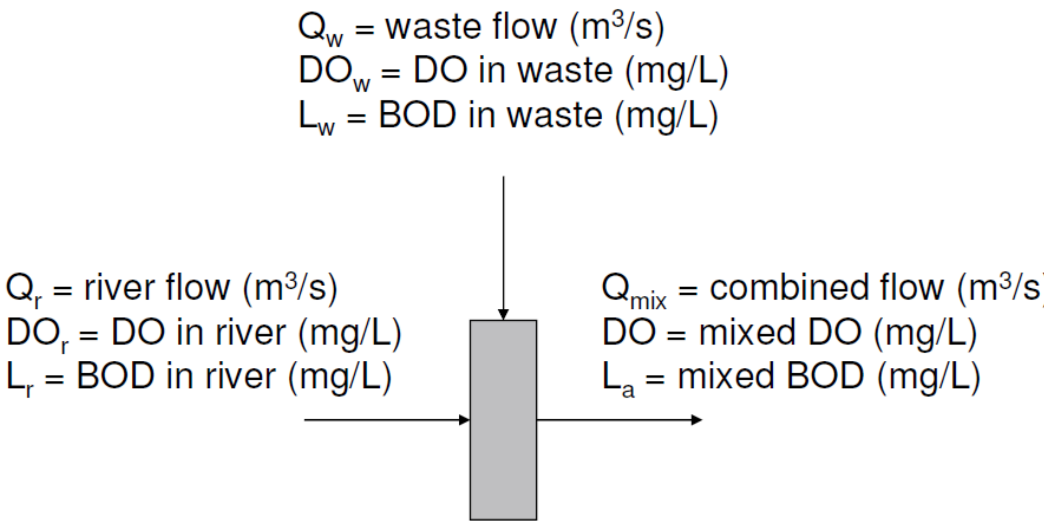



- Mass balance
  - Oxygen is depleted by BOD exertion (deoxygenation)
  - Oxygen is gained through re-aeration

# 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 $\Theta$ = 1.024

# 4. DO as function of time (<u>Streeter-Phelps equation</u> 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 !

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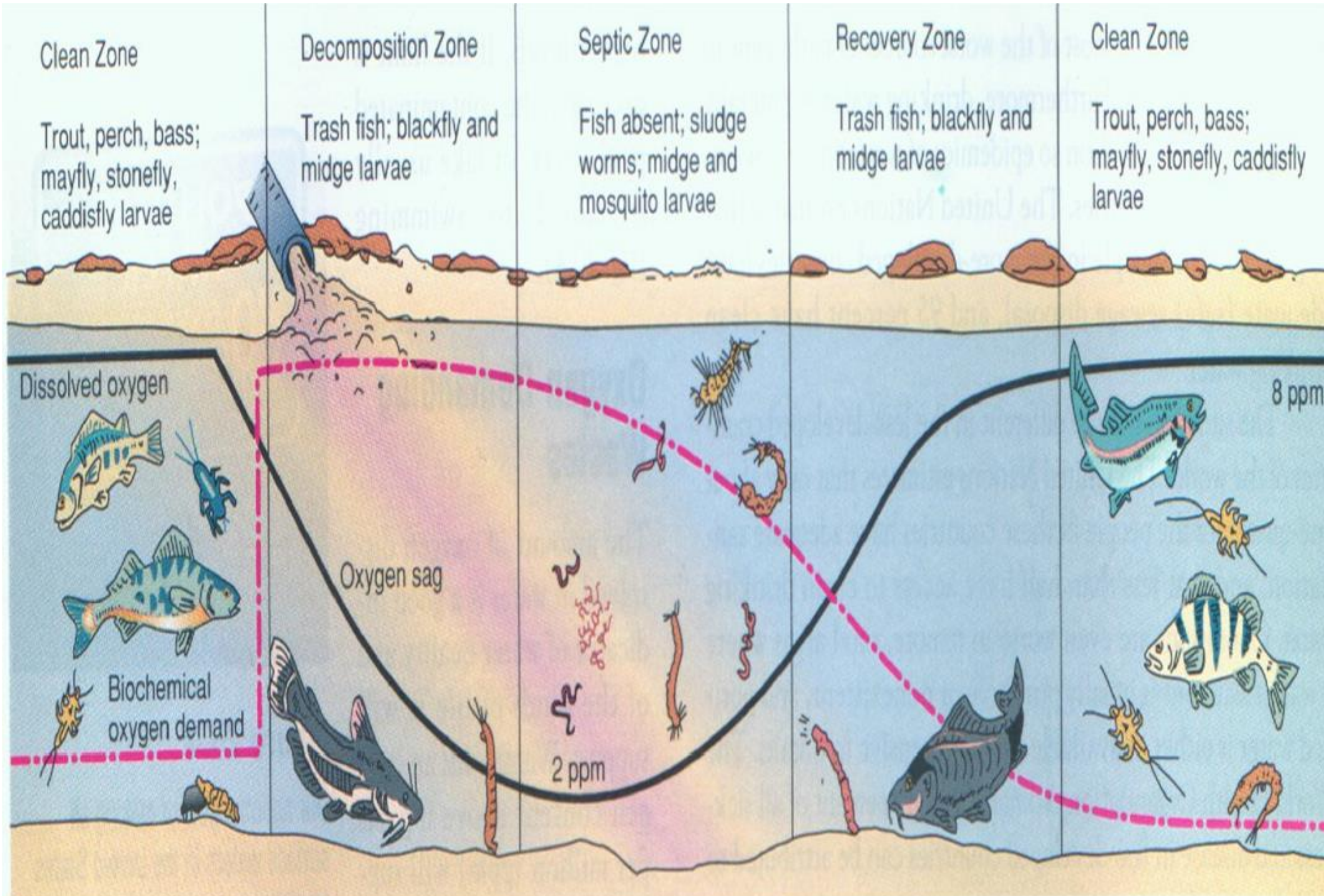


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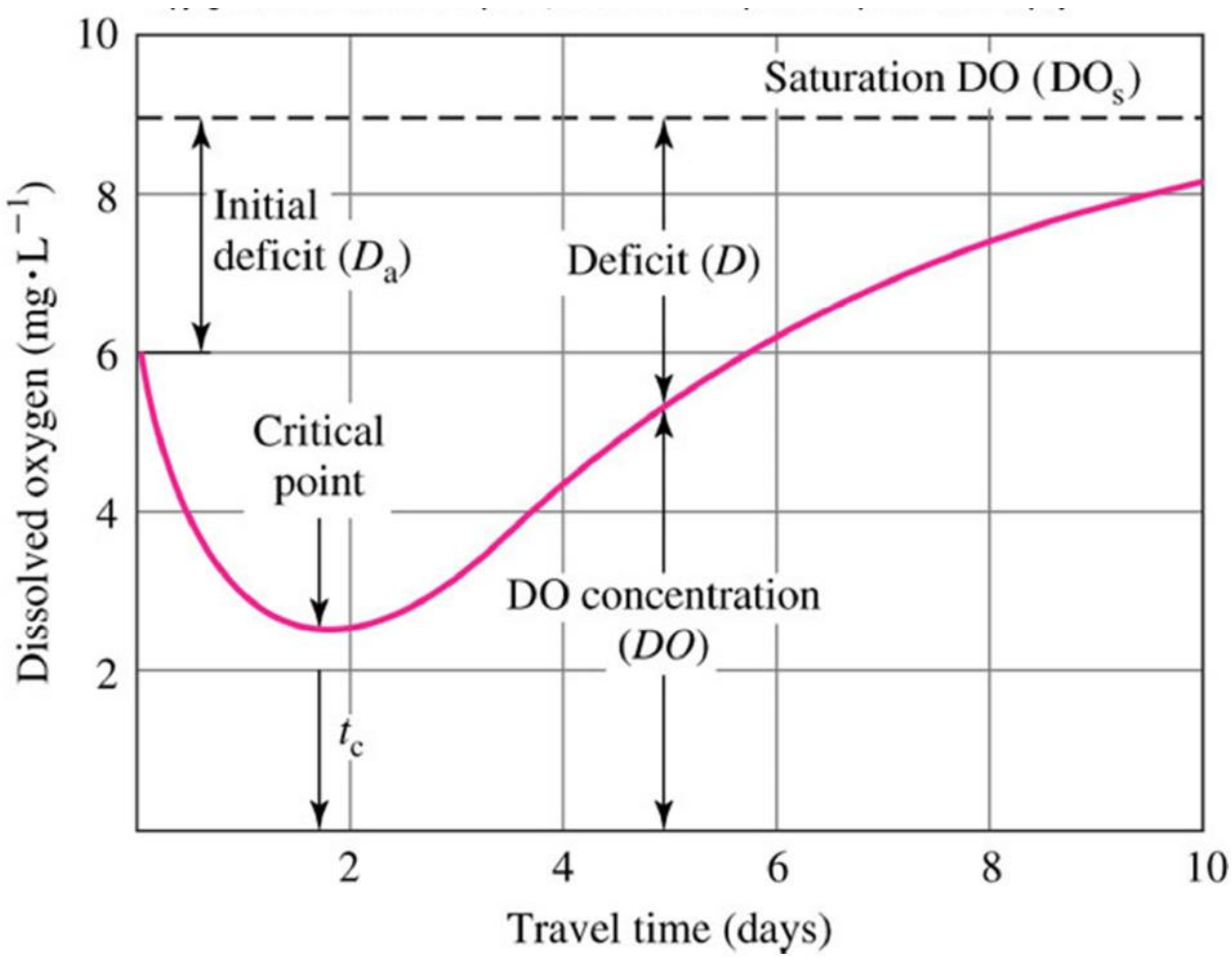
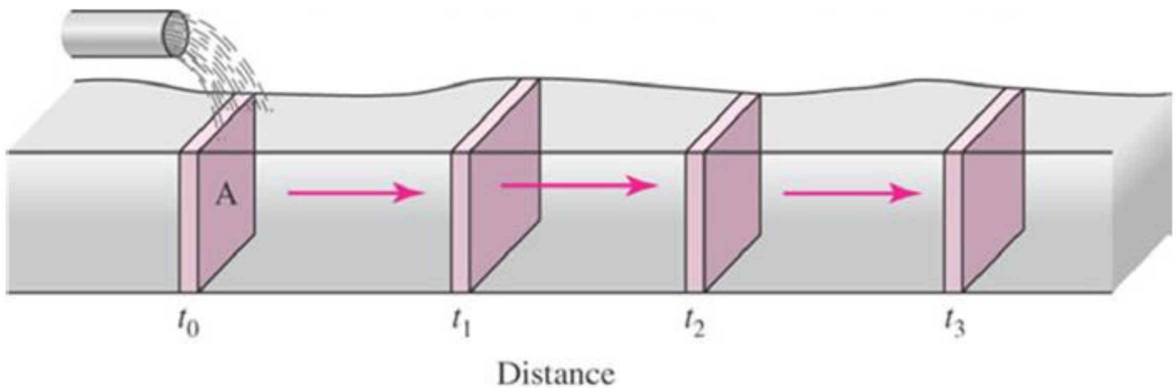
  - The removal of oxygen by microorganisms during biodegradation (de-oxygenation)
  - The replenishment of oxygen at the interface between the river and the atmosphere (re-aeration)

# Dissolved Oxygen Sag Curve



# Mass Balance Approach

- River described as “plug-flow reactor”

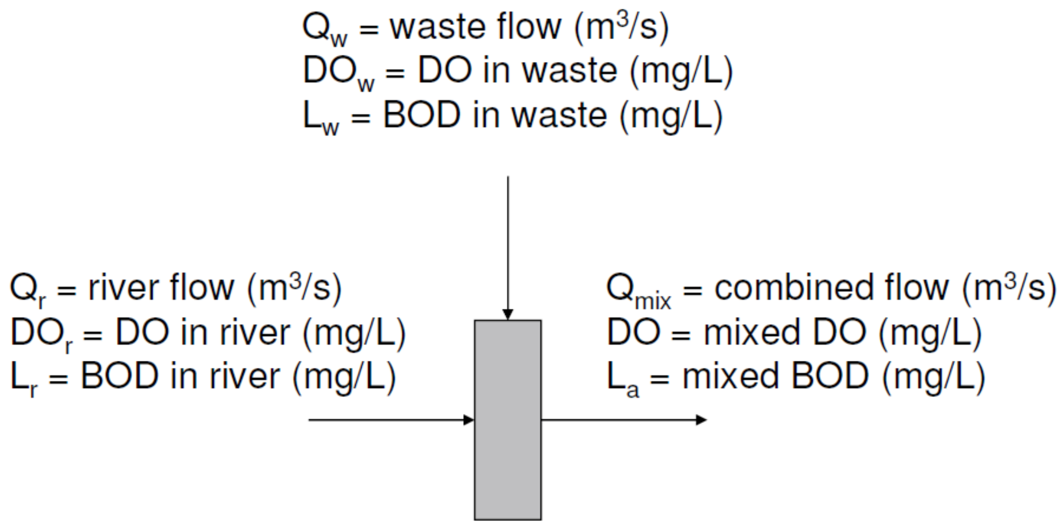



- Mass balance
  - Oxygen is depleted by BOD exertion (deoxygenation)
  - Oxygen is gained through re-aeration

# 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

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

# 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 $\Theta$ = 1.024

# 4. DO as function of time (<u>Streeter-Phelps equation</u> 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
- Dc = 3.28 mg/L
- $DO_{critical}$ = 5.89 mg/L

- Is any modifications required in WWTP?

**Thank you !**

**Problem Illustrating the Use of The Streeter-Phelps Equation**

A city discharges 25 million gallons per day (mgd) of domestic sewage into a stream with a typical flow rate of 250 cubic feet per second (cfs). The velocity of the stream is approximately 3 miles per hour. The temperature of the sewage is 21 °C, while that of the stream is 15 °C. The 20 °C $BOD_5$ of the sewage is 180 mg/L, while that of the stream is 1.0 mg/L. The sewage contains no dissolved oxygen, but the stream is 90 percent saturated upstream of the discharge. At 20 °C, k' is estimated to be 0.34 per day while $k'_2$ is 0.65 per day.

(1) Determine the critical-oxygen deficit and its location.
(2) Also estimate the 20 °C $BOD_5$ of a sample taken at the critical point. Use temperature coefficients of 1.135 for k' and 1.024 for $k'_2$.
(3) Plot the dissolved-oxygen-sag curve.
(4) Determine the dissolved oxygen concentration at 1000 km from the point source.

SOLUTION:

(1) Determine the dissolved oxygen in the stream before discharge.

Saturation concentration at 15 °C (from table on worksheet) = 10.2 mg/L
Dissolved oxygen in stream = 0.90 (10.2 mg/L) = 9.2 mg/L

(2) Determine the temperature, dissolved oxygen, and BOD of the mixture using the mass balance approach. Note that units should be compatible.

Flow rate of stream (conversion to liters):

$$\left(\frac{250\text{ cubic feet}}{\text{s}}\right)\left(\frac{7.48\text{ gal}}{\text{cubic foot}}\right)\left(\frac{60\ s}{\text{min}}\right)\left(\frac{60\text{ min}}{\text{hr}}\right)\left(\frac{24\text{ hr}}{\text{d}}\right)=161.6\text{ x }10^6\text{ gallons/d}$$

$$\left(161.6\text{ x }10^6\text{ gallons}\right)\left(\frac{3.79\text{ L}}{\text{gal}}\right)=612\text{ x }10^6\text{ L/d} = 612\text{ million liters/d}$$

Flow rate of sewage effluent:

$$\left(\frac{25\text{ x }10^6\text{ gallons}}{\text{d}}\right)\left(\frac{3.79\text{ L}}{\text{gal}}\right) = 94.8\text{ x }10^6\text{ L / d} = 94.8\text{ million liters / d}$$

**Temperature of mixture:**

$$\text{Net Change in Temperature } (\Delta T) = \text{Stream Input} + \text{Sewage Input} - \text{Output}$$

$$0 = (\text{stream flow rate})(\text{stream temp.}) + (\text{sewage flow rate})(\text{sewage temp.}) - (\text{mixture flow rate})(\text{mixture temp})$$

$$0 = \left(612 \text{ x } 10^6 \text{ L/d}\right)\left(15 \text{ C}\right) + \left(94.8 \text{ x } 10^6 \text{ L/d}\right)\left(20 \text{ C}\right) - \left(612 \text{ x } 10^6 \text{ L/d} + 94.8 \text{ x } 10^6 \text{ L/d}\right)T_{\text{mixture}}$$

upon rearrangement yields:

$$T_{\text{mixture}} = \frac{\left(612 \text{ x } 10^6 \text{ L/d}\right)\left(15 \text{ C}\right) + \left(94.8 \text{ x } 10^6 \text{ L/d}\right)\left(20 \text{ C}\right)}{612 \text{ x } 10^6 \text{ L/d} + 94.8 \text{ x } 10^6 \text{ L/d}} = 15.7 \text{ C}$$

## Dissolved oxygen of mixture:

$$\text{Net Change in D.O.} = \text{Stream Input} + \text{Sewage Input} - \text{Output}$$

$$0 = (\text{stream flow rate})(\text{stream D.O.}) + (\text{sewage flow rate})(\text{sewage D.O.}) - (\text{mixture flow rate})(\text{mixture D.O.})$$

$$0 = \left(612 \text{ x } 10^6 \text{ L/d}\right)\left(9.2 \text{ mg/L}\right) + \left(94.8 \text{ x } 10^6 \text{ L/d}\right)\left(0.0\right) - \left(612 \text{ x } 10^6 \text{ L/d} + 94.8 \text{ x } 10^6 \text{ L/d}\right)\left(\text{D.O.}_{\text{mixture}}\right)$$

upon rearrangement yields:

$$\text{D.O.}_{\text{mixture}} = \frac{\left(612 \text{ x } 10^6 \text{ L/d}\right)\left(9.2 \text{ mg/L}\right) + \left(94.8 \text{ x } 10^6 \text{ L/d}\right)\left(0.0 \text{ mg/L}\right)}{612 \text{ x } 10^6 \text{ L/d} + 94.8 \text{ x } 10^6 \text{ L/d}} = 7.97 \text{ mg/L}$$

## $BOD_5$ of mixture:

$$\text{Net Change in } BOD_5 \ (\Delta BOD_5) = \text{Stream Input} + \text{Sewage Input} - \text{Output}$$

$$0 = (\text{stream flow rate})(\text{stream } BOD_5) + (\text{sewage flow rate})(\text{sewage } BOD_5) - (\text{mixture flow rate})(\text{mixture } BOD_5)$$

$$0 = \left(612 \text{ x } 10^6 \text{ L/d}\right)\left(1.0\right) + \left(94.8 \text{ x } 10^6 \text{ L/d}\right)\left(180\right) - \left(612 \text{ x } 10^6 \text{ L/d} + 94.8 \text{ x } 10^6 \text{ L/d}\right)BOD_{5\text{mixture}}$$

upon rearrangement yields:

$$BOD_{5\text{mixture}} = \frac{\left(612 \text{ x } 10^6 \text{ L/d}\right)\left(1.0\right) + \left(94.8 \text{ x } 10^6 \text{ L/d}\right)\left(180\right)}{612 \text{ x } 10^6 \text{ L/d} + 94.8 \text{ x } 10^6 \text{ L/d}} = 25.0 \text{ mg/L}$$

## $BOD_L$ of mixture (at 20 °C):

$$BOD_L = \frac{BOD_5}{1 - e^{-k'(x/v)}} = \frac{25.0 \text{mg/L}}{1 - e^{-(0.34/d)(5d)}} = 30.6 \text{ mg/L}$$

(3) Correct the rate constants to 15.7 °C:

Rate constants are not linearly related to changes in temperature, therefore we must correct them using an exponential relationship. Typically these can be corrected using the two constants and equations given below. Note that 20 °C is used as the reference point since this is where the original data for the k's were collected.

$k' = 0.34(1.135)^{15.7-20} = 0.197 \text{ day}^{-1}$

$k'_2 = 0.65(1.024)^{15.7-20} = 0.587 \text{ day}^{-1}$

(4) Determine the critical time ($t_c$) and critical distance ($x_c$). In the table note that the saturation value for $O_2$ at 15.7 °C = 10.1 mg/L, however the stream is at 90% of the saturation value (9.2 mg/L). Thus, the initial oxygen deficit,

$D_o$ = (the initial stream $O_2$ value - the $O_2$ of the mixture)
= (9.2 - 7.97) = 1.23 mg $O_2$/L

$$t_c = \frac{1}{k'_2 - k'} \ln \frac{k'_2}{k'} \left[ 1 - \frac{D_o(k'_2 - k')}{k' BOD_L} \right]$$

$$t_c = \frac{1}{0.587/d - 0.197/d} \ln \frac{0.587/d}{0.197/d} \left[ 1 - \frac{2.13 mg/L(0.587/d - 0.197/d)}{0.197/d(30.6 mg/L)} \right]$$

$$t_c = 2.42 \text{ d}$$

$$x_c = vt_c$$

$$= \left(\frac{3 \text{miles}}{\text{h}}\right)\left(\frac{24\text{h}}{\text{d}}\right)(2.42 \text{ d}) = 174.2 \text{ miles}$$

or

$$= \left(\frac{3 \text{miles}}{\text{h}}\right)\left(\frac{1.61 \text{ km}}{\text{mile}}\right)\left(\frac{24\text{h}}{\text{d}}\right)(2.42 \text{ d}) = 280 \text{ km}$$

(5) Determine $D_c$.

To calculate the critical oxygen deficit, $D_c$, we must first convert the water velocity into units of miles/d or km/d. Therefore, 3 miles/hr = 72 miles/d.

$$D_c = \frac{k'}{k'_2} BOD_L e^{-k'(xc/v)}$$

$$= \left(\frac{0.197 / \text{d}}{0.587 / \text{d}}\right)(30.6) e^{-(0.197/d)(174.2 miles)/(72 mile/d)} = 6.37 \text{ mg / L}$$

Thus, the D.O. will be depressed 6.37 mg/L from its saturation value. The intital $O_2$ concentration of the stream will be the saturation value minus the $D_c$,
or 9.2 - 6.37 = 2.83 mg $O_2$/L.

(6) Determine the $BOD_5$ of a sample taken at distance $x_c$.

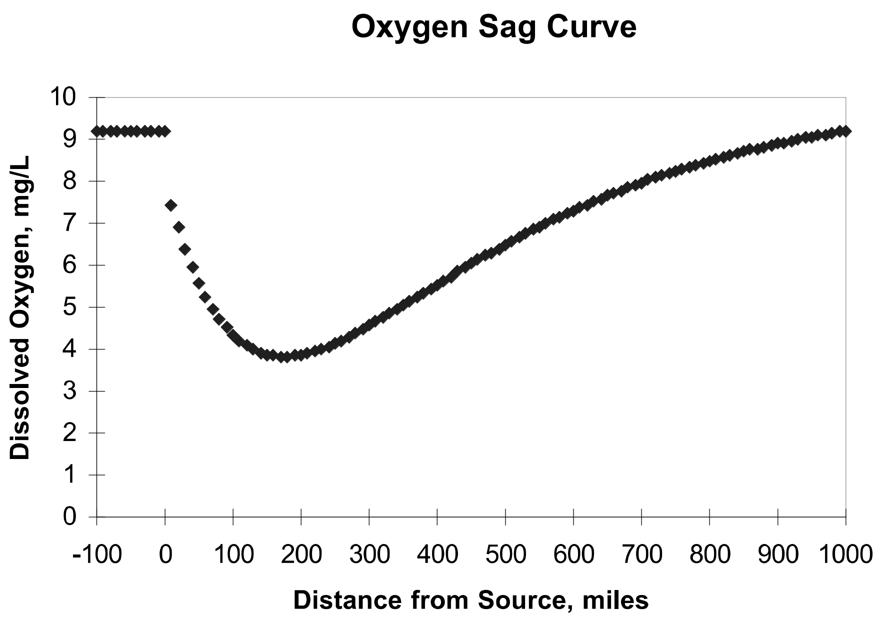
$$BOD_{L5} = BOD_L e^{-k'(x/v)}$$

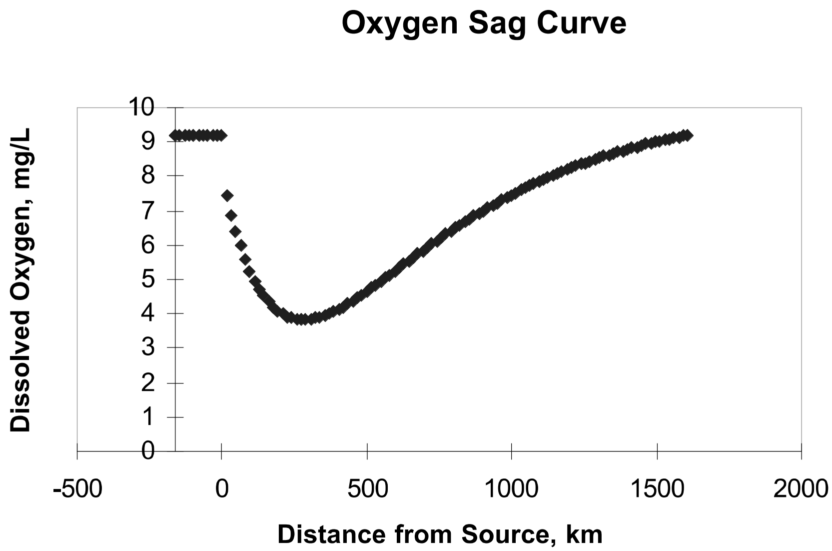
$$= (30.6 mg/L)e^{-0.197/d(174.2 miles/72 miles/d)} \quad = \quad 19.0\ mg/L$$

$$20\ ^{\circ}C\ BOD_5 = BOD_L\left[1 - e^{-(k')(5)}\right]$$

$$= 19.0 mg/L\left[1 - e^{-(0.34/d)(5d)}\right] \quad = \quad 15.5\ mg/L$$

(7) Draw the oxygen sag curves for both miles and km from the point source.






Note, that in this example all $O_2$ concentration values are above those normally encountered in the Zone of Active Decomposition. Thus, we basically have a Zone of Degradation and a Recovery Zone, delineated by the low point in the data plot.

(8) Determine the dissolved concentration at 1000 km from the point source.

$$D = \frac{k'\,BOD_L}{k'_2 - k'}\left(e^{-k'(x/v)} - e^{-k2'(x/v)}\right) + D_o\,e^{-k2'(x/v)}$$

$$= \frac{(0.197\,/\,d)(30.6\ mg\,/\,L)}{(0.587\,/\,d)\ -\ (0.197\,/\,d)}\left[EXP\left(-(0.197\,/\,d)\frac{1 \times 10^6\ m}{1.16 \times 10^5\ m\,/\,d}\right) - EXP\left(-(0.587\,/\,d)\frac{1 \times 10^6\ m}{1.16 \times 10^5\ m\,/\,d}\right)\right]$$

$$+\ 2.13EXP\left(-(0.587)\frac{1 \times 10^6\ m}{1.16 \times 10^5\ m\,/\,d}\right)$$

$$= 15.46\big[EXP(-1.70) - EXP(-5.06)\big] + 2.13EXP(-5.06)$$

$$= 15.46(0.18) + 2.13((0.01)$$

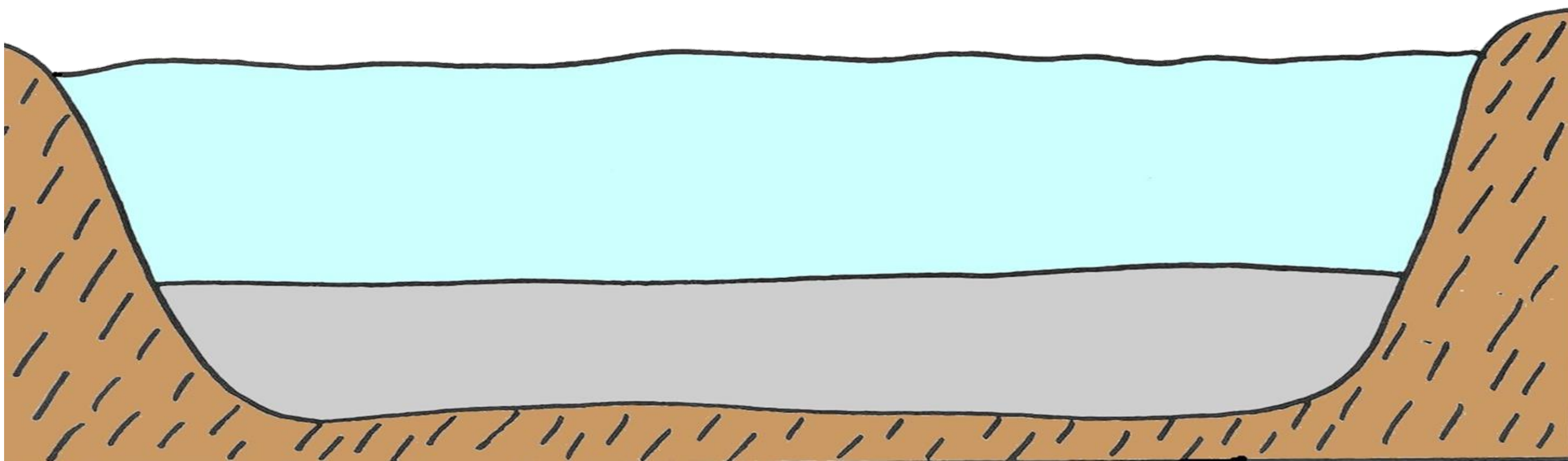
$$= 2.80\ mg\,/\,L$$

The calculated oxygen deficit created by the BOD is 2.80 mg/L. The initial oxygen concentration in the natural stream is 9.2 mg/L. Thus, the D.O. at 1000 km will be 9.2 - 2.8 = 6.40 mg/L which agrees with the data plot shown above.

# WASTEWATER STABILIZATION POND/ LAGOON SYSTEMS

# Waste Stabilization Ponds/Lagoons

A structure constructed to contain and to facilitate the operation and control of a complex process of treating or stabilizing wastewater.



# Waste Stabilization Ponds/ Lagoons

Physical Processes

Chemical Processes

Biological Processes

BACTERIA Types

## Aerobic

Bacteria that can use only oxygen that is “free” or not chemically combined.

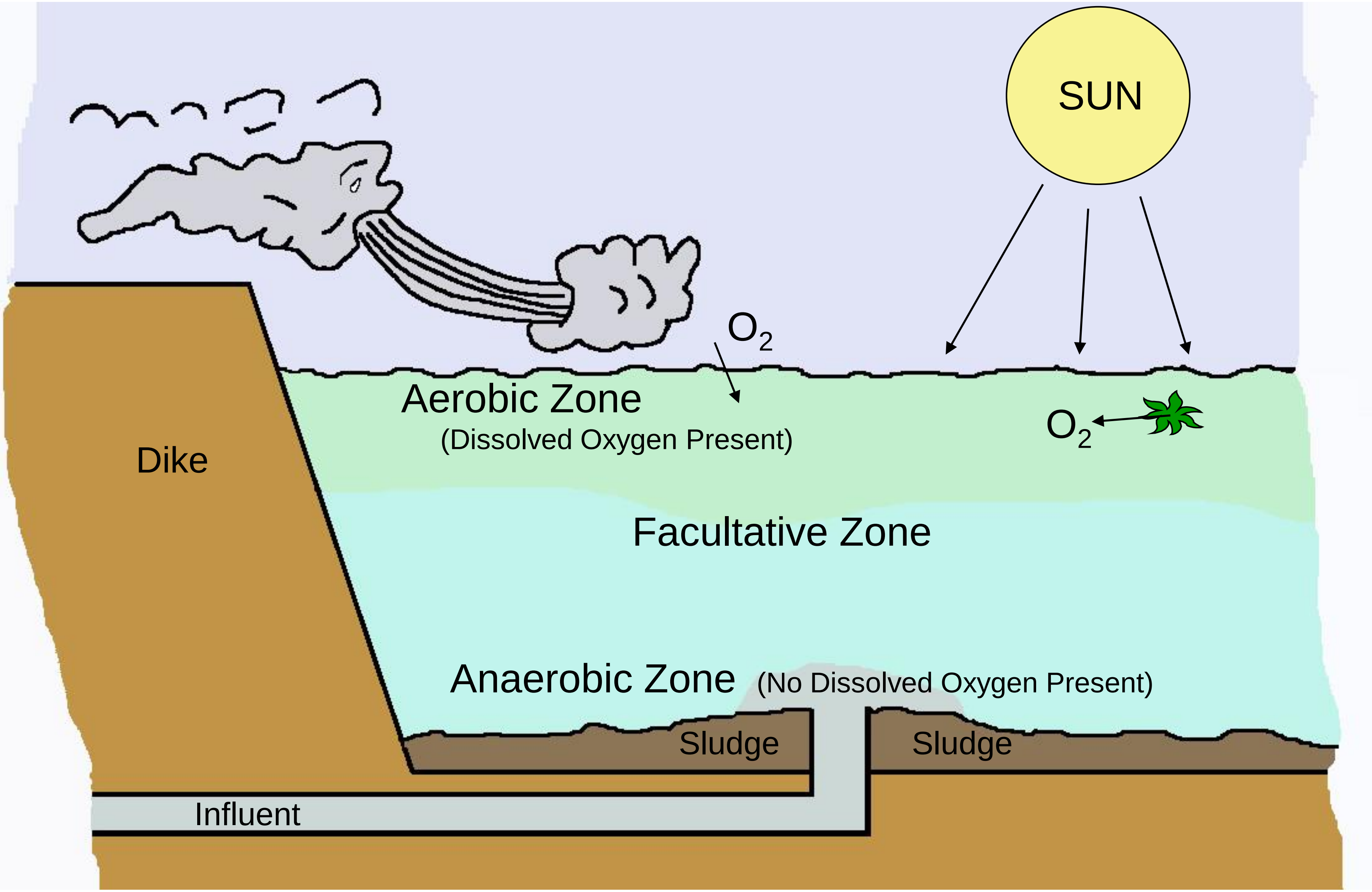
## Anaerobic

Bacteria that can live in the absence of “free” oxygen.

## Facultative

Bacteria that use either “free” or combined oxygen.

# Zonal Relationships in a Lagoon



# ANAEROBIC ZONE

SOLIDS

Sedimentation

Stabilization

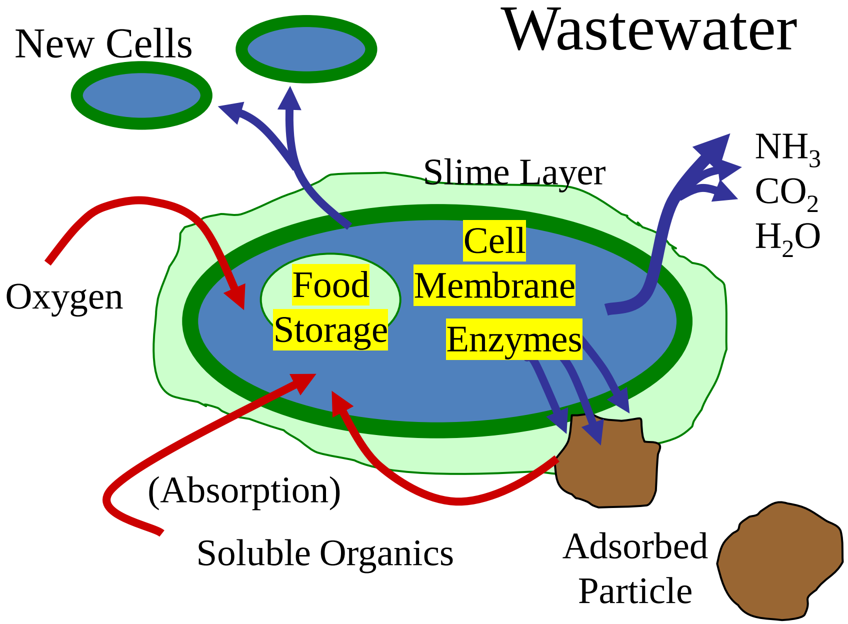
Organics $\xrightarrow{\text{Bacteria}}$ Organic Acids

Organic Acids $\xrightarrow{\text{Bacteria}}$ $CO_2$, $NH_3$, $H_2S$, $CH_4$

# AEROBIC ZONE

Bacteria Use Soluble Organics

Organic Compounds + Oxygen → Carbon Dioxide + Water



# FACULTATIVE ZONE

Organisms Utilize Dissolved Oxygen
or Combined Oxygen

Adapt to Changing Conditions

Continue Decomposition
during
Changing Conditions

# DO

ABSORPTION from ATMOSHERE
PHOTOSYNTHESIS

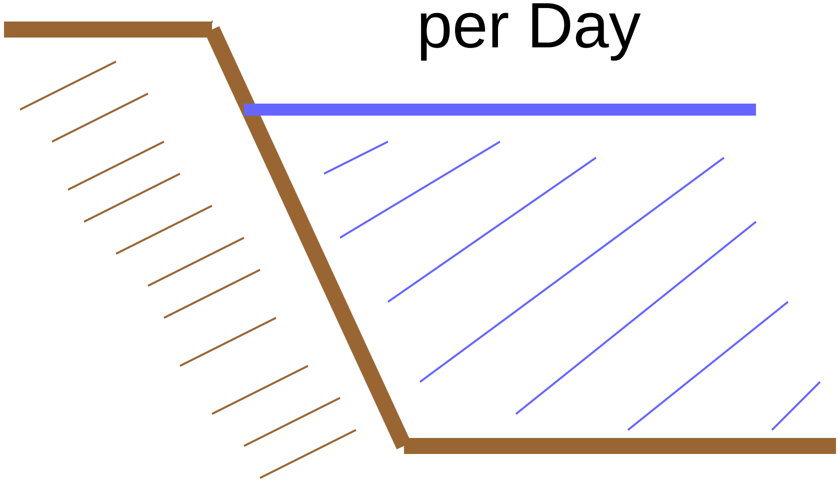
Efficient Treatment

Preventing Odors

# OXYGEN SOURCES

Surface Aeration Provides

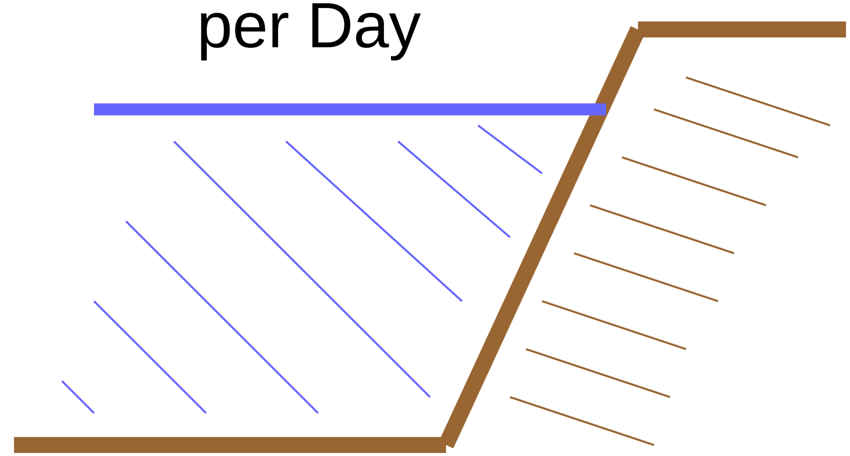
2.7 Kg
per Acre
per Day



At Lagoon D.O. of 2.0 mg/L
Temperature Permitting 8.0 mg/L

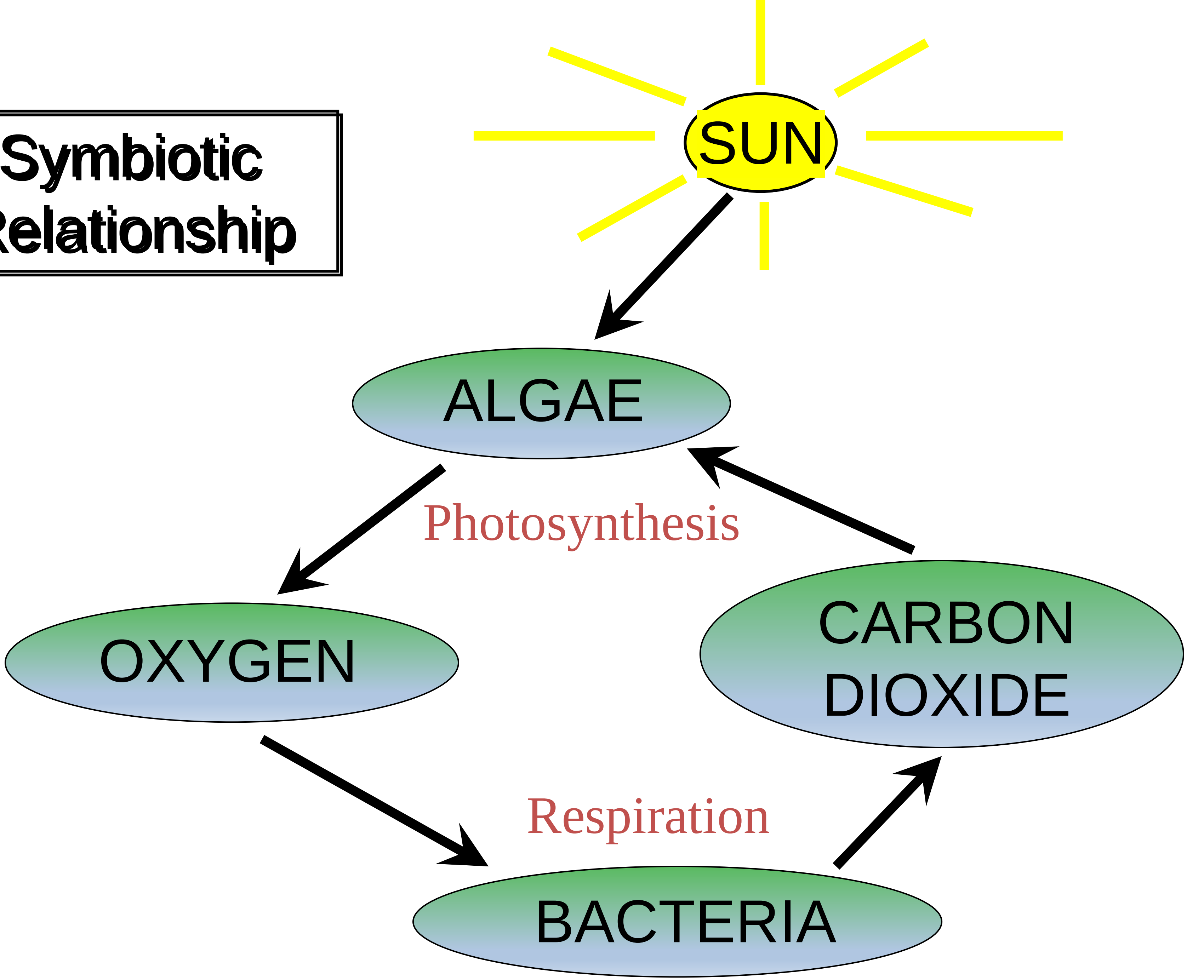
Algae (Photosynthesis) Provides

45 Kg
per Acre
per Day

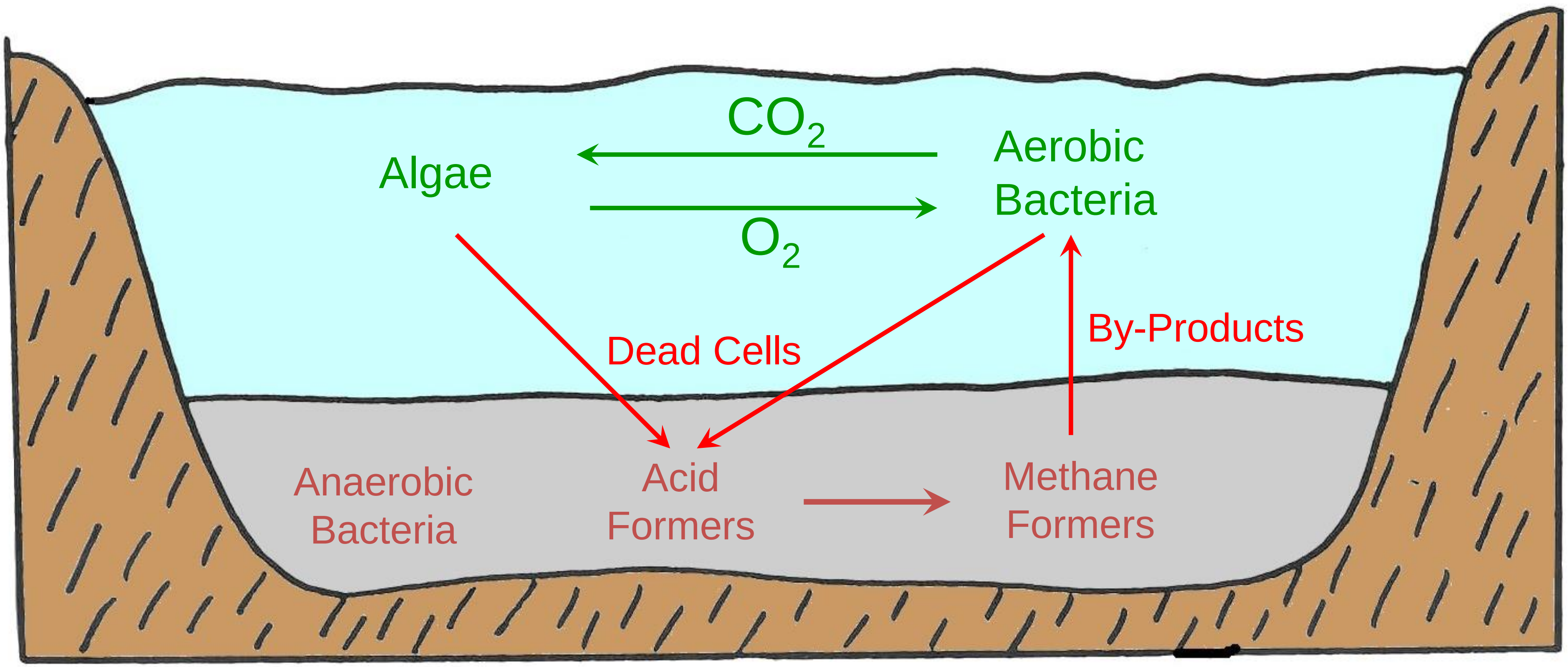


Each 27 Kg of Algae
Produce 45 pounds Oxygen

# Symbiotic Relationship



# ACTIVITY IN FACULTATIVE PONDS



# Influence of Wind

Adds Oxygen

Increases Mixing

# Influence of Light

Photosynthesis

Disinfection

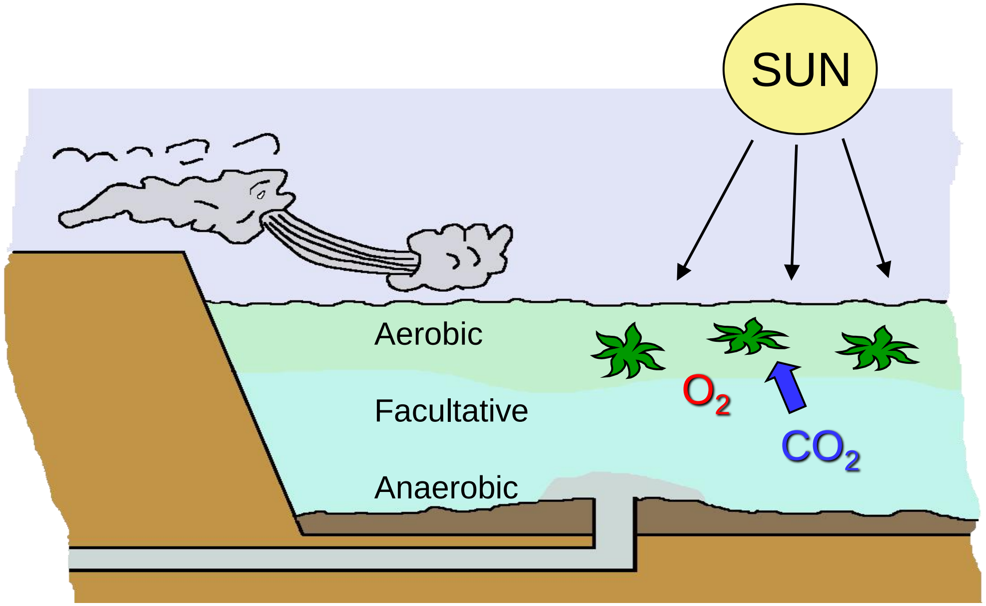
# Influence of Temperature

Rate of Bacterial Activity

Growth of Algae

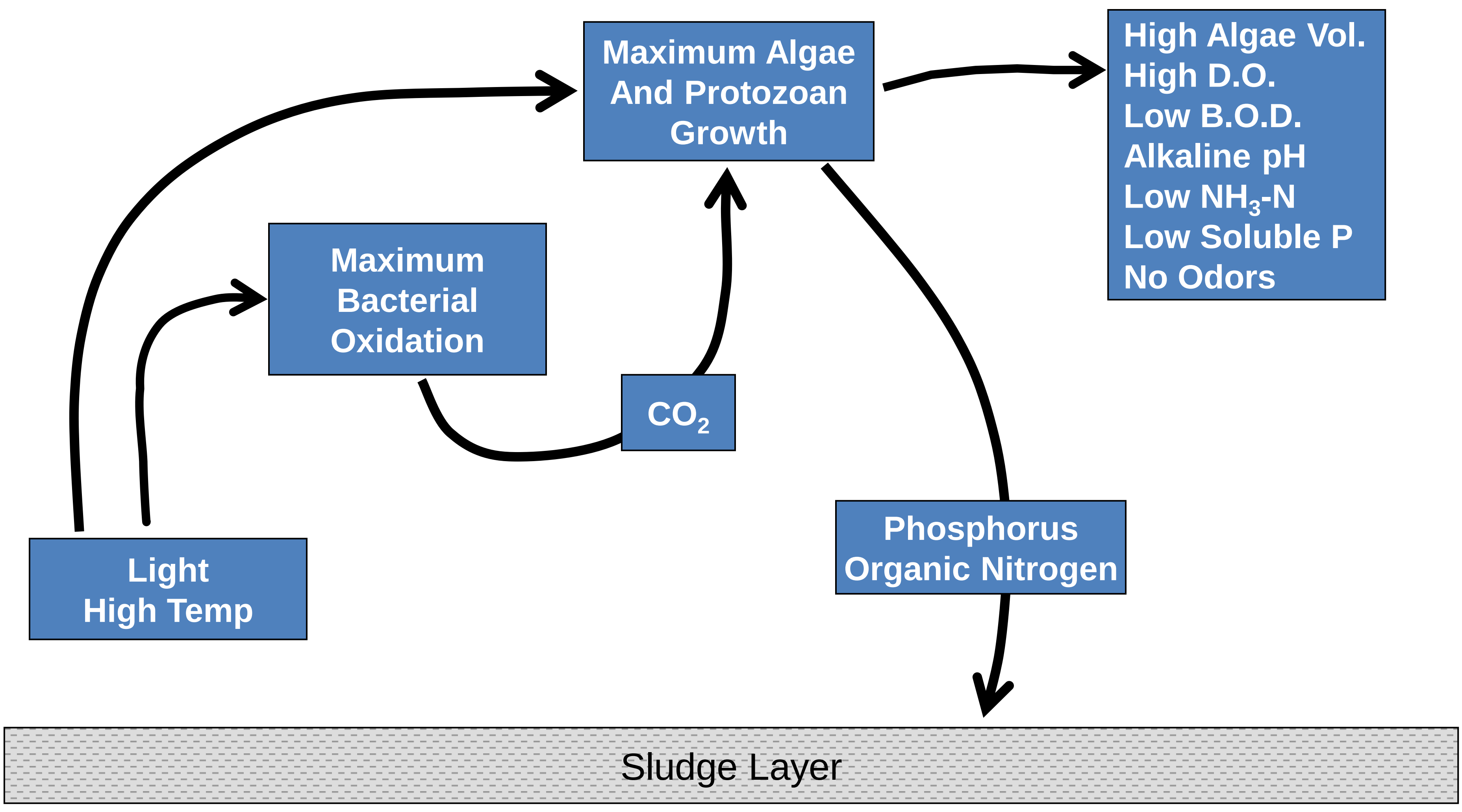
D.O. Saturation

# Daily Fluctuations

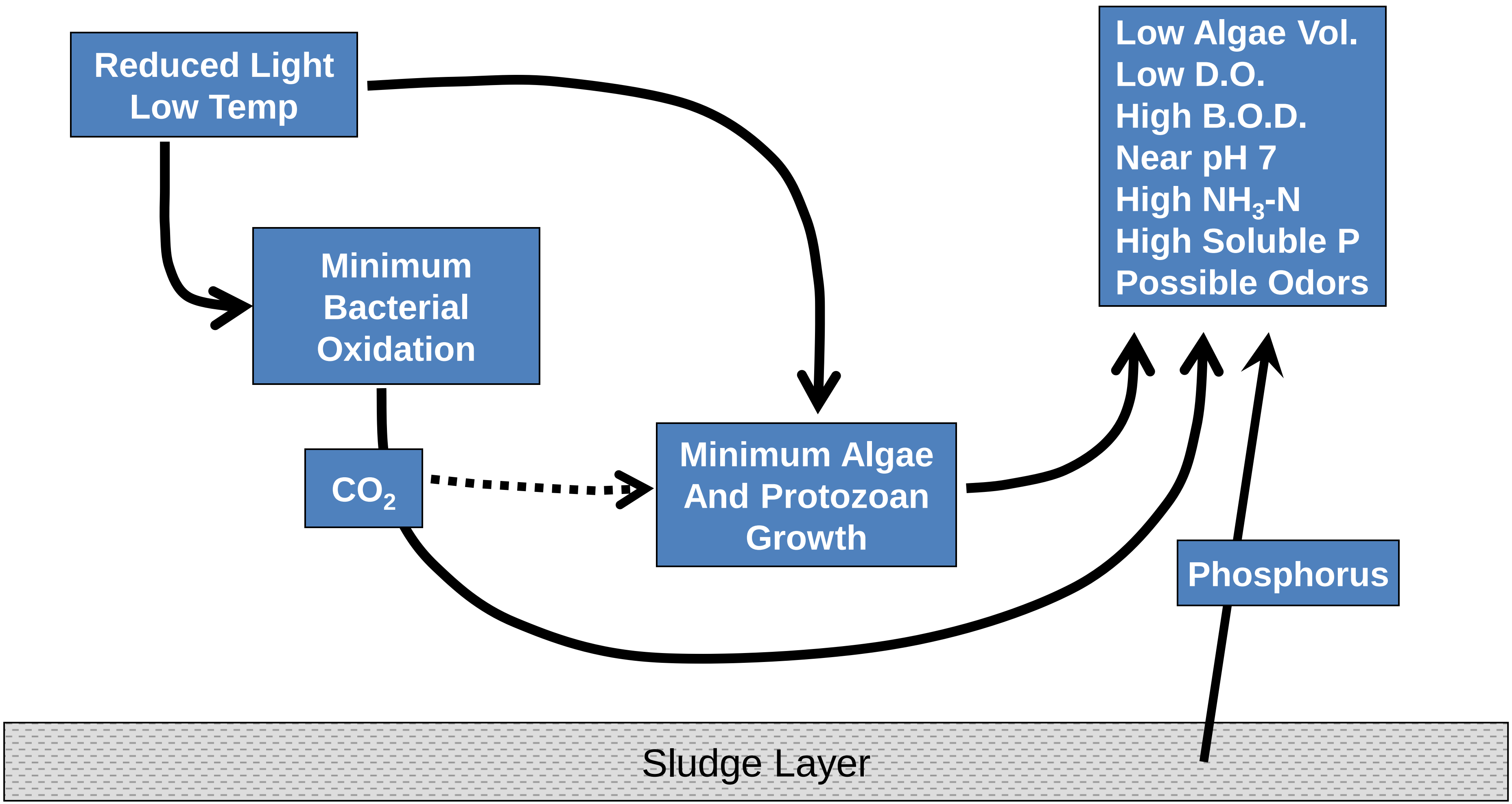



Temperature
DO
pH

# Summer


Maximum Algae And Protozoan Growth
High Algae Vol.
High D.O.
Low B.O.D.
Alkaline pH
Low $NH_3$-N
Low Soluble P
No Odors
Maximum Bacterial Oxidation
$CO_2$
Light
High Temp
Phosphorus
Organic Nitrogen
Sludge Layer

# Winter


Reduced Light
Low Temp
Minimum Bacterial Oxidation
$CO_2$
Minimum Algae And Protozoan Growth
Low Algae Vol.
Low D.O.
High B.O.D.
Near pH 7
High $NH_3$-N
High Soluble P
Possible Odors
Phosphorus
Sludge Layer

# ADVANTAGES

1. Economical to Construct & Operate.
2. Low Monitoring & Control Requirements.
3. Rapid Recovery from “Shock” Loads.
4. Low Energy & Chemical Usage.
5. Low Mechanical Failure.
6. Minimal Sludge Disposal.
7. Long Life.

# DISADVANTAGES

1. Large Land Usage.
2. Low Control Options.
3. Operations Dependant on Climate.
4. Often High Suspended Solids.
5. Seasonal Odors.
6. Possible Ground Water Contamination.
7. Not Good In High Loading Situations.

# GOOD PRACTICES

- Process Is In Balance
- Properly Designed Facility
- Process Is Controlled
- System Is Maintained

# Design of Ponds and Lagoons

$BOD_{in}$ = $BOD_{out}$ + $BOD_{consumed}$

$Q\,So = Q\,S + V\,(kS)$

$S/So = 1/(1+(k\,V/Q)) = 1/(1+k\,\theta)$

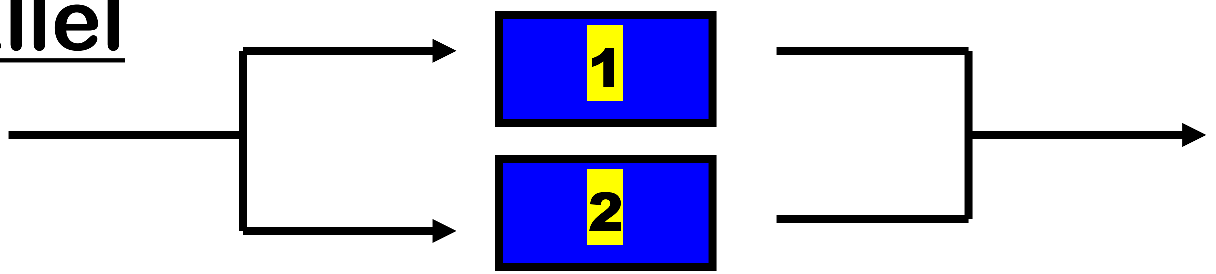
S = soluble BOD remaining, mg/L
So = initial Soluble BOD, mg/L

k = reaction rate coefficient, $d^{-1}$
$\theta$ = hydraulic retention time, d
V = reactor volume, $m^3$
Q = flow rate, $m^3/d$

## Series


Placing Majority of Load on First Cell
Summer Operation

## Parallel




Dividing Organic Load Between At Least Two Cells
Winter Operation

# Thank you !

# CVL100:Environmental Science(2-0-0)

## Water and Wastewater Treatment Part


**Dr. Arun Kumar**


**(Tuesday and Friday)**


Email: arunku@civil.iitd.ac.in


Check IITD course email daily for information


भारतीय प्रौद्योगिकी संस्थान दिल्ली
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# Learning Objectives

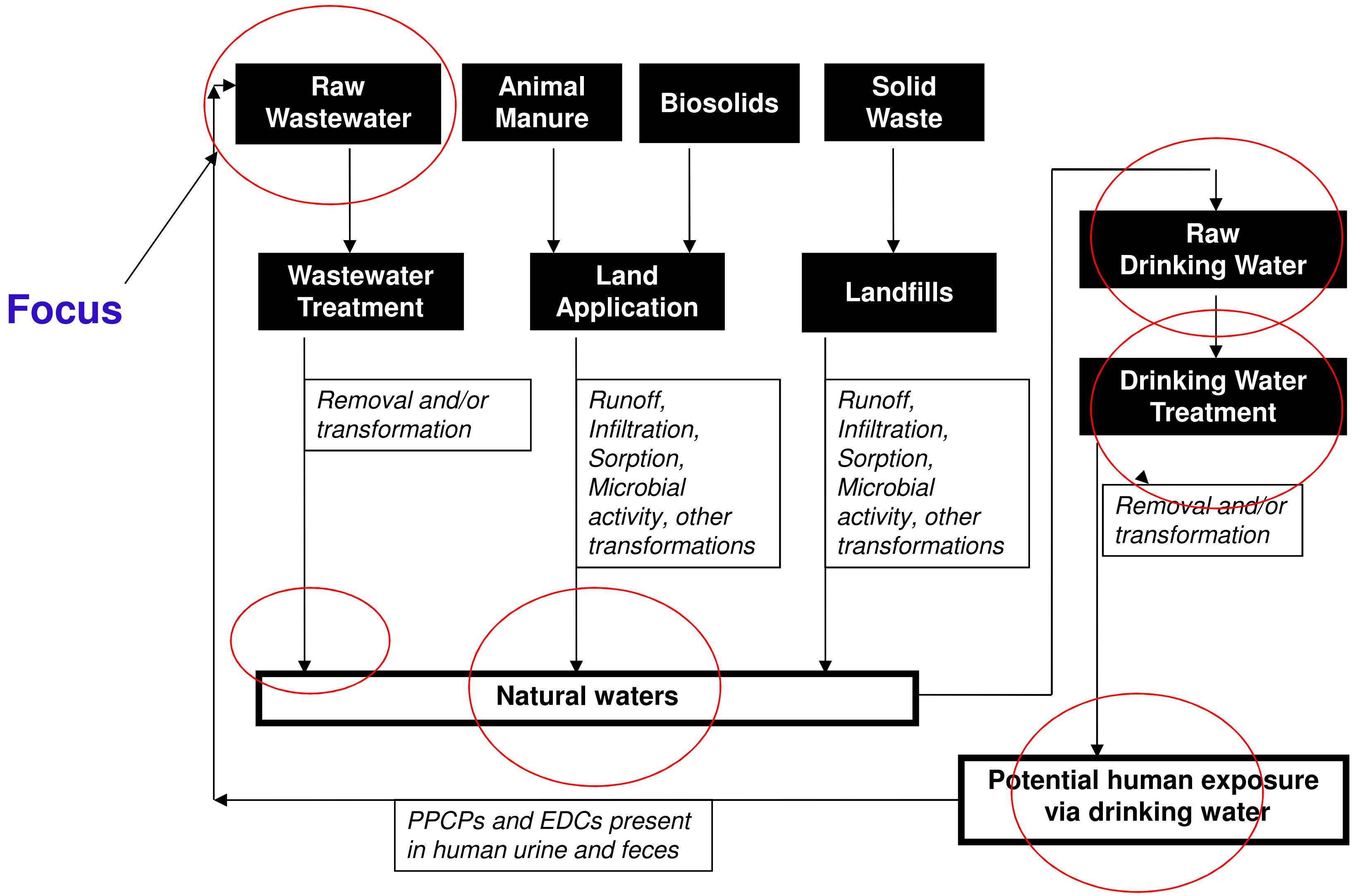
- To introduce water contaminants and their health effects
- To decide about treatment need for a given use objective
- To make aware of reading treatment plant schematic and estimating removal efficiency
- To provide basic  information on processes for removing contamiants from water

# Water Pollution

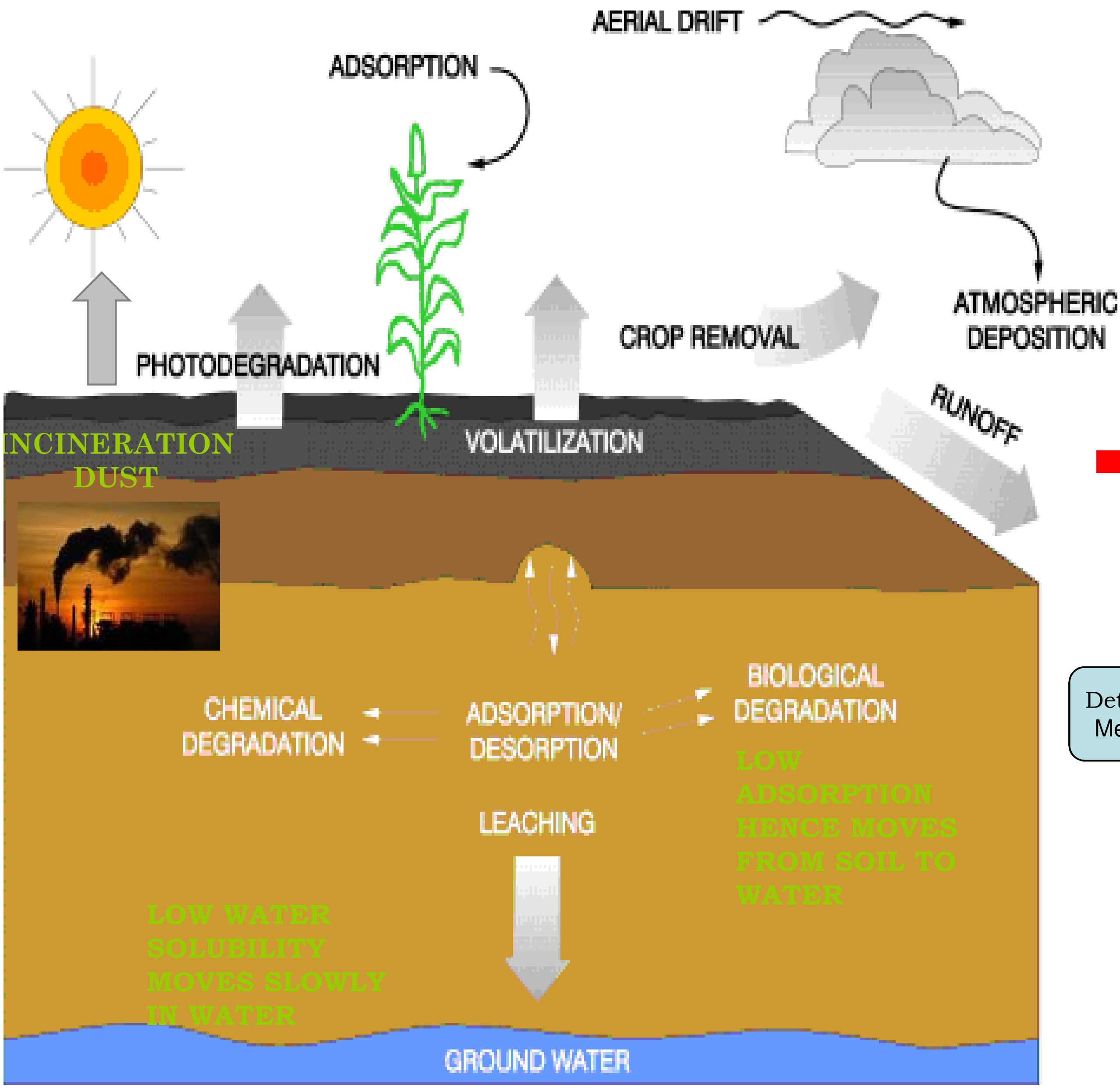


un Ku
(arunku@civil.iitd.ac.in)

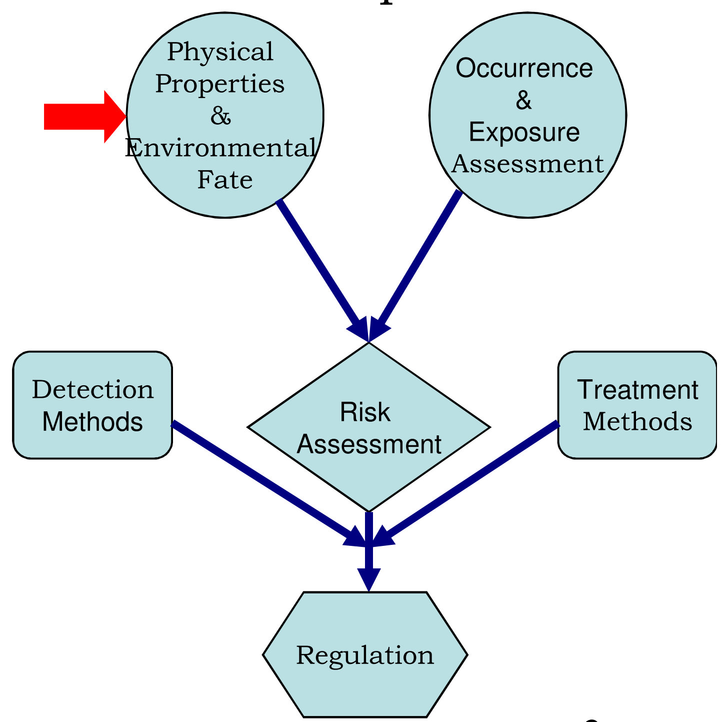
# Emerging Contaminants in Environment



# Physical Properties & Environmental Fate



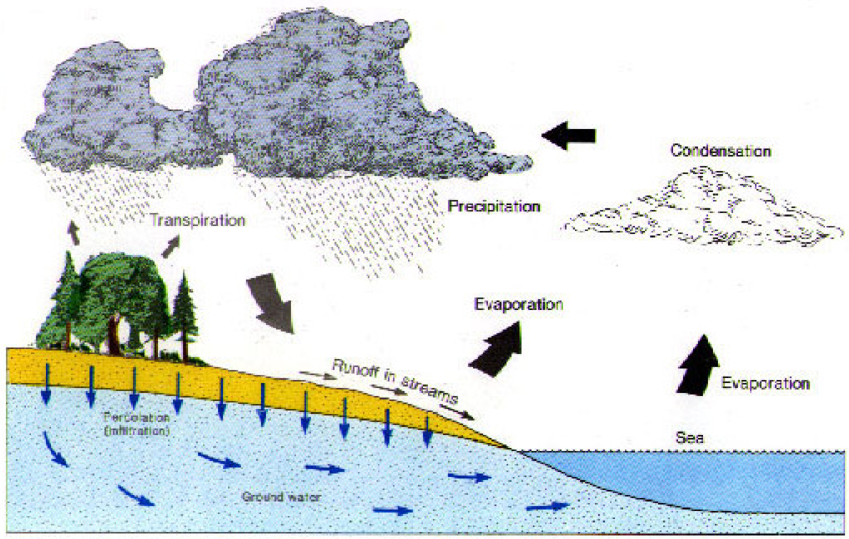

- Water solubility – 32-40 mg/L
- Weakly volatile
- Low sorption to soil






Source: Layton D. et al., 1987

# Transport of Enteric Viruses (Wong, K.; MSU)



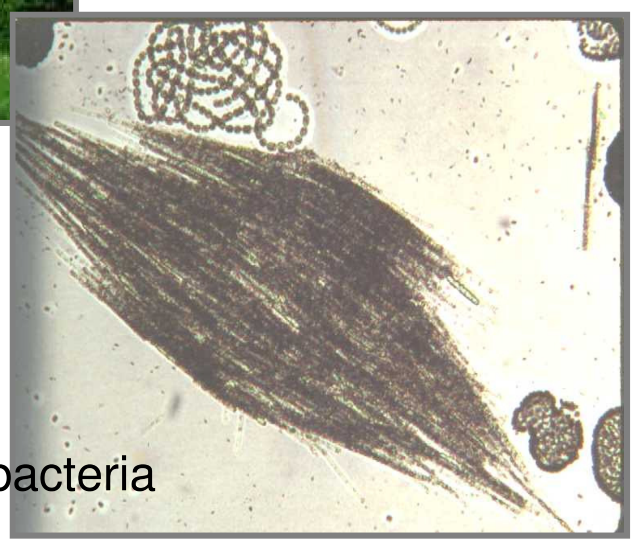

- Viruses can contaminate the surface water and groundwater by runoff and infiltration.

# Harmful Algal Blooms (HABs)
## *(part of reason on eutrophication)*

*Microcystis sp.* bloom

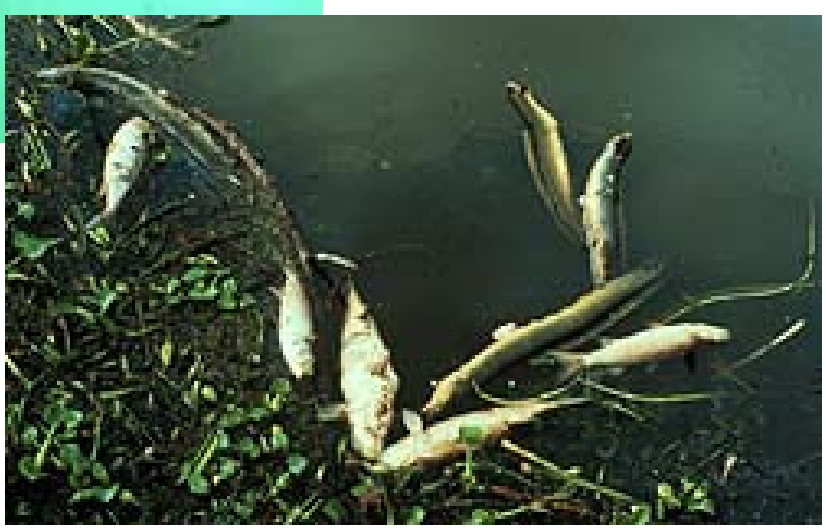
HAB

*Anabaenopsis sp.* bloom



mixture of cyanobacteria

# Eutrophication



# Effects on human and environmental components

- **Direct** ← Effects on HUMANS
  - Infections,
  - Toxicity,
  - Carcinogenesis
  - Other disease acute or chronic
- **Indirect** ← Effects on ECOSYSTEMS
  - Eutrophication,
  - Oxygen depletion - Hypoxia,
  - Harmful algal bloom formation,
  - Aquatic toxicity,
  - Accumulation in fish and sediments,
  - Bioaccumulation,
  - Endocrine disruption,
  - Antibiotic resistance development

# Exercise 1

- List names of 3 water pollutants for your city and find out their standards for drinking water and for discharging in surface water.
- Spots: river, lake, nallah, sea
- Man made pollution (domestic, industrial)
- Accidental water pollution (oil spill situation)

# Water Contaminants

- Heavy metals
- Pathogens (not indicator organisms such as fecal coliform and total coliforms)
- Organic compounds (pesticides, antibiotics, endocrine-disrupting chemicals, etc.)
- Nanoparticles

# Water Pollutants

**TYPES:**

- **Biological:**
  - Viruses
  - Bacteria
  - Parasites
  - Helminths
  - Bacterial Toxins
- **Chemical:**
  - Inorganic
  - Organic

**EFFECTS:**

- **To Humans:**
  - Infections
  - Toxicity
  - Carcinogenesis
- **To Ecosystems:**
  - Oxygen Depletion
  - Environmental Toxicity
  - Accumulation in fish and sediments

***Courtesy: Dr. Irene Xagoraraki, MSU (USA)***

# Pollutants that cause ecological damage

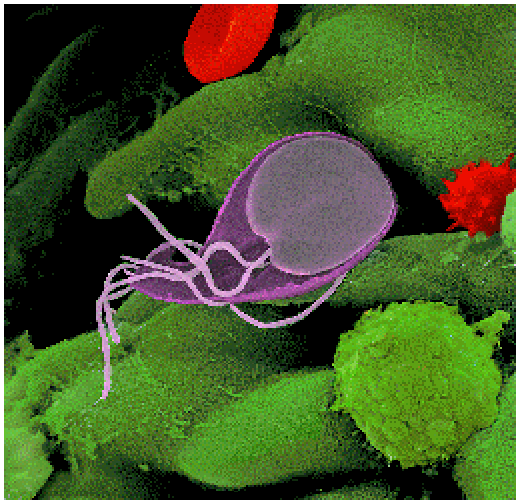
- Oxygen demanding wastes (hypoxia, eutrophication)
- Excess nutrients (hypoxia, eutrophication)
- Salts (fresh water population damaged)
- Suspended solids (settling)
- Toxicants (aquatic toxicity)
- Antibiotics (antibiotic resistance bacteria)
- Pharmaceuticals and personal care products (endocrine disruption)

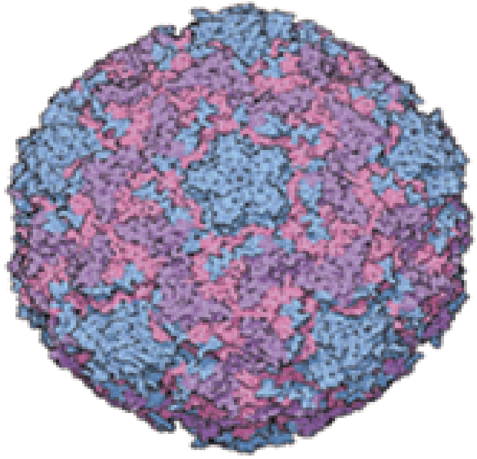
# Pathogenic Microorganisms in Water

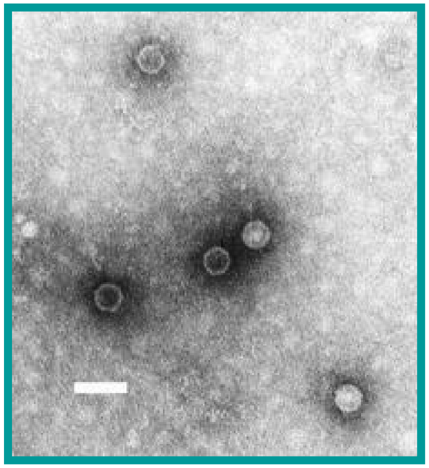
Bacteria

Parasites

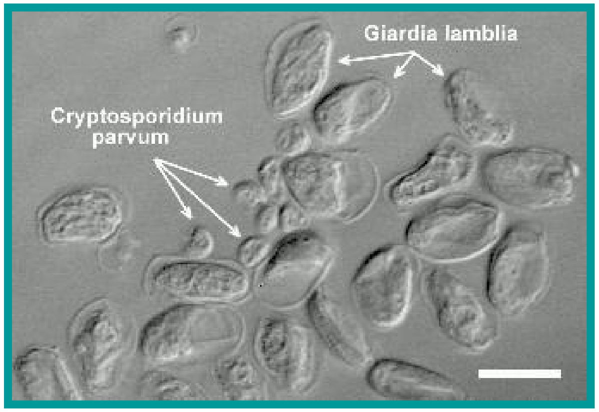
Viruses

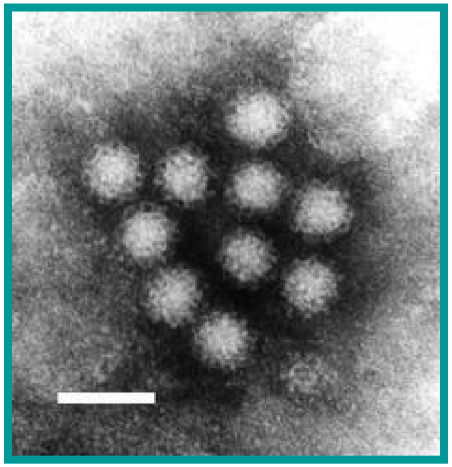






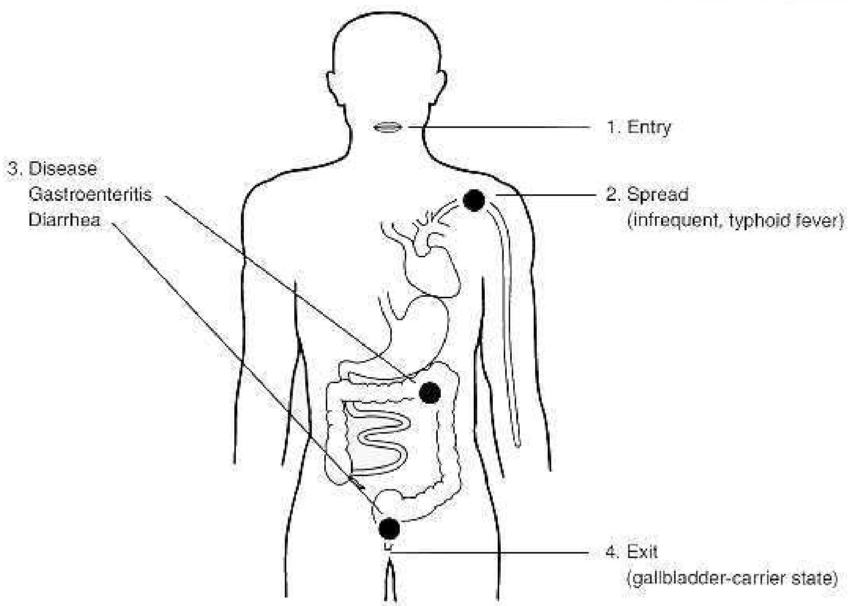
Poliovirus



Norwalk virus (norovirus)

# Enteric Pathogens




- Exposure is via ingestion
- Primary site of infection is gastrointestinal tract
- Gastroenteritis symptoms
  – Nausea
  – Vomiting
  – Diarrhea
  – Fever
- May spread to other sites (blood, liver, nervous system)
- Shed in fecal material
- "Fecal-oral" route of transmission

# Pathogenic Microorganisms

Typical Pathogens Excreted In Human Feces

| Pathogen Group and Name | Associated Diseases |
|---|---|
| **Virus** | |
| Adenoviruses | Respiratory, eye infections |
| Enteroviruses | |
| Polioviruses | Aseptic meningitis, poliomyelitis |
| Echoviruses | Aseptic meningitis, diarrhea, respiratory infections |
| Coxsackie viruses | Aseptic meningitis, herpangina, myocarditis |
| Hepatitis A virus | Infectious hepatitis |
| Reoviruses | Not well known |
| Other viruses | Gastroenteritis, diarrhea |
| **Bacterium** | |
| *Salmonella typhi* | Typhoid fever |
| *Salmonella paratyphi* | Paratyphoid fever |
| Other salmonellae | Gastroenteritis |
| *Shigella* species | Bacillary dysentery |
| *Vibrio cholerae* | Cholera |
| Other vibrios | Diarrhea |
| *Yersinia enterocolitica* | Gastroenteritis |

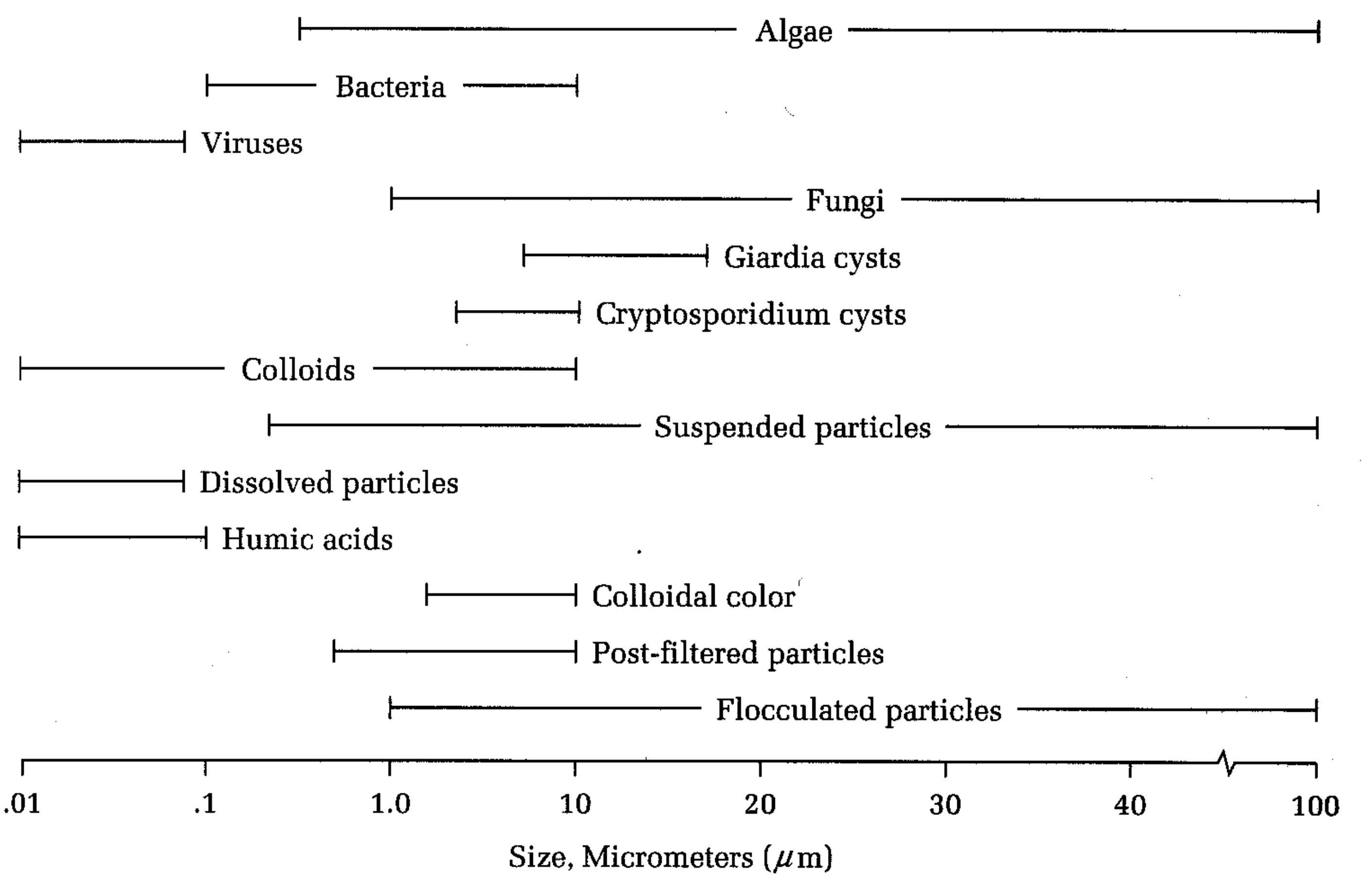
# Pathogenic Microorganisms

| | |
|---|---|
| **Protozoan** | |
| *Entamoeba histolytica* | Amoebic dysentery |
| *Giardia lamblia* | Diarrhea |
| *Cryptosporidium* species | Diarrhea |
| **Helminth** | |
| *Ancylostoma duodenale* (hookworm) | Hookworm |
| *Ascaris lumbricoides* (roundworm) | Ascariasis |
| *Hymenolepis nana* (dwarf tapeworm) | Hymenolepiasis |
| *Necator americanus* (hookworm) | Hookworm |
| *Strongyloides stercoralis* (threadworm) | Strongyloidiasis |
| *Trichuris trichiura* (whipworm) | Trichuriasis |

*Source:* Hammer and Hammer, 1996.

Q: Can you list sources which might give you exposure of pathogenic microorganisms?

# Sizes of Microorganisms and Other Particles *(size influences removal through filtration method)*



# Inorganic Pollutants

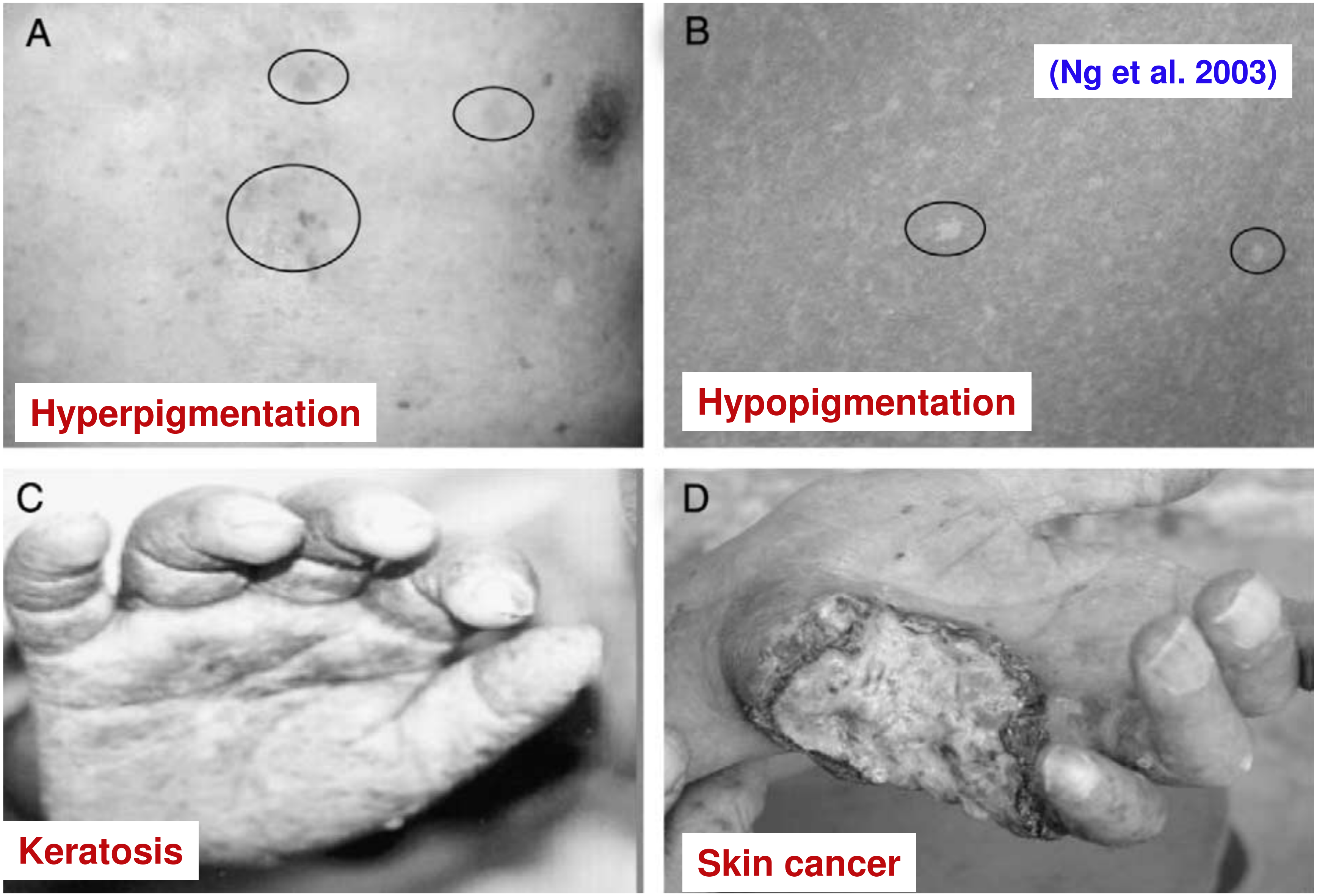
- Heavy Metals
- Arsenic
- Nitrates
- chromium
- Asbestos
- Other?

Effect =f(valency type, concentration)

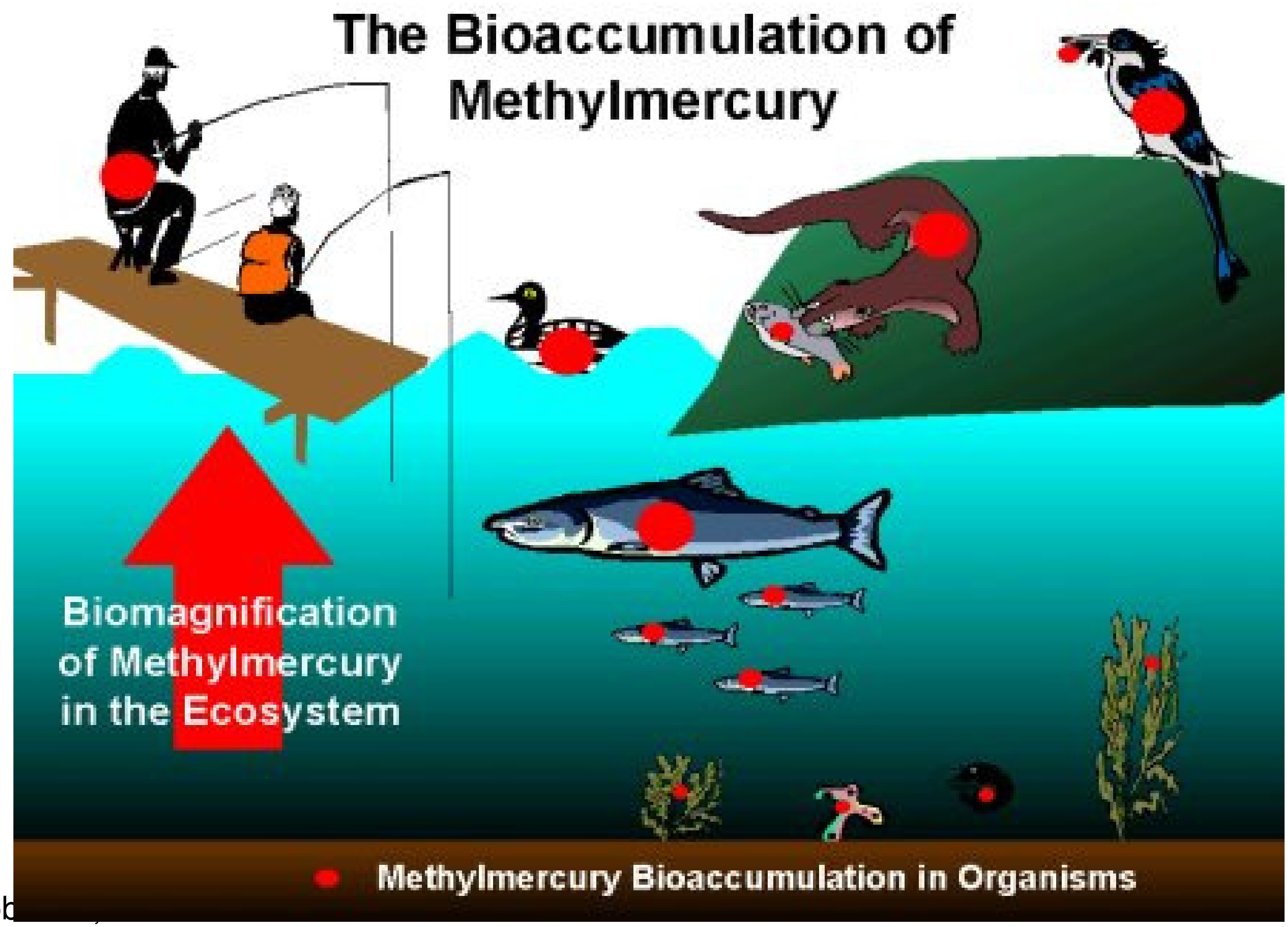
For example: toxic effects of arsenate(AsIV)) and arsenite (As(III)) might be different.

Q: Can you list sources which might give you exposure of these inorganic pollutants?

# Arsenic


A
B
(Ng et al. 2003)
Hyperpigmentation
Hypopigmentation
C
D
Keratosis
Skin cancer

# Mercury in water and then exposure to human beings through fish consumption



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# Pharmaceutical compounds

RESEARCH ARTICLE

## Antibiotics and antibiotic-resistant bac waters associated with a hospital in Ujj

Vishal Diwan*[1,2], Ashok J Tamhankar[3,4], Rakesh K Khandal[5], Shanta Sen[5], Manjeet Aggarw
Rama V Iyer[6], Karin Sundblad-Tonderski[7] and Cecilia Stålsby- Lundborg[1]

Available online at www.sciencedirect.com
ScienceDirect
Journal of Hazardous Materials 148 (2007) 751–755
www.else

Short communication

## Effluent from drug manufactures contains extremely high levels of pharmaceuticals

D.G. Joakim Larsson[a,*], Cecilia de Pedro[a], Nicklas Paxeus[b]

Contents lists available at ScienceDirect
Ecotoxicology and Environmental Safety
journal homepage: www.elsevier.com/locate/ecoenv

## Mutagenicity and genotoxicity of tannery effluents used for irrigation at Kanpur, India

Mohammad Zubair Alam[a,*], Shamim Ahm

Contents lists available
Food and Chemic
journal homepage: www.elsevie

## Sperm motility in the fishes of pesticide exposed and from polluted rivers of Gomti and Ganga of north India

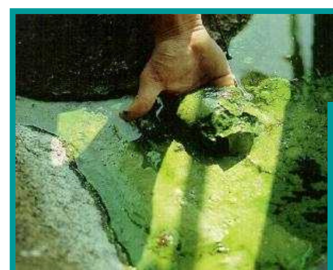
Pratap B. Singh *, Vikash Sahu, Vandana Singh, Santosh K. Nigam, Hement K. Singh
Department of Zoology, Tilak Dhari College, Jaunpur 222002, India

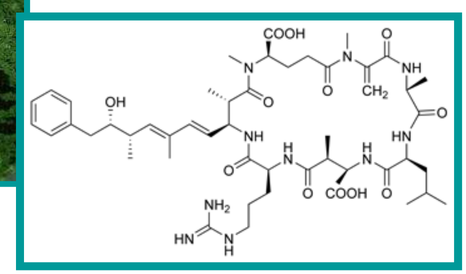
# Pesticides (hydrophobic organic compounds)

- **Organochlorine Insecticides:** were commonly used in the past (e.g. DDT and chlordane).
- **Organophosphate Pesticides:** most are insecticides, some are very poisonous (they were used in World War II as nerve agents)
- **Carbamate Pesticides:** affect the nervous system
- **Pyrethroid Pesticides:** were developed as a synthetic version of the naturally occurring pesticide pyrethrin, which is found in chrysanthemums

# Other Organic Pollutants

- Fertilizers
- Surfactants
- Explosives, propellants
- Chlorination By-Products (e.g. trihalomethanes)
- Antibiotics
- Pharmaceuticals
- Personal care products
- Cyanobacterial toxins
- nanomaterials





Microcystin-LR
(hepatotoxin)

# Excess Nutrients

- Nitrogen and phosphorus are nutrients required by all living organisms. They are considered pollutants when they are in excess.
- Excessive nutrients often lead to large growths of algae which in turn become oxygen-demanding material whey they die and settle.

# Excess Nutrients

$$106\ CO_2 + 16\ NO_3^- + HPO_4^{2-} + 122\ H_2O \rightarrow C_{106}H_{263}O_{110}N_{16}P + 138\ O_2$$

algae

$$\text{Algae} + O_2 \Rightarrow CO_2 + H_2O + NH_3$$

Nitrogen and phosphorus are typically the limiting factors

# Phosphorus

- Phosphorus is typically the limiting nutrient in lakes, and algae growth is linked to phosphorus inputs.
- P Sources
  - fertilizers
  - detergents
  - wastewater
- P can exist in a variety of chemical forms

# Nitrogen

- Nitrogen is often the limiting nutrient in ocean waters and some streams
- Nitrogen can exist in numerous forms, but nitrate ($NO_3^-$), nitrite ($NO_2^-$), ammonia ($NH_3$) are most commonly measured
- Sources are primarily from fertilizers and acid deposition

# Factors Controlling Eutrophication

- Stoichiometry of photosysnthesis (C,N,P, O & H)

$$106\ CO_2 + 16\ NO_3^- + HPO_4^{2-} + 122\ H_2O \rightarrow C_{106}H_{263}O_{110}N_{16}P + 138\ O_2$$

$$\frac{N}{P} = \frac{16 \times 14}{1 \times 31} = 7.2$$

It takes ~ 7 times more N than P to produce a given mass of algae

- *Liebig's law of the minimum* – growth will be limited by the availability of the nutrient that is least available relative to the need
- Most fresh water systems are phosphorus limited

# Salts

- Dissolved solids, or salts, may be present as any number of ions
  - cations: $Na^+$, $K^+$, $Mg^{2+}$, $Ca^{2+}$
  - anions: $Cl^-$, $SO_4^{2-}$, $HCO_3^-$
- Typically measures as *total dissolved solids* (TDS)
- Water classification
  - freshwater <1500 mg/L TDS
  - brackish water 1500 – 5000 mg/L
  - saline water >5000 mg/L
  - sea water 30-34 g/L

# Salts

- Sources
  - industrial discharges
  - deicing
  - evaporative losses
  - minerals
  - sea water intrusion
- Effects
  - natural fresh water population threatened
  - limits use for drinking
  - crop damage/soil poisoning (cannot use for irrigation)

# Suspended Solids

- Organic and inorganic particles in water are termed <u>suspended solids</u>
- May be distinguished from <u>colloids</u>, particles that do not settle readily

- Sources
  - storm water
  - wastes
  - erosion

- Problems
  - sedimentation
  - may exert oxygen demand
  - primary transport mechanism for many metals, organics and pathogens
  - aesthetic
  - complicates drinking water treatment

# Oxygen-Demanding Wastes

- When <u>organic substances</u> are broken down in water, oxygen is consumed

$$\text{organic C} + O_2 \rightarrow CO_2$$

- For example:

$$CH_3COOH + 2O_2 \Rightarrow 2CO_2 + 2H_2O$$

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

# Oxygen-Demanding Wastes

- High oxygen levels necessary for healthy stream ecology.
- For example:
  - trout require 5-8 mg/L dissolved oxygen (DO)
  - carp require 3 mg/L DO

# Oxygen Demanding Wastes- measurement/estimation

- Estimated stoichiometrically by theoretical oxygen demand (ThOD)

- Measured by oxygen demand potential
  - biochemical oxygen demand (BOD)
  - Nitrogenous oxygen demand (NBOD)
  - chemical oxygen demand (COD)

# CVL100:Environmental Science(2-0-0)

## Lecture 3:
## Water Quality Parameters and Water Treatment

**Dr. Arun Kumar**

**(Tuesday and Friday)**

Email: arunku@civil.iitd.ac.in

Check IITD course email daily for information

भारतीय प्रौद्योगिकी संस्थान दिल्ली
Indian Institute of Technology Delhi
Hauz Khas, New Delhi-110016 INDIA

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  - chemical oxygen demand (COD)

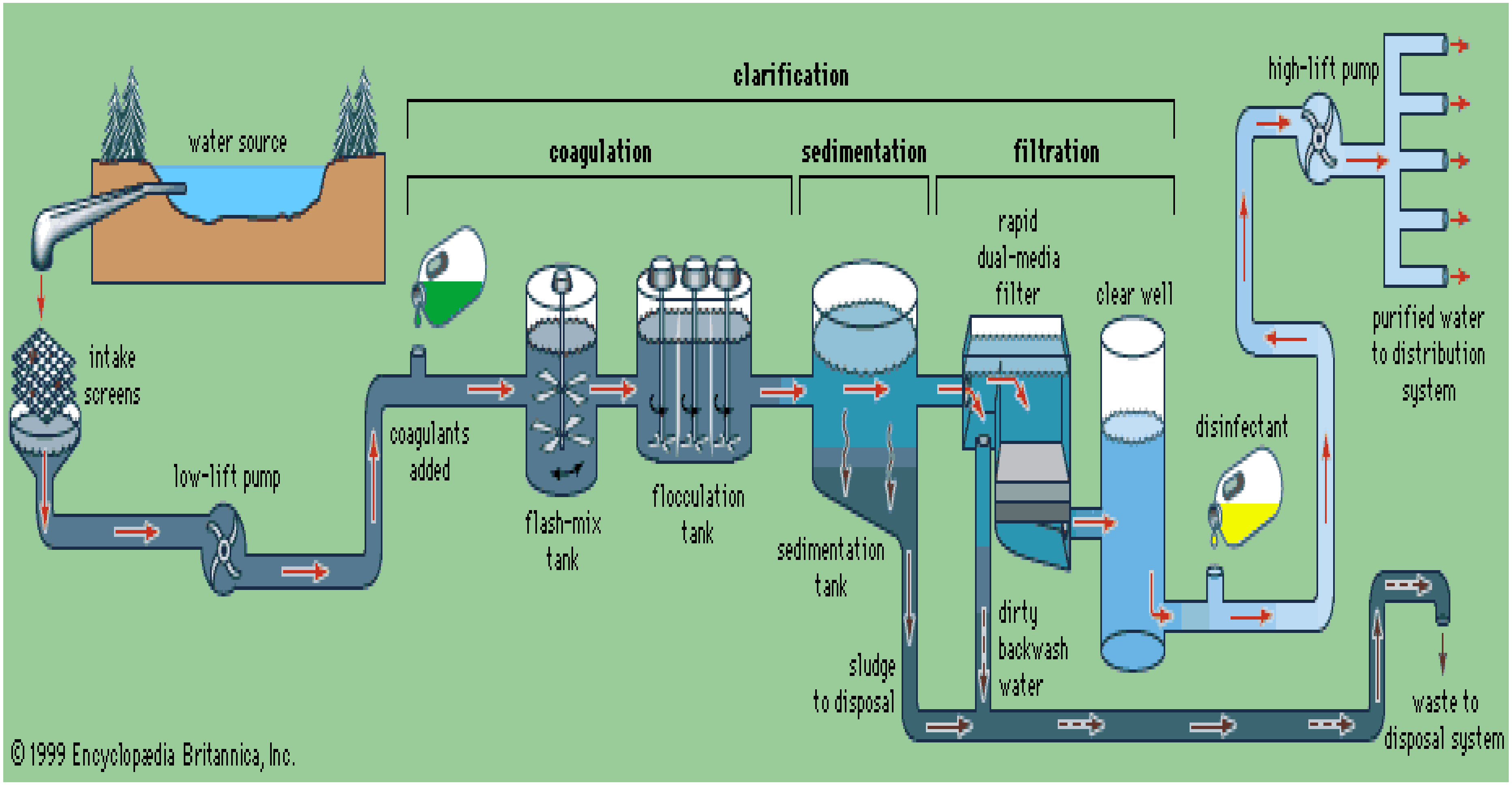
# Example: Calculation of ThOD

- reaction:

  $$CH_3COOH + 2O_2 \Rightarrow 2CO_2 + 2H_2O$$

- 1 mole/L acetic acid requires 2 moles/L of oxygen
- Theoretical oxygen demand= 2 moles/L * 32g/mole=64000mg/L oxygen

# Water Treatment



# Exercise 1

- Search name of treatment plant in your city and note names of processes and their sequence. Is it water treatment plant or wastewater treatment plant?

- Search names of 3 point-of-use system from market and note what contaminants it can remove and what is sequence of different units you can see. Draw it.

# Overall Constituents

- constituents:
  - Ions (calcium; arsenate; chromate ions;nitrate)(anions/cations)
  - Organic compounds (pesticides, pharmaceutical compounds,etc.)
  - Pathogens (viruses, if we have human fecal pollution)
  - Solids (depends if there is a fracturing in subsurface or solids in surface water)
  - Gases(methane, etc.)
  - nutrients

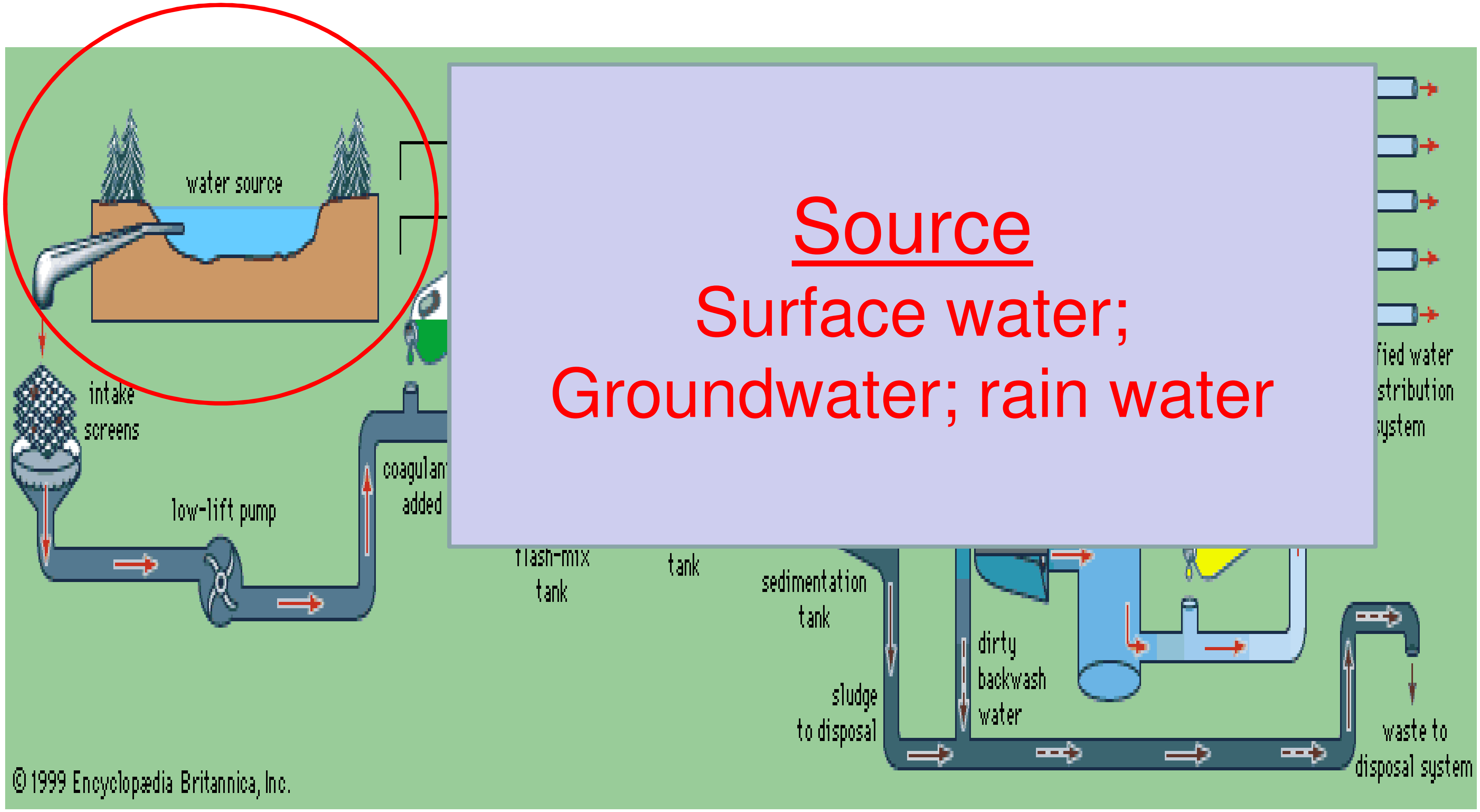
# Overall Parameters

| Constituents | Parameters |
|---|---|
| Ions | Hardness; alkalinity; acidity; conductivity |
| Solids | Turbidity; total solids; total suspended solids; dissolved solids; volatile solids; fixed solids |
| Organic compounds | ThOD; biological oxygen demand; chemical oxygen demand; total organic carbon |
| Nutrients | Ammonium ions; phosphates |
| pathogens | Indicators (bacterial; viral); pathogen |

# Water Treatment Plant Schematic

Objective: To introduce water treatment plant schematic and need for different unit processes

# Water: Source



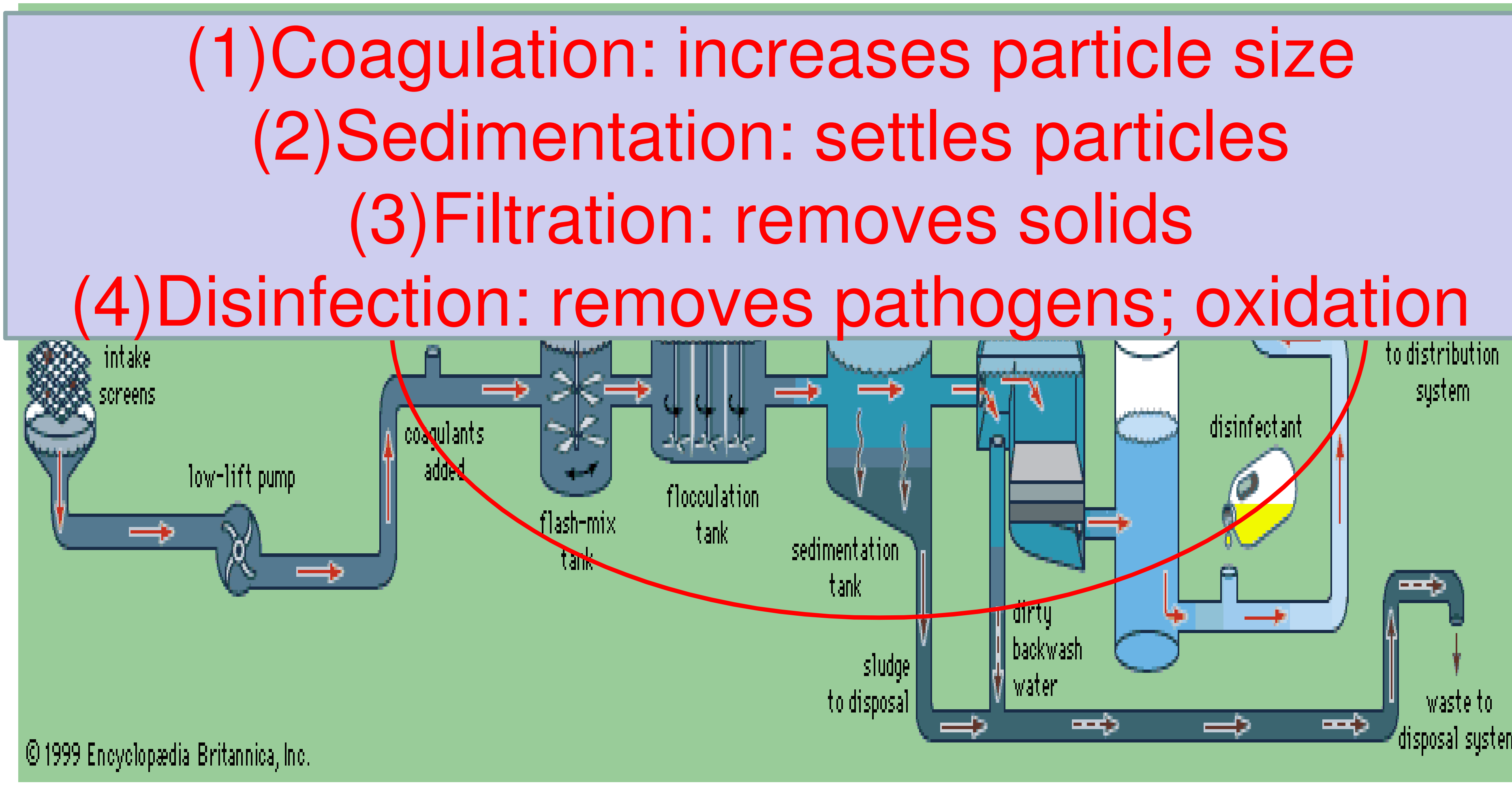

Source

Surface water;

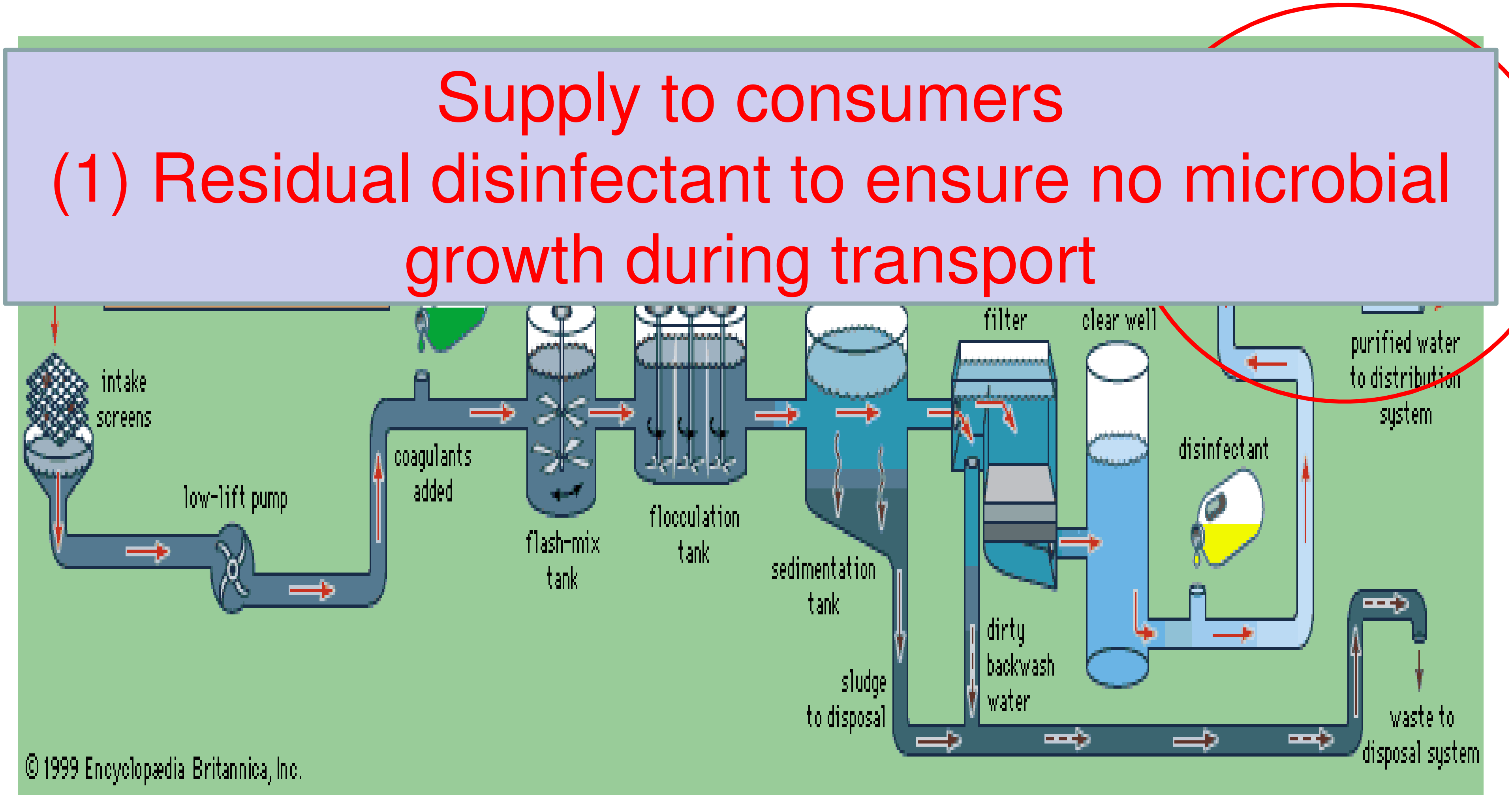
Groundwater; rain water

# Water: Treatment train of unit processes

(1)Coagulation: increases particle size
(2)Sedimentation: settles particles
(3)Filtration: removes solids
(4)Disinfection: removes pathogens; oxidation



# Water: Supply part




Supply to consumers

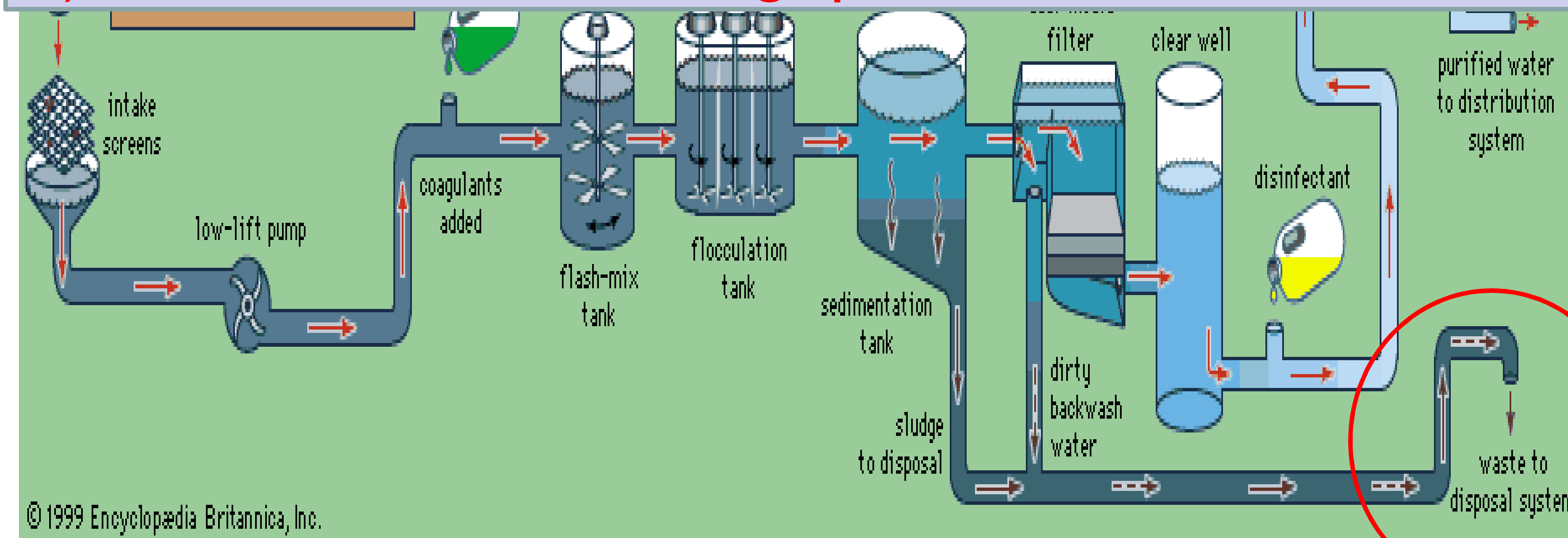
(1) Residual disinfectant to ensure no microbial growth during transport

# Water: Disposal part (solids waste)

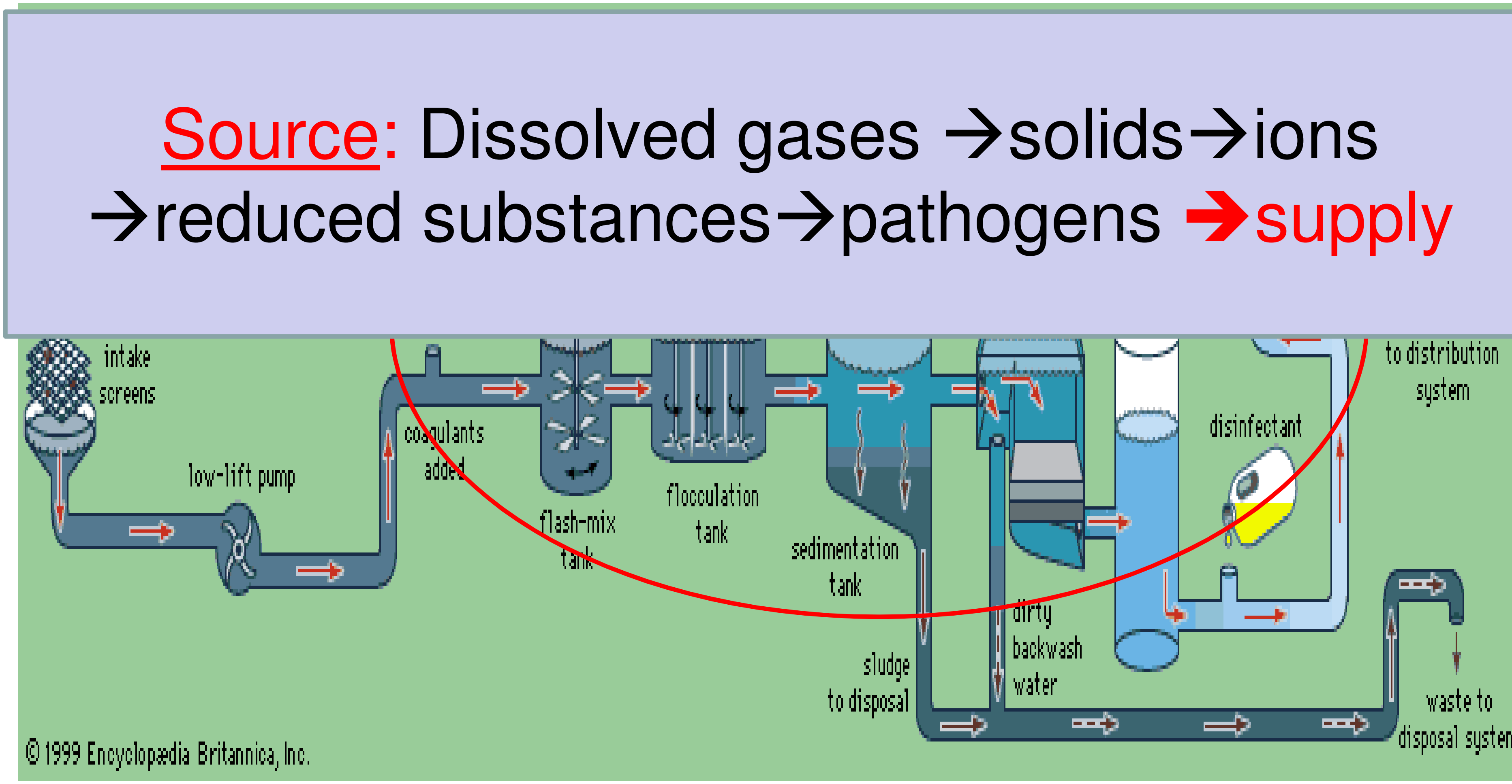
1)Chemical sludge

2) Disposal to municipal landfill

3)Reuse in brick making; pavement material, etc.



# Water: Order of constituents removal




Source: Dissolved gases →solids→ions →reduced substances→pathogens →supply



Arun Kumar
(arunku@civil.iitd.ac.in)

# Step 1. List water quality characteristics which need to be removed

- Nutrients
- Ions (arsenate; chromate ions; nitrate)
- Organic compounds (pesticides, etc.)
- Pathogens (viruses, if we have human fecal pollution)
- Solids (depends if there is a fracturing in subsurface)
- Gases(methane, etc.)

# Step 2. Identify unit(s) which can remove at least one type of contamination

- Ions (removal by: adsorption; coagulation-flocculation; chemical precipitation; bio-adsorption; membrane process)

# *Step 2 contd.*

- Organic compounds (degradation/removal by: oxidation; adsorption; biodegradation; reduction-oxidation; irradiation; membrane process)

## *Step 2 contd.*

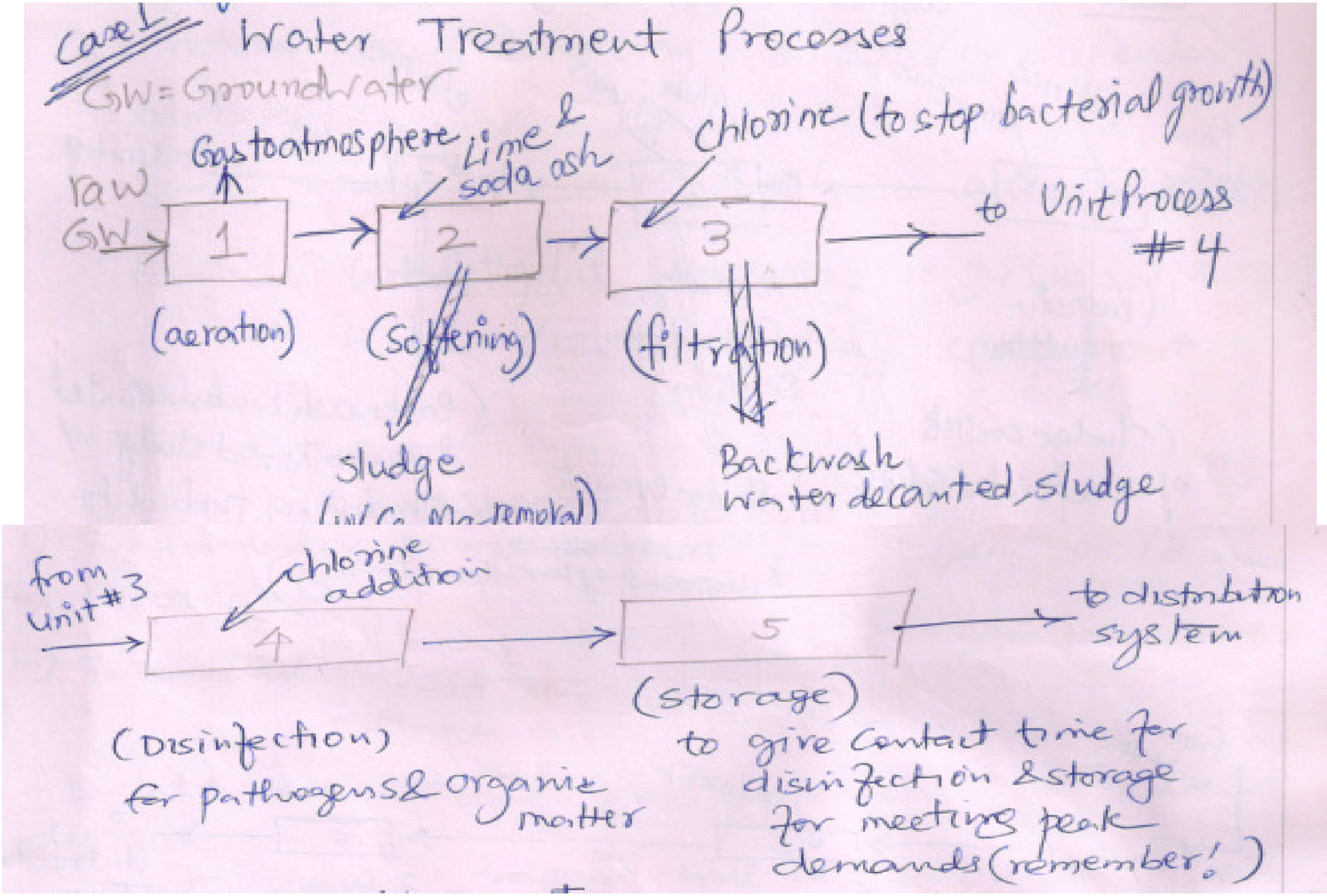
- Pathogens (killed by : adsorption; coagulation-flocculation; chemical precipitation; disinfection; boiling; irradiation; membrane process)

# *Step 2 contd.*

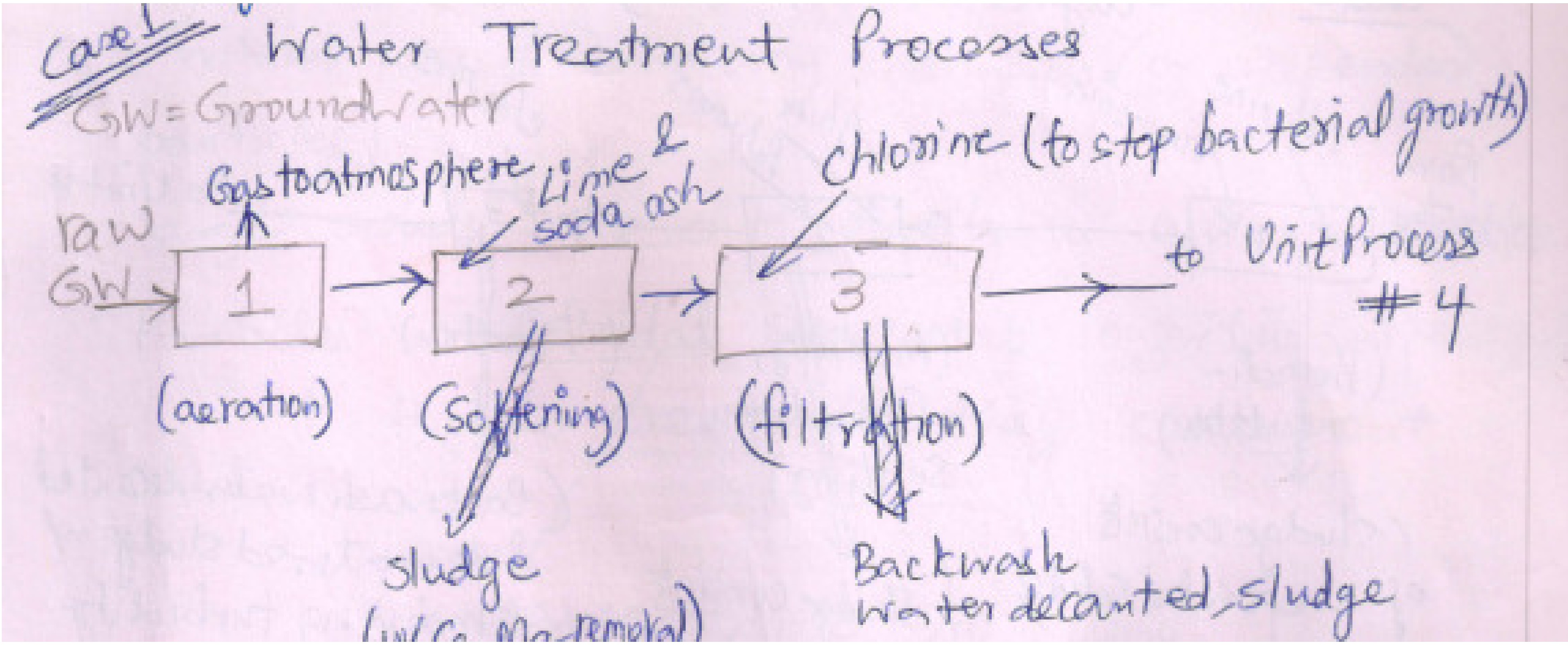
- Solids (removal by : settling; filtration; membrane process)

- Gases (removal by) : aeration; adsorption; solubilization)

# Case:Groundwater →produce drinking water



# Exercise: Groundwater →Drinking water




Name: constituents to be removed; unit processes; their role; their sequence; solid waste generation

# Treatment schematic (GW→ Potable drinking water)

- Raw Ground water → aeration chamber → Softening unit → Filtration with chlorination →Disinfection → Storage
- See sequence of units used
- Chemical is required to be added
- Water is treated
- Chemical sludge is produced

## Units used for (GW→ Potable drinking water

- Aeration chamber (to remove gases; using air)
- Softening unit (to remove cations; using softener and/or cation exchangers)

# Treatment schematic (GW→ Potable drinking water)

- Filtration with chlorination (to remove solids; to kill microbial growth on filter unit surface)

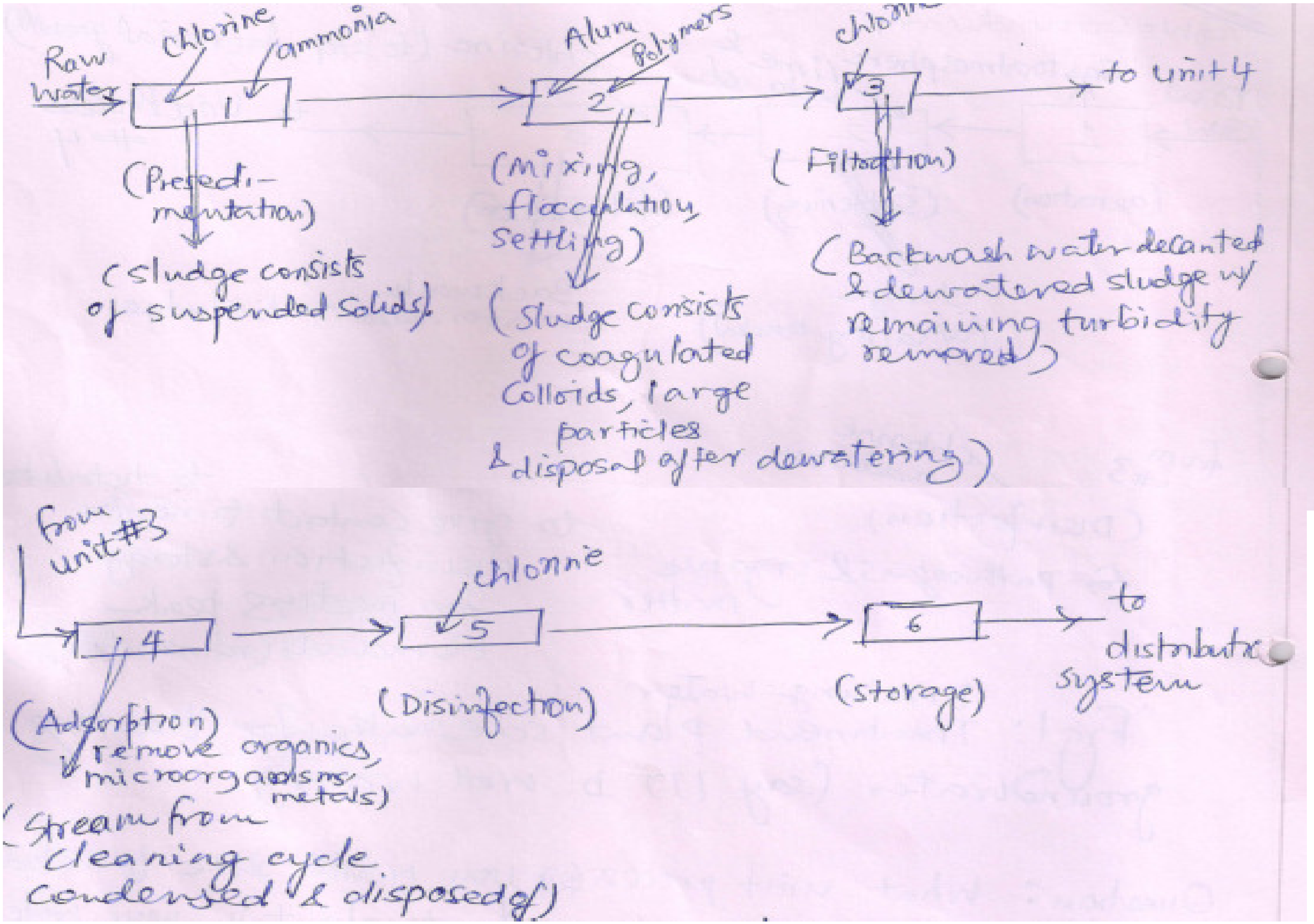
- Disinfection (to kill microorganisms before water is supplied for public consumption)

- Storage

# Exercise 2: Yamuna River Water $\rightarrow$produce drinking water

- Think for 5 minutes for two steps.
- Step 1: water quality characteristics determination
- Step 2: selection of units, their order

# Exercise 2: Yamuna River Water →Drinking water



## <u>INDIAN STANDARDS FOR DRINKING WATER</u>

| PARAMETER | DESIRABLE | REJECTION |
|---|---|---|
| Colour (Platinum-cobalt scale) | 5 | 25 |
| Odour | free | free |
| taste | agreeable | agreeable |
| Turbidity | 1NTU | 10NTU |
| pH | 7-8.5 | <7&>8.5 |
| Total hardness | 200mg/l | 600mg/l |
| Chlorides | 200mg/l | 1000mg/l |
| Residual chlorine | 0.2mg/l | 1.0mg/l |
| Total dissolved solids | 500mg/l | 2000mg/l |
| Sulphates | 200mg/l | 400mg/l |
| Nitrates | 45mg/l | 45mg/l |
| Alkalinity | 200mg/l | 600mg/l |
| Fluorides | 1.0mg/l | 1.5mg/l |
| Cyanides | 0.05mg/l | 0.05mg/l |
| BOD | Nil | >Nil |
| Pesticides | Nil | >Nil |
| Phenolic compounds | 0.001mg/l | 0.002mg/l |
| Anionic detergents | 0.2mg/l | 1.00mg/l |
| Mineral oil | 0.01mg/l | 0.03mg/l |
| As | 0.01mg/l | 0.05mg/l |
| Pb | 0.05mg/l | 0.05mg/l |
| Cd | 0.01mg/l | 0.01mg/l |
| $Cr^{+6}$ | 0.05mg/l | 0.05mg/l |
| Hg | 0.001mg/l | 0.001mg/l |
| Fe | 0.10mg/l | 1.00mg/l |
| Mg | 30.0mg/l | 150mg/l |
| Mn | 0.05mg/l | 0.05mg/l |
| Cu | 0.05mg/l | 1.5mg/l |
| MPN | 0/100ml | 1/100ml |

***The concentration of the Pollutants should not exceed the concentrations given above***

## INDIAN STANDARDS FOR DISCHARGE OF POLLUTANTS IN EFFLUENTS

1) Discharge into inland surface water.
2) Discharge into public sewer line
3) Discharge on land for irrigation
4) Discharge into ocean.

| PARAMETER | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Suspended solid | 100mg/l | 600mg/l | 200mg/l | - |
| Dissolved solids | 2100mg/l | - | 2100mg/l | - |
| pH | 5.5-9 | 5.5-9 | 5.5-9 | 5.5-9 |
| Temperature | not>5$^0$Cthan the receiving water | - | - | Not>5 $^0$C than the receiving water |
| Oil & greese | 10mg/l | 20mg/l | 10mg/l | 20mg/l |
| Free $NH_3$ | 5.0 | - | - | 5.0 |
| $BOD_{5d,20^0C}$ | 30 | 350 | 100 | 100 |
| COD | 250 | - | - | 250 |
| Arsenic | 0.20 | 0.20 | 0.20 | 0.20 |
| Hg | 0.01 | 0.01 | - | 0.01 |
| Pb | 0.01 | 1.0 | - | 2.0 |
| Cd | 2.0 | 1.0 | - | 2.0 |
| $Cr^{+6}$ | 0.1 | 2.0 | - | 1.0 |
| Total Cr | 2.0 | 2.0 | - | 2.0 |
| Cu | 3.0 | 3.0 | - | 3.0 |
| Zn | 5.0 | 15 | - | 15 |
| Ni | 3.0 | 3.0 | - | 5.0 |
| Cyanide | 0.2 | 2.0 | 0.2 | 0.2 |
| Chlorides | 1000 | 1000 | 600 | - |
| Fluorides | 2.0 | 15 | - | 15 |
| Phosphates | 5.0 | - | - | - |
| Sulphates | 1000 | 1000 | 1000 | - |
| Sulphides | 2.0 | - | - | 5.0 |
| Phenolic compounds | 1.0 | 5.0 | - | 5.0 |

Units: mg/litre except for pH

***The concentration of the Pollutants should not exceed the limits given above***

# CVL100:Environmental Science(2-0-0)

**Dr. Arun Kumar**

## Water Pollution and Treatment

Lec: Nov02nd and Nov3rd, 2021

# Treatment schematic (GW→ Potable drinking water)

- Raw Ground water → aeration chamber → Softening unit → Filtration with chlorination →Disinfection → Storage
- See sequence of units used
- Chemical is required to be added
- Water is treated
- Chemical sludge is produced

## Units used for (GW→ Potable drinking water

- Aeration chamber (to remove gases; using air)
- Softening unit (to remove cations; using softener and/or cation exchangers)

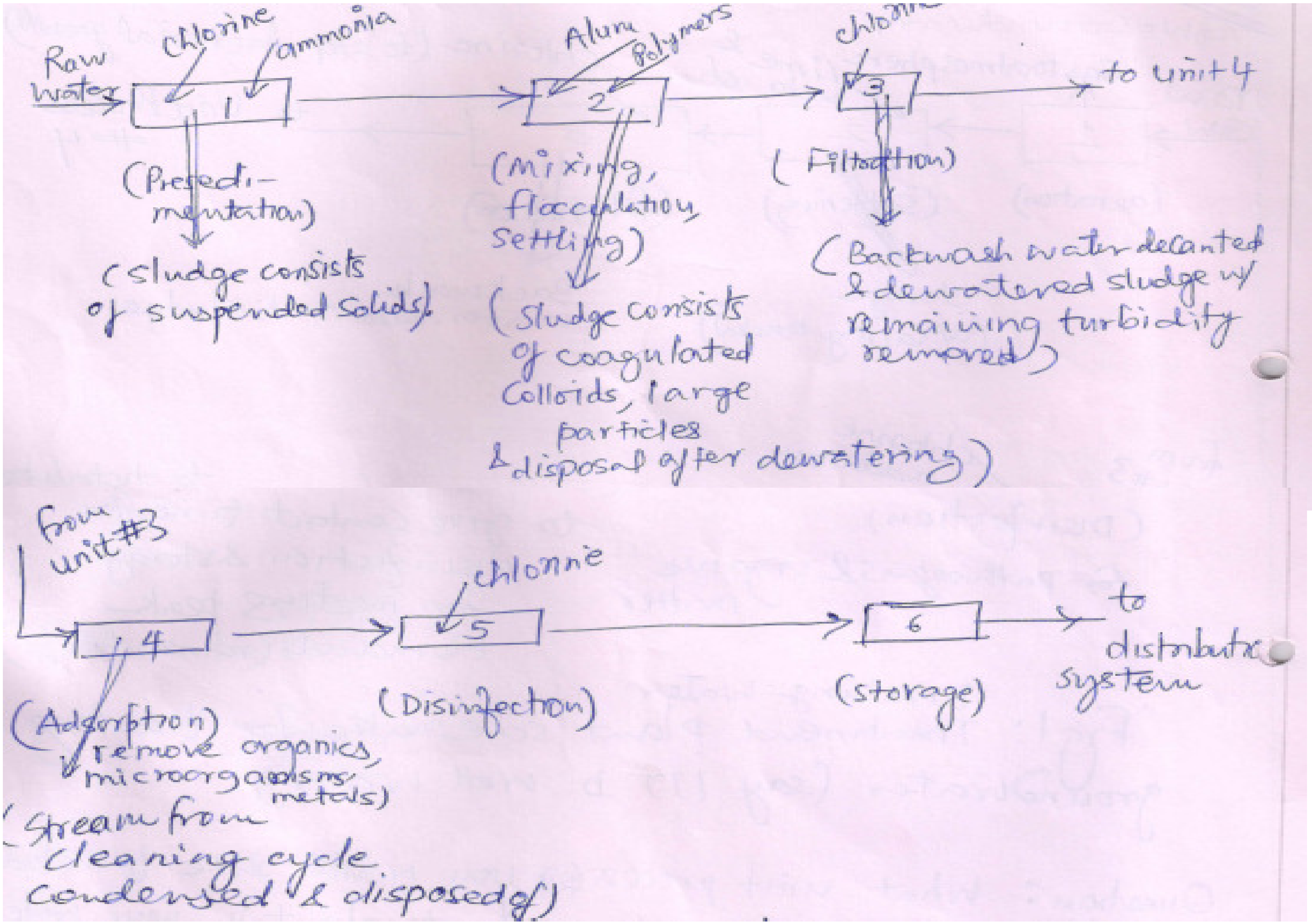
## Treatment schematic (GW→ Potable drinking water)

- Filtration with chlorination (to remove solids; to kill microbial growth on filter unit surface)
- Disinfection (to kill microorganisms before water is supplied for public consumption)
- Storage

# Exercise 2: Yamuna River Water →produce drinking water

- Think for 5 minutes for two steps.
- Step 1: water quality characteristics determination
- Step 2: selection of units, their order

# Exercise 2: Yamuna River Water →Drinking water



# *Exercise 2: Yamuna River Water →produce drinking water*

- Pre-sedimentation → coagulation-flocculation-sedimentation → filtration → adsorption → disinfection→storage/supply
- Soldis removal and ion removal → organic matter removal and ion removal and some pathogen removal→ pathogen removal→ supply
- See the importance of sequence of consitituents removal

- Sludge from steps: Pre-sedimentation, sedimentation, filtration (exhausted media), adsorption (exhausted media)

# Indian Standards for Drinking Water

## INDIAN STANDARDS FOR DRINKING WATER

| PARAMETER | DESIRABLE | REJECTION |
|---|---|---|
| Colour (Platinum-cobalt scale) | 5 | 25 |
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| Mn | 0.05mg/1 | 0.05mg/1 |
| Cu | 0.05mg/1 | 1.5mg/1 |
| MPN | 0/100ml | 1/100ml |

*The concentration of the Pollutants should not exceed the concentrations*

*Courtesy: Prof. B.J.Alappat, IIT Delhi*

# Example 2

*(read the paper from course moodle area)*

SEVIER

Science of the Total Environment 329 (2004) 99–113

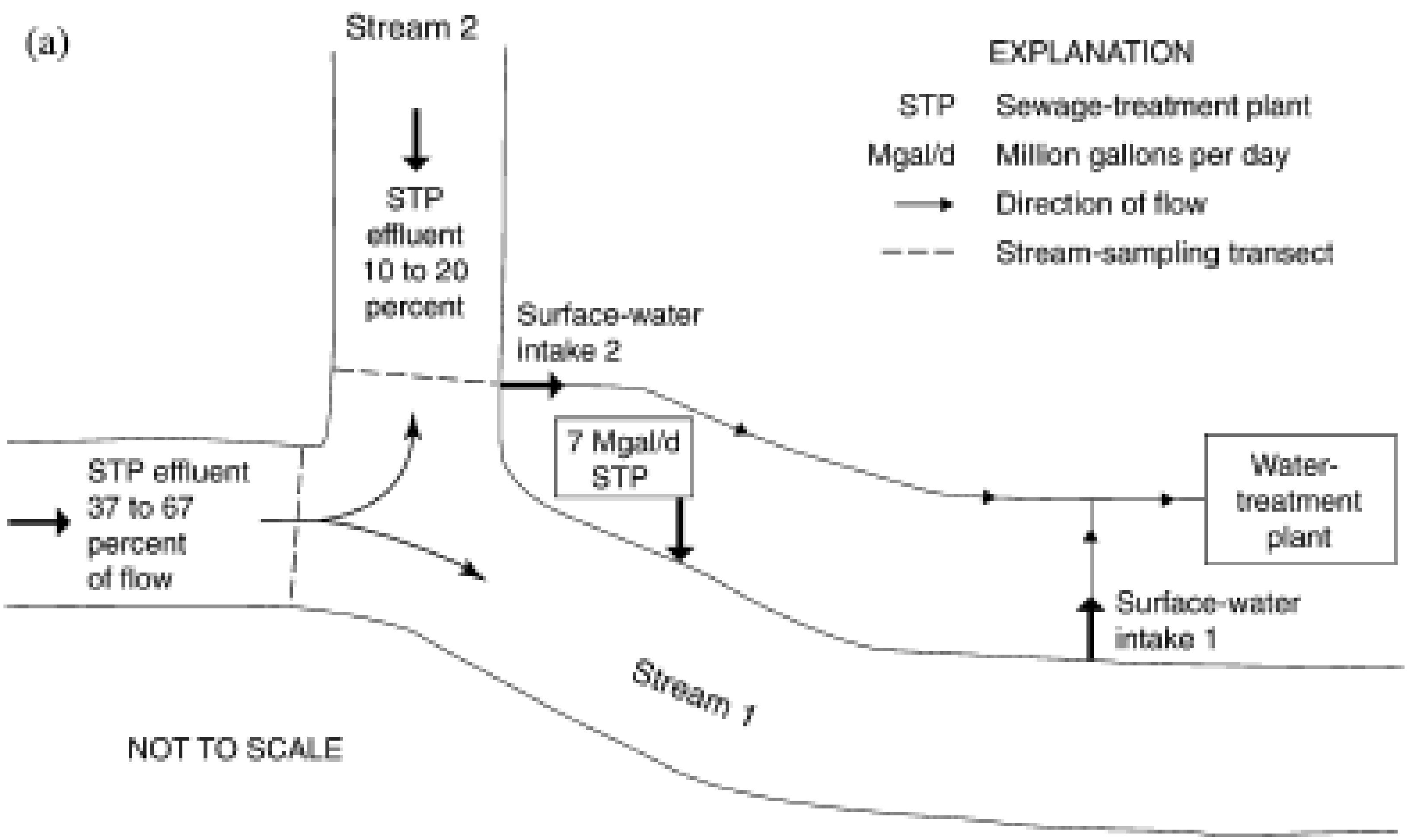
www.elsevier.com/locate/scitotenv

## Persistence of pharmaceutical compounds and other organic wastewater contaminants in a conventional drinking-water-treatment plant

Paul E. Stackelberg[a,*], Edward T. Furlong[b], Michael T. Meyer[c], Steven D. Zaugg[b], Alden K. Henderson[d], Dori B. Reissman[d]

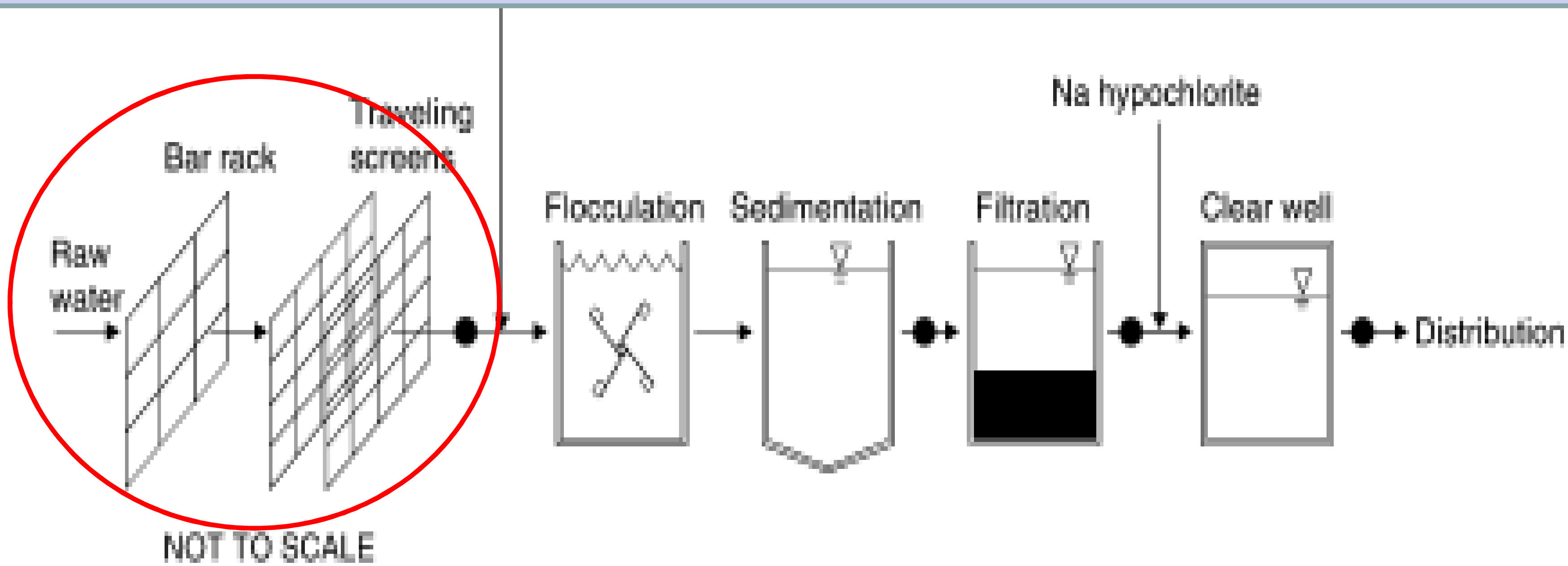
[a]*US Geological Survey, 810 Bear Tavern Road, West Trenton, NJ 08628, USA*
[b]*US Geological Survey, Box 25046, MS 407, Denver, CO 80225-0046, USA*
[c]*US Geological Survey, 4500 SW 40th Avenue, Ocala, FL 34474, USA*
[d]*Centers for Disease Control and Prevention, 1600 Clifton Road, MS E23, Atlanta, GA 30333, USA*

Accepted 18 March 2004

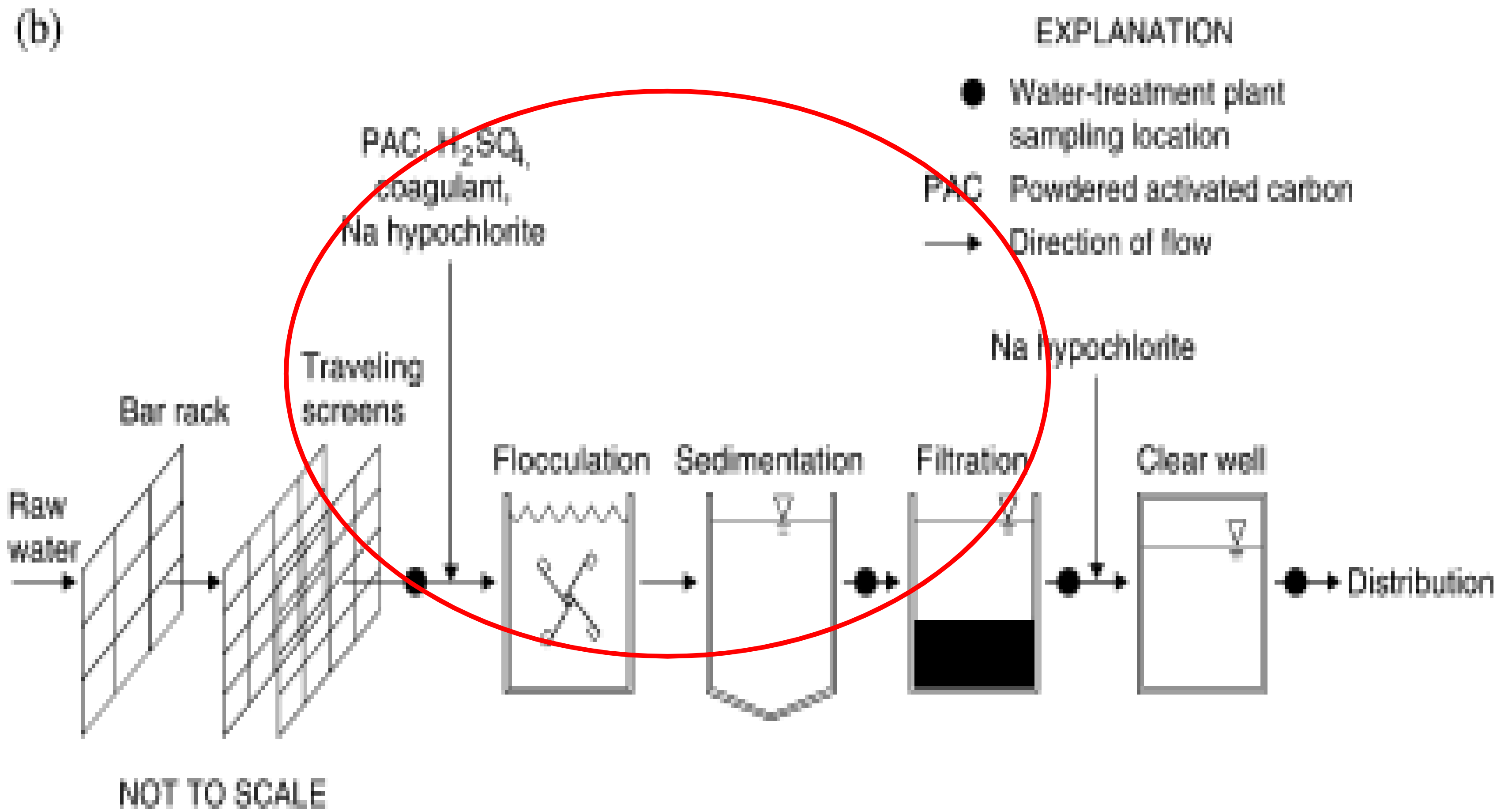

(a)
Stream 2
STP effluent 10 to 20 percent
EXPLANATION
STP Sewage-treatment plant
Mgal/d Million gallons per day
Direction of flow
Stream-sampling transect
Surface-water intake 2
7 Mgal/d STP
STP effluent 37 to 67 percent of flow
Water-treatment plant
Surface-water intake 1
Stream 1
NOT TO SCALE

*Stackelberg et al. 2004*

To remove large materials and solids

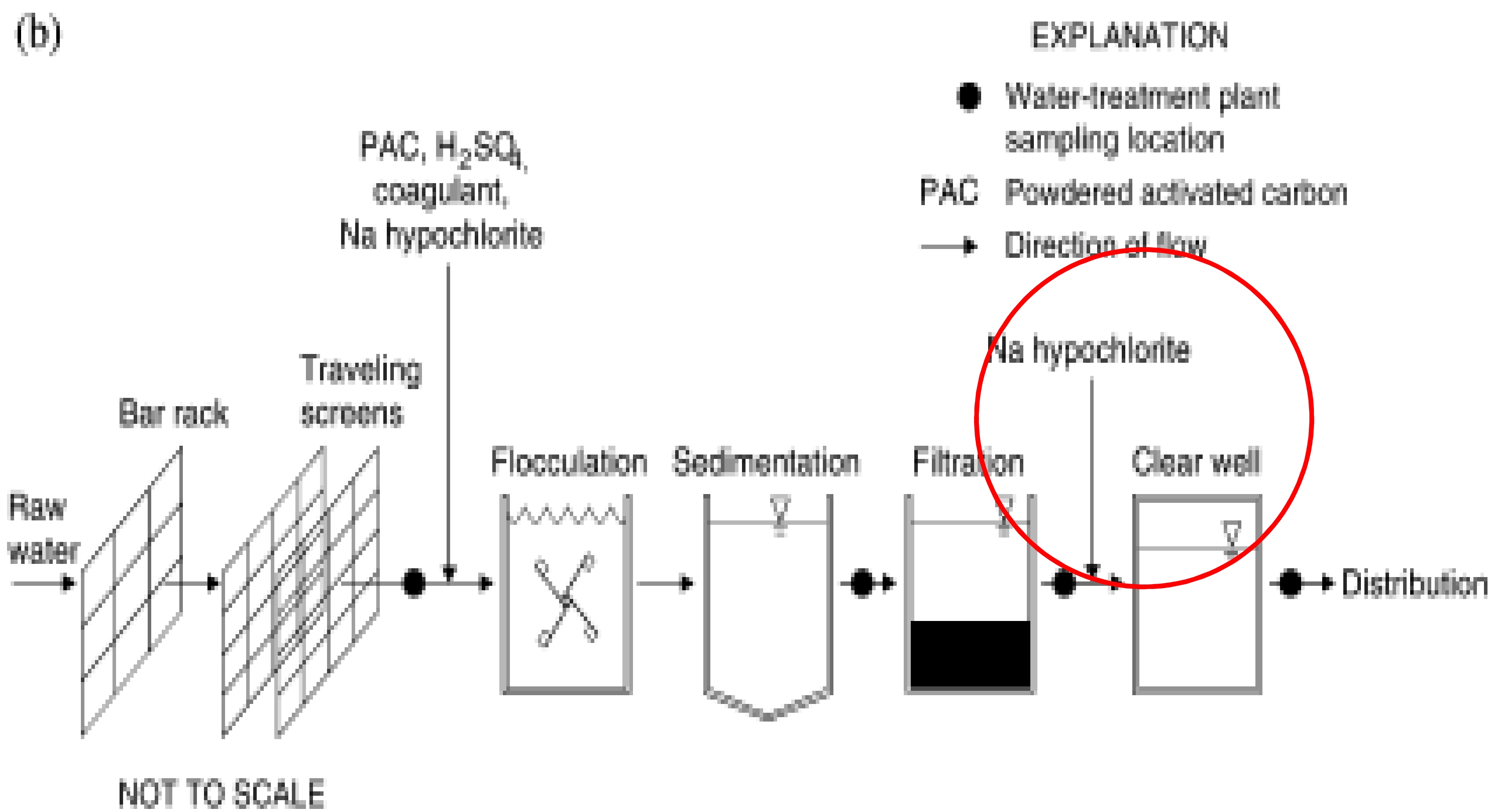


# To remove solids; coagulants addition

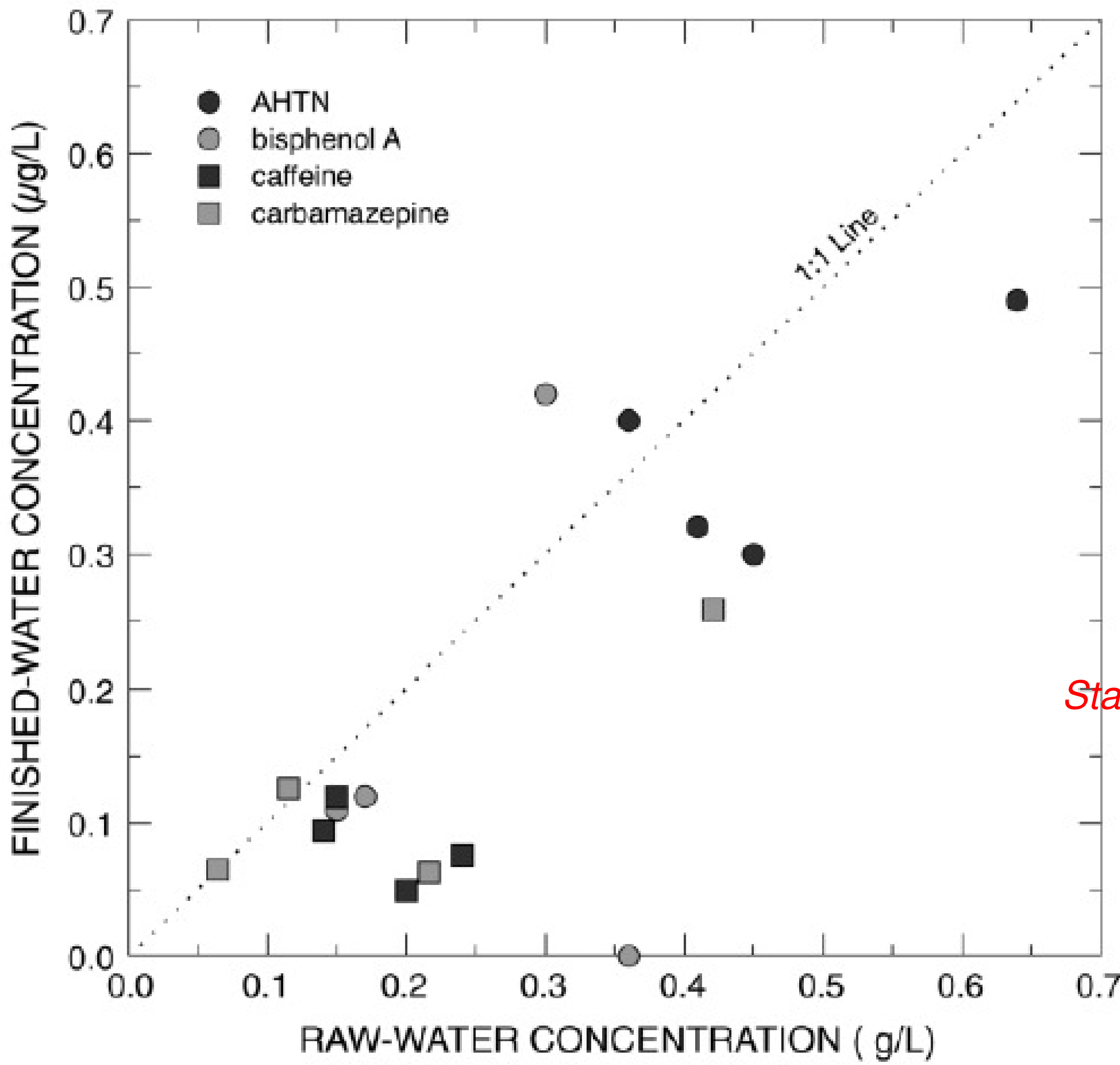



*Stackelberg et al. 2004*

# To remove pathogens; oxidize reduced substances also



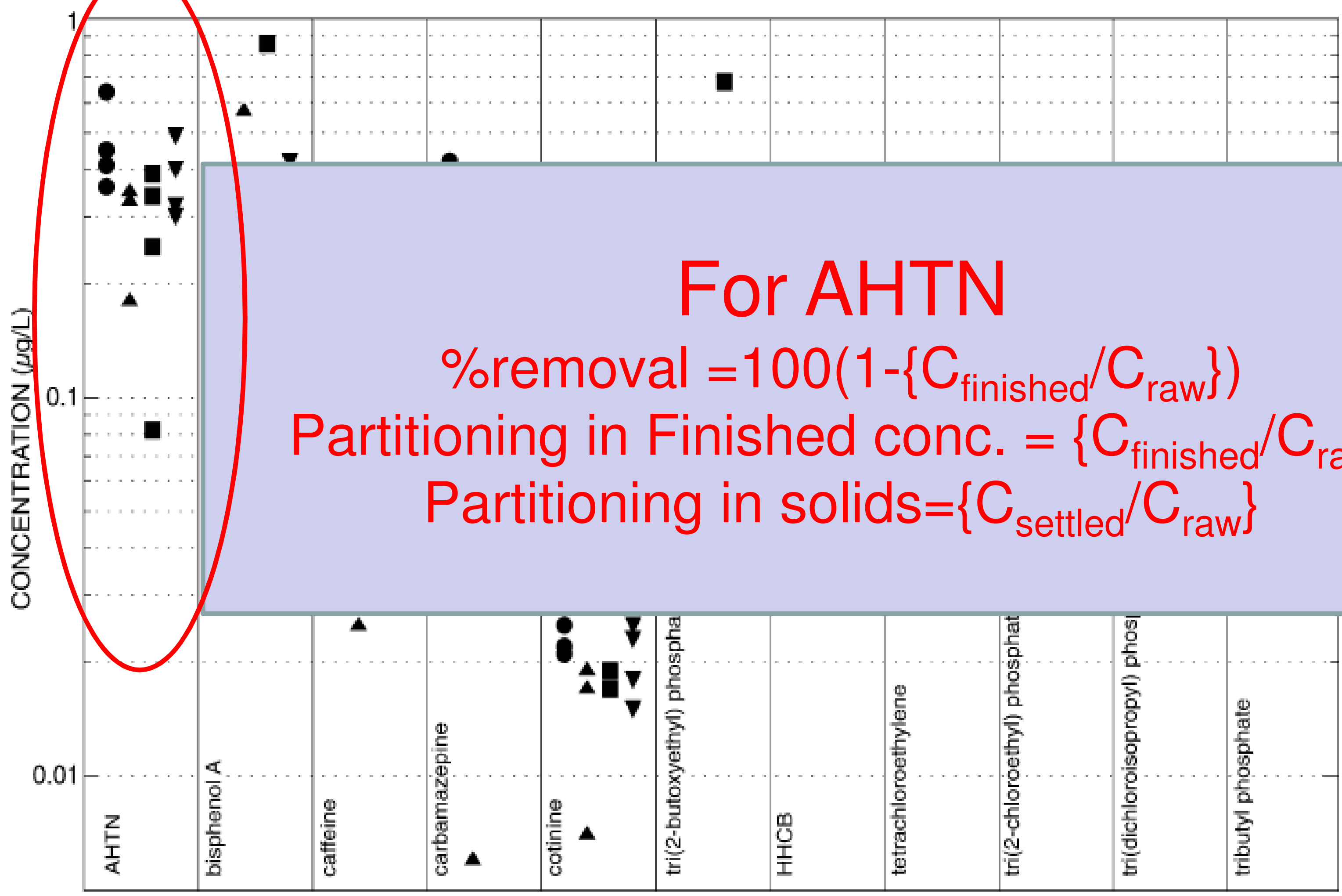

*Stackelberg et al. 2004*




Stackelberg et al. 2004

Fig. 4. Concentrations of selected compounds in samples of raw and finished water.

# Calculate: (a)% removal; (b)partitioning of initial compounds in finished water and in solids




## For AHTN

$\%\text{removal} = 100(1-\{C_{finished}/C_{raw}\})$

Partitioning in Finished conc. = $\{C_{finished}/C_{raw}\}$

Partitioning in solids $=\{C_{settled}/C_{raw}\}$

Fig. 3. Concentrations of selected compounds in samples of raw (circles), settled (triangles), filtered (squares), and finished (inverted triangles) water.

# Exercise 2

Say I am considering volunteering for a one-way trip to Mars *[I can send weekly updates, though!]*, which requires my commitment on optimizing/reducing my daily water consumption. One option is to use treated wastewater for my non-drinking activities. Which two parameters do you suggest me to monitor before I accept the condition and why?

# Exercise 3

Suppose IIT Delhi water has suspended solids, organic matter, microorganisms, hardness, and dissolved $CO_2$, which are problematic constituents. Other dissolved constituents are below problem levels. Draw a schematic diagram of a treatment plant that will render this water potable. Identify each unit and show points of chemical addition with their names.

# CVL100:Environmental Science(2-0-0)

**Dr. Arun Kumar**

## Water Treatment-Mass Balance

Nov 9th and 10th, 2021

भारतीय प्रौद्योगिकी संस्थान दिल्ली
Indian Institute of Technology Delhi
Hauz Khas, New Delhi-110016 INDIA

# Re-cap

- Overall removal of pharmaceutical compounds in water treatment plants
  - Example approach

# Understanding partitioning of contaminant in water and solids

- Hydrophilic compounds (more affinity to water)
- Hydrophobic compounds (less affinity to water)
- Octanol-water partition coefficient

# Example 1

*(read the paper from course web area)*

## Meta-Analysis of Mass Balances Examining Chemical Fate during Wastewater Treatment

JOCHEN HEIDLER[†] AND ROLF U. HALDEN[*,†,‡]

*Johns Hopkins University Center for Water and Health, Department of Environmental Health Sciences, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, Maryland 21205, and Center for Environmental Biotechnology at The Biodesign Institute, Arizona State University, Tempe, Arizona 85287*

*Received December 3, 2007. Revised manuscript received June 11, 2008. Accepted June 11, 2008.*

Mass balances are an instructive means for investigating the fate of chemicals during wastewater treatment. In addition

composition of biosolids is important because us
sewage sludge as fertilizer in agriculture, f

ere to search

TABLE 1. Chemical Abstract Service (CAS) Registry Number and Logarithmic 1-Octanol−Water Partitioning and Organic Carbon Normalized Sorption Coefficients ($K_{OW}$ and $K_{OC}$, respectively) of Organic Wastewater Compounds Examined in This Review

| compound | CAS no. | log $K_{OW}$ | log $K_{OC}$ |
|---|---|---|---|
| | Estrogens | | |
| estrone | 53-16-7 | 3.13 (*31*) | 3.59 (*29*) |
| 17$\beta$-estradiol | 50-28-2 | 4.01 (*31*) | 3.41 (*29*) |
| 17$\alpha$-ethinylestradiol | 57-63-6 | 3.67 (*31*) | 3.53 (*29*) |
| | Antimicrobials | | |
| triclosan | 3380-34-5 | 4.8 (*4*) | 4.1[a] |
| triclocarban | 101-20-2 | 4.9 (*4*) | 4.5[a] |
| sulfamethoxazole | 723-46-6 | 0.5[b] | 2.77 (*29*) |
| trimethoprim | 738-70-5 | 0.91(*31*) | 2.7[c] |
| clarithromycin | 81103-11-9 | 3.16 (*33*) | 2.8[c] |
| ciprofloxacin | 85721-33-1 | −0.001[b] | 4.23 (*29*) |
| norfloxacin | 70458-96-7 | −0.3[b] | 4.6[d] |
| | Prescription Drugs | | |
| carbamazepine | 298-46-4 | 2.45 (*30*) | 2.87 (*29*) |
| | Fragrances | | |
| galaxolide (HHCB) | 1222-05-5 | 5.9 (*34*) | 5.22 (*29*) |
| tonalide (AHTN) | 21145-77-7 | 5.7 (*34*) | 5.36 (*29*) |
| | Surfactants and Industrial Chemicals | | |
| nonylphenol | 104-40-5 | 5.76 (*35*) | 4.52 (*32*) |
| perfluorooctanesulfonate (PFOS) | 1763-23-1[e] | 6.3[b] | 2.6 (*28*) |
| perfluorodecanesulfonate (PFDS) | 335-77-3[e] | 8.2[b] | 3.5 (*28*) |

A)Order antimicrobials and estrogens in chance of affinity to solids
B)Out of these, which will be found more in solids than in water?

**TABLE 2. Concentrations of Compounds Reported in Wastewater Influent, Effluent, and Digested Sludge as Well as Their Corresponding Aqueous-Phase Removal Efficiency (Φ)[a]**

| compound | reference | influent (ng/L) | effluent (ng/L) | digested sludge (μg/kg) | Φ (%) | per-capita mass input (μg/person/day) |
|---|---|---|---|---|---|---|
| | | | **Estrogens** | | | |
| estrone | 9 | 65.7 | <1[c] | 25.2 | >99 | 15 |
| | 10 | 54.8 | <0.1[b,c] | 14.3[d] | 100 | 33 |
| 17β-estradiol | 9 | 15.8 | <1 [c] | 5.1 | >94 | 4 |
| | 10 | 22.0 | <0.1[b,c] | 0.57[d] | 100 | 14 |
| 17α-ethinylestradiol | 9 | 8.2 | <1 [c] | <1.5[c] | >88 | 2 |
| | 10 | <5.0[c] | <0.1[b,c] | 0.61[d] | >98 | NA |
| | | | **Antimicrobials** | | | |
| triclosan | 14 | 1200 | 51 | 1200 | 96 | 620 |
| | 15 | 4.700 | 70 | 30000 | 98 | 2490 |
| triclocarban | 16 | 6100 | 170 | 51000 | 97 | 2870 |
| sulfamethoxazole | 11 | 1700[e,h] (1400[g]) | 400[e,h] (10[g]) | ND | 77 | 450 |
| trimethoprim | 11 | 290[e] | 70[e] | <0.1[c] | 76 | 100 |
| trimethoprim | 12 | 1373[f] | 1424[f] | ND | −4 | 500 |
| clarithromycin | 11 | 380[e] | 240[e] | 0.7 | 37 | 180 |
| ciprofloxacin | 12 | 220[f] | 48[f] | 5970[f] | 78 | 480 |
| ciprofloxacin | 13 | 427 | 71 | 3100 | 83 | 340 |
| norfloxacin | 12 | 293[f] | 58[f] | 6970[f] | 80 | 610 |
| norfloxacin | 13 | 431 | 51 | 2,900[f] | 88 | 350 |

A)Which estrogen is removed more?
B) What does it say about their fate in water and in solids?
C) Compare maximum allowable values of these things with numbers here? Do they comply or not?
D) If not, how much removal do we have to further do?

- See previous table
- Provides information on conc. Of compons one can get in influent and in effluent
- Which compound has a higher chance of detection in liquid phase? In solid phase?
- This data is useful in deciding  what to monitor in liquid line and in solid line

TABLE 3. Summary of Mass Balance Studies Indicating the Mass Fraction of Individual Compounds Found in Effluent or Digested Sludge or Lost from the System, Relative to the Total Loading (100%) Entering the Plant in Influent

| compound | ref | mass in effluent (%) | mass in processed sludge (%) | mass lost (%) | label in Figure *3* |
|---|---|---|---|---|---|
| | | Estrogens | | | |
| estrone + 17β-estradiol | *9* | <2 | 11 | 87 | 1 + 2 |
| | *10* | 12 | 4 | 84 | 3 + 4 |
| 17α-ethinylestradiol | *12* | <13 | <6 | >81 | 5 |
| Antimicrobials | | | | | |
| ciprofloxacn | *12* | 4 | 77 | 19 | 6 |
| | *13* | 12 | 83 | 5 | 7 |
| clarithromycin | *12* | 79 | <1 | >21 | 8 |
| norfloxacin*12* | *12* | 3 | 72 | 25 | 9 |
| | *13* | 8 | 75 | 17 | 10 |
| sulfamethoxazole | *11* | 38 | <0.2 | >62 | 11 |
| triclocarban | *16* | 3 | 76 | 21 | 12 |
| triclosan | *14* | 4 | 31 | 65 | 13 |
| | *15* | 2 | 50 | 48 | 14 |
| trimethoprim | *11* | 36 | <0.2 | >64 | 15 |
| | *12* | 104 | NA | −4 | |
| | | Prescription Drugs | | | |

- $A = Q\_inf * C\_in$ = mass of compounds coming in

- $B = Q\_eff * C\_eff$ = mass of compounds exit (i.e., B/A fraction of incoming compound has gone from liquid line)

- $D = Q\_{_{solidwastage}} * X\_solidwastage$ = mass of compounds exiting during solid disposal (i.e., D/A fraction of incoming compound has gone from solid line)

- E=Some mass could be lost due to degradation or measurement error

- $A = B+D+E$

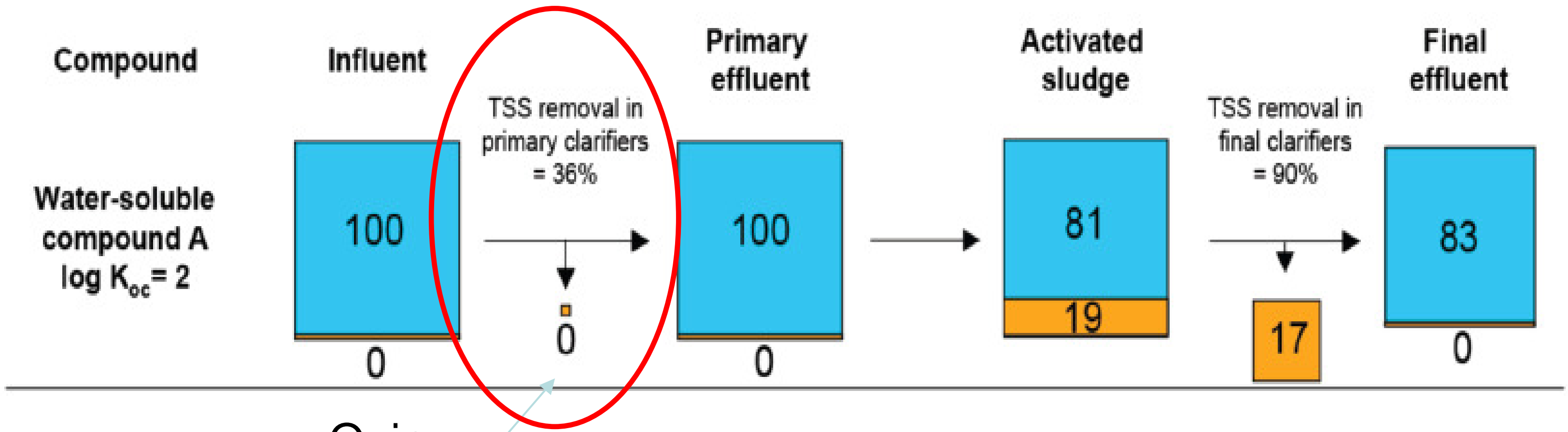
## Mass balance calculation approaches

Generally, a mass balance can be described as a method to measure mass flows entering and leaving a system. In terms of wastewater treatment, this concept can be applied by determining the mass of a chemical entering the plant in raw wastewater, and the mass that exits the plant contained in treated wastewater, sewage sludge or both. A simple scheme for a mass balance is shown in equation S-1.

Equation S-1 $$M(i)_{enter} = M(i)_{exit} + M(i)_{lost}$$

with $M(i)_{enter}$ being the mass of chemical *i* entering the plant (mass/time), $M(i)_{exit}$ the mass of chemical *i* leaving the plant (mass/time) and $M(i)_{lost}$ (mass/time) the mass of chemical *i* being degraded or lost. A mass balance approach can be conducted for a plant as a whole (8,10),

FIGURE 2. Schematic illustrating the role of sorption in the fate of organic wastewater compounds during their hypothetical passage through a conventional activated sludge wastewater treatment plant assuming a lack of both transformation and loss processes. The partitioning of compounds between the dissolved phase (blue) and wastewater solids (orange) is shown for three organic wastewater compounds featuring logarithmic organic carbon normalized sorption coefficients (log $K_{OC}$) of 2, 4, and 6 (top, middle, and bottom panels, respectively).

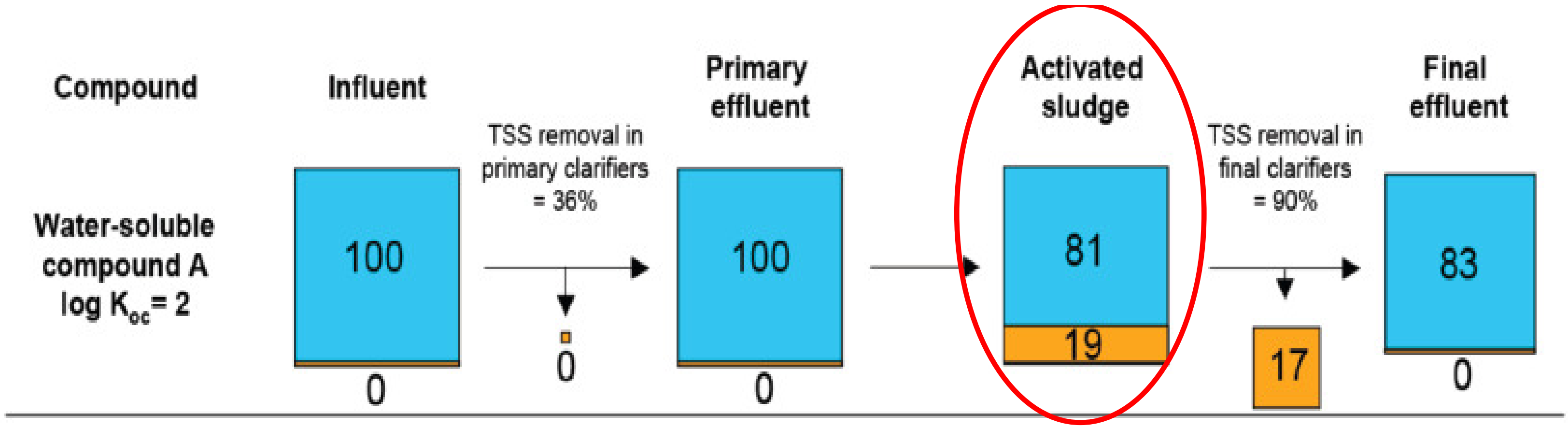



Q_in;
C_in

Q_in;
C_prim_eff=C_in

Solid is removed
But not organic compounds
⇒ 0 is shown for organic compounds

No removal of organics in primary unit
=> All present in water line



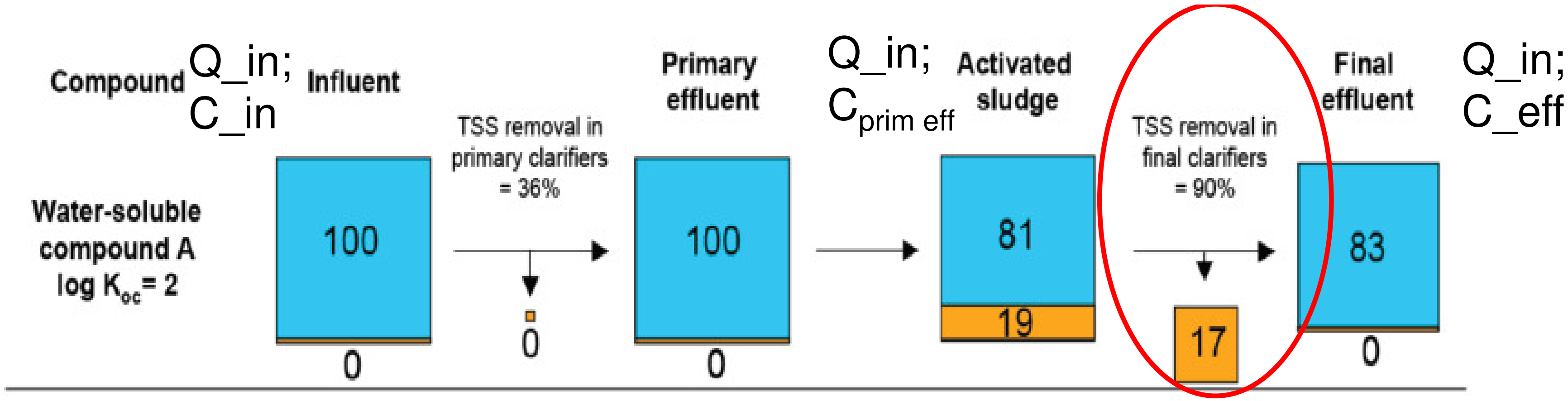

Q_in (MLD=million liters/day; 1gallon=3.78liters);
C_prim_eff=C_in (mg/L)
TSS=total suspended solids

Mass of organic entering into activated sludge tank =Q_in*C_prim_eff=Say (F) (mg)

Reactor volume=V_as (L); solids in AS tank = (AA) mg/L
81% is in liquid phase and rest in solid phase

Organic conc. In liquid phase in AS =C_AS=(0.81*F/V_as) (mg/L)

Organc conc on solids in AS (mg organic/mg solids)=X_AS =(0.19*F)/(AA*V_as) (mg/mg)

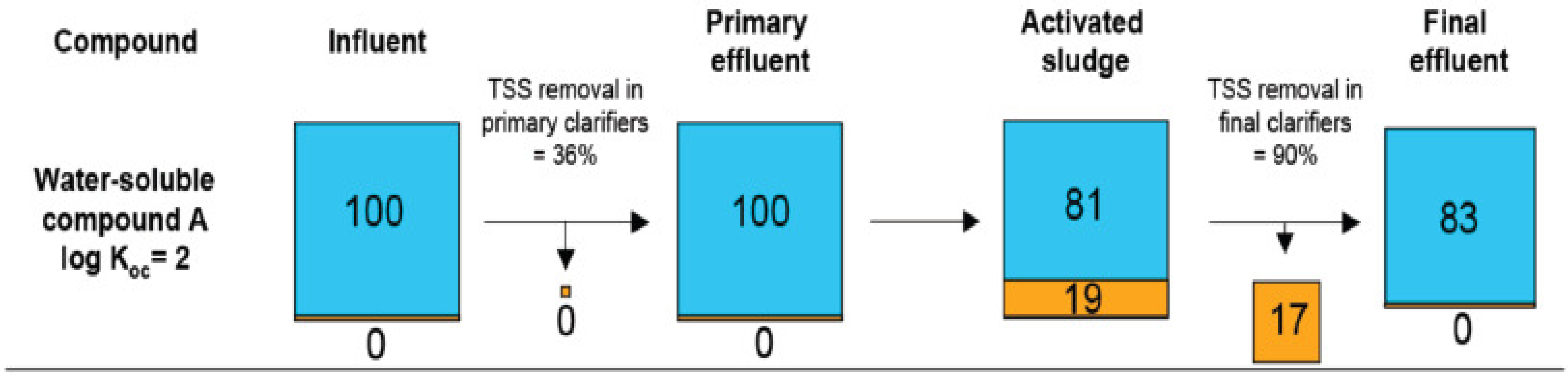



Q_in (MLD=million liters/day; $1m^3$=3.78liters??/);
Organic conc. In liquid phase in AS =C_AS=(0.81*F/V_as) (mg/L)
Organc conc on solids in AS (mg organic/mg solids)=X_AS =(0.19*F)/(AA*V_as) (mg/mg)

Now 90% solids removed in secondary clarifier. Amount of solids removed in secondary clarifier= X_wastage_Secondary tank= 0.9*X_AS
(17=0.9*19 => so amount of organic on solids wasted per day =90% of solids present in AS suspension)

⇒ Organic going out in effluent=C_eff_final=10% contribution from organic present on solids and organic in AS (i.e., C_AS)

FIGURE 2. Schematic illustrating the role of sorption in the fate of organic wastewater compounds during their hypothetical passage through a conventional activated sludge wastewater treatment plant assuming a lack of both transformation and loss processes. The partitioning of compounds between the dissolved phase (blue) and wastewater solids (orange) is shown for three organic wastewater compounds featuring logarithmic organic carbon normalized sorption coefficients (log $K_{OC}$) of 2, 4, and 6 (top, middle, and bottom panels, respectively).



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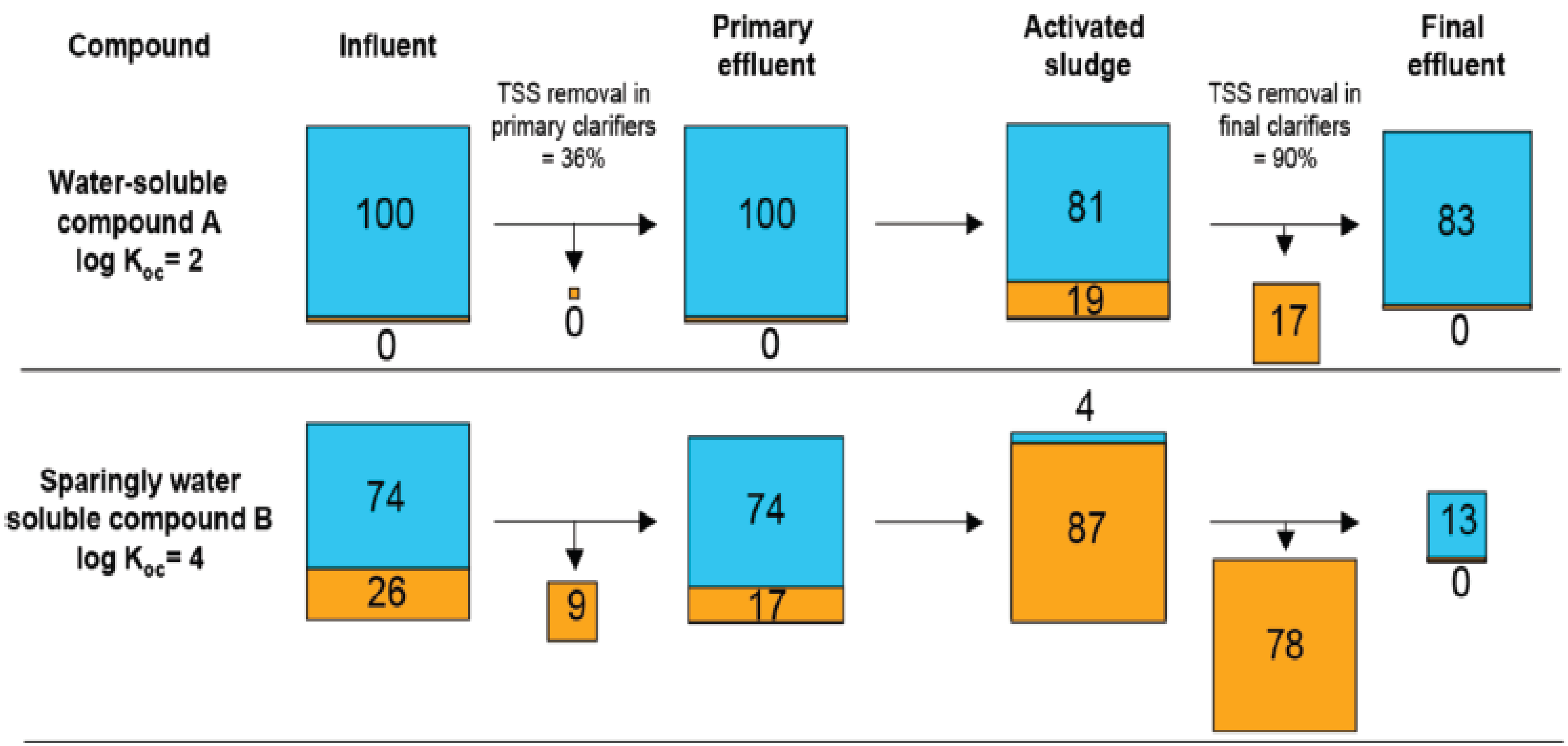

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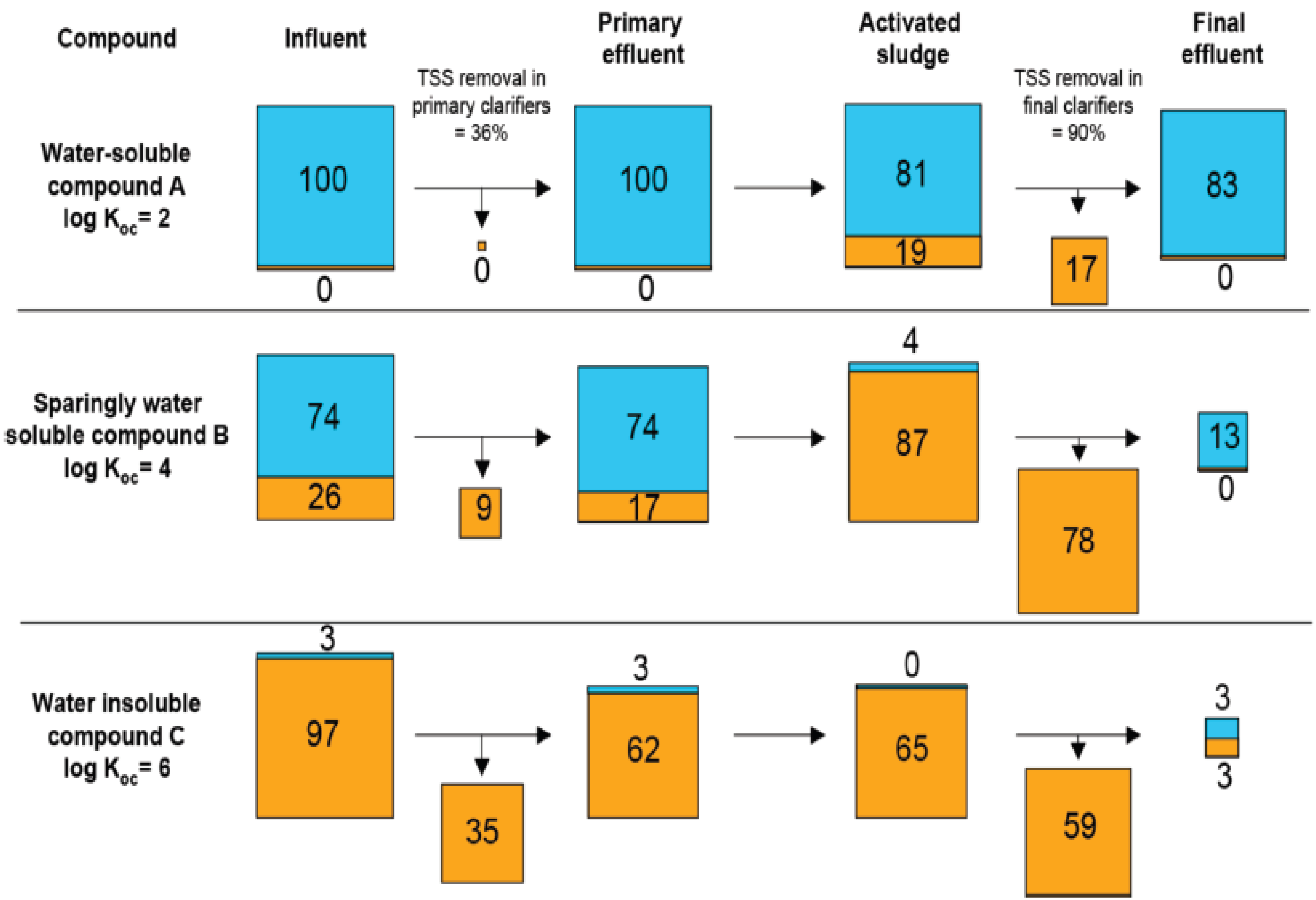


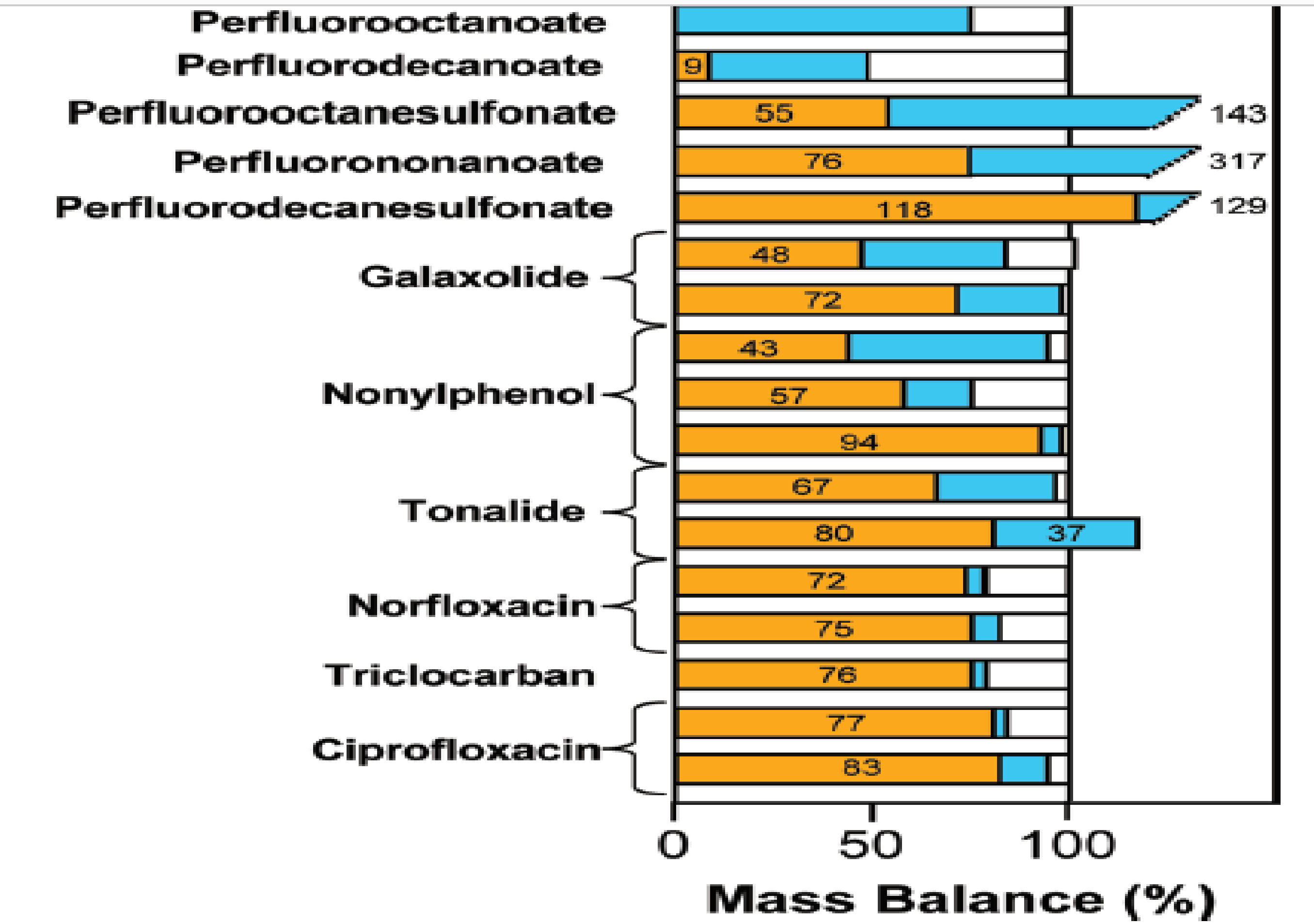


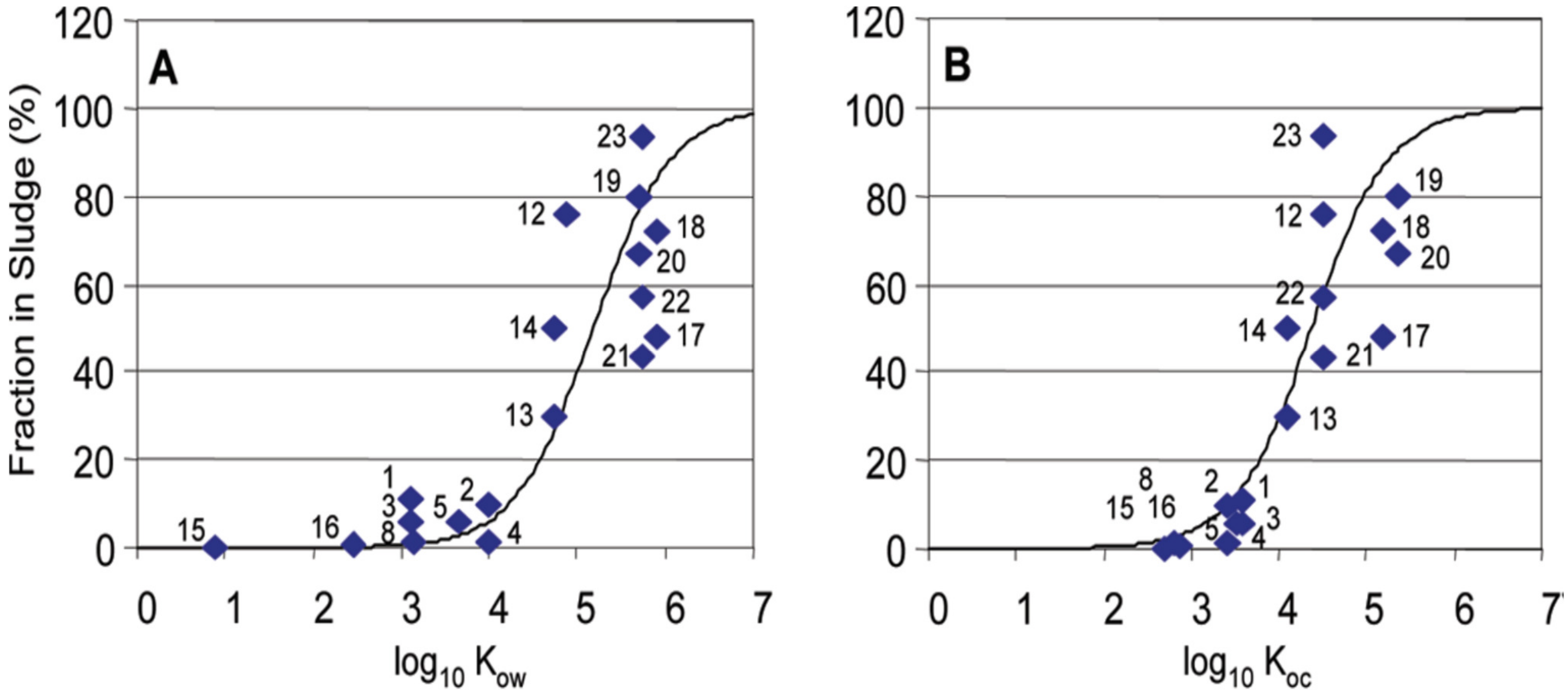

**FIGURE 1.** Compilation of select mass balances for organic wastewater compounds published in the peer-reviewed literature. Shown for each compound are the mass fractions emitted by the plant in effluent (blue), lost to degradation or otherwise unaccounted for (white), and persisting in sludge after digestion of wastewater solids (orange). Compounds are grouped based on structural similarities and sorted according

e here to search

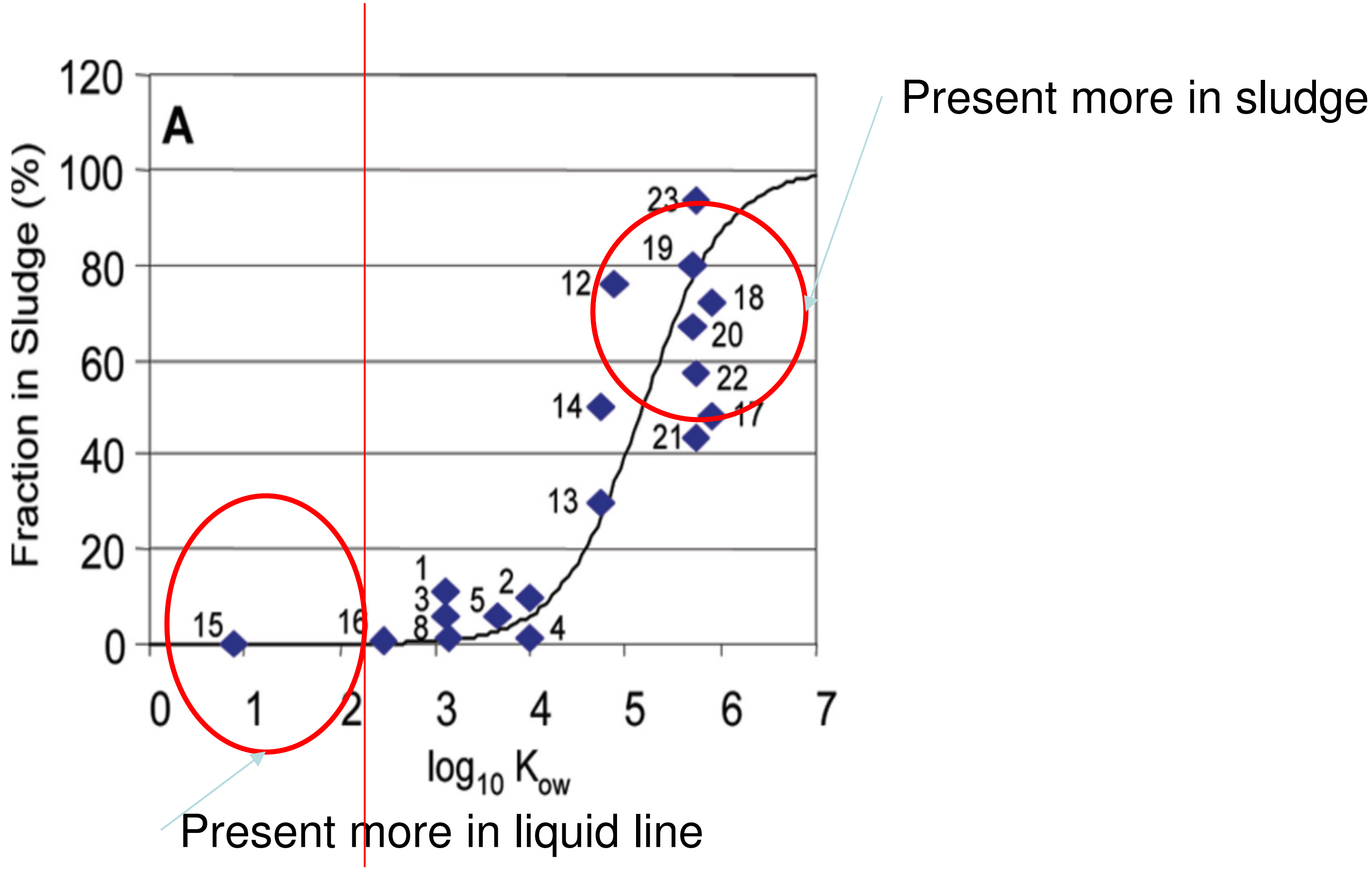
- See previous figure 1
- What does the fraction information tell about K_OW of compounds?
- Which compound has a higher chance of detection in liquid phase? In solid phase?

- This data is useful in deciding  what to monitor in liquid line and in solid line

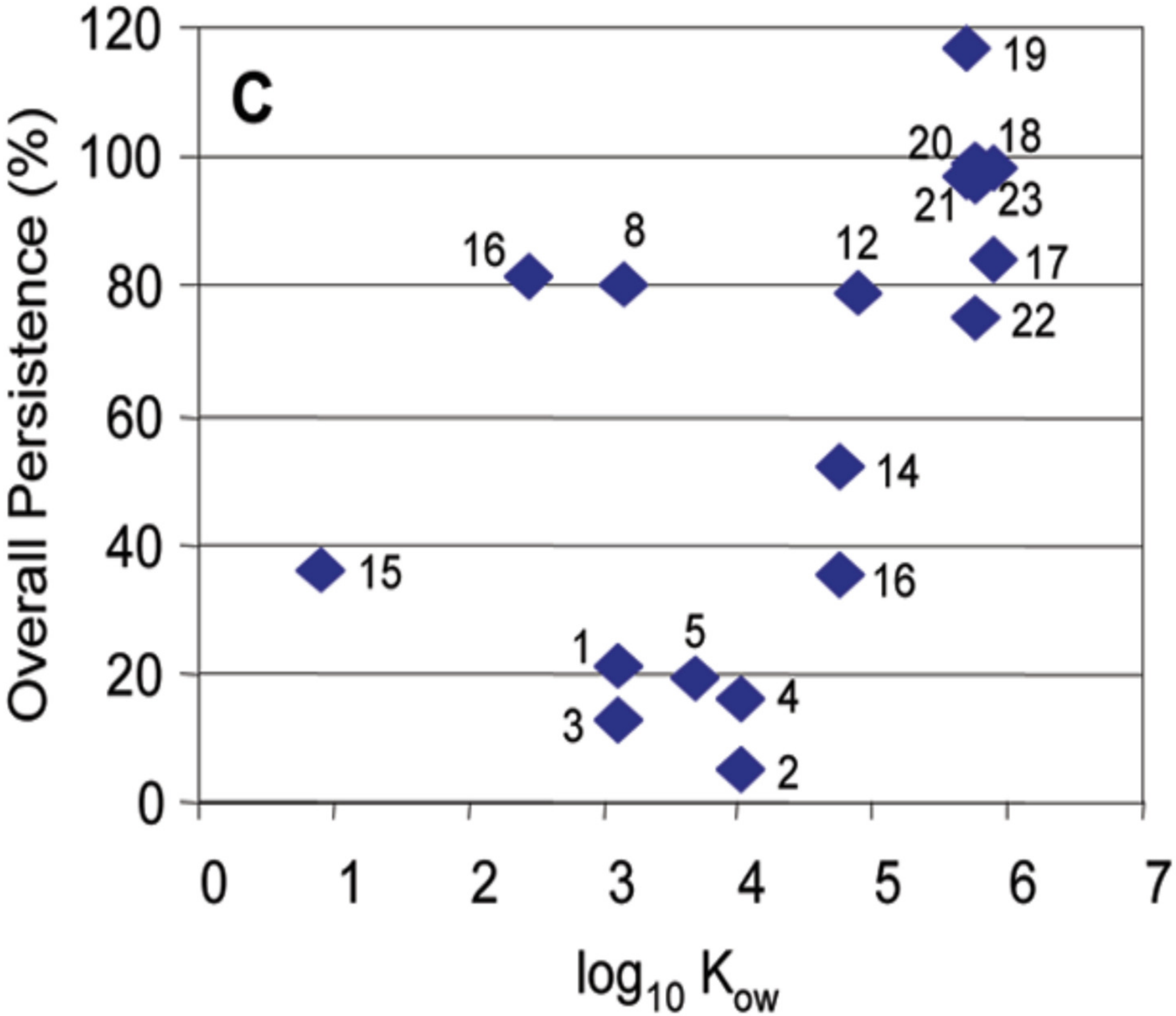
# Fraction in sludge =f($K_{ow}$;$K_{oc}$)

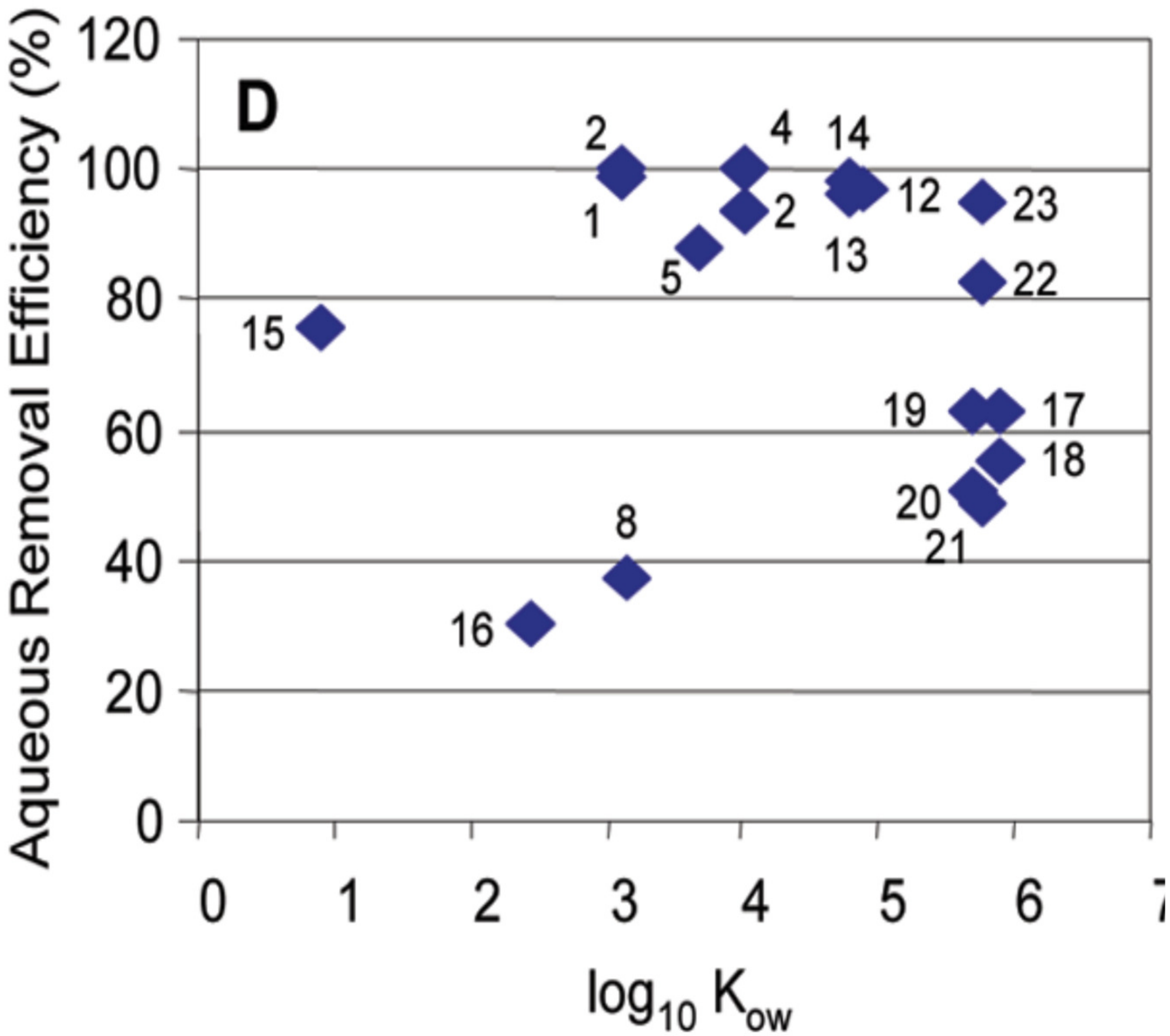


# Role of K_OW in partitioning to sludge part



The trend is similar to that of fraction in sludge =f(K_ow)




D
Aqueous Removal Efficiency (%)
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
$\log_{10} K_{ow}$
2
1
4
2
5
14
12
13
23
22
15
19
17
18
20
21
8
16

Chemosphere 88 (2012) 17–24

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# Occurrence of pharmaceuticals in a municipal wastewater treatment plant: Mass balance and removal processes

Pin Gao [a,b,*], Yunjie Ding [c], Hui Li [c], Irene Xagoraraki [b]

[a] College of Environmental Science and Engineering, Donghua University, Shanghai 201620, China
[b] Department of Civil and Environmental Engineering, Michigan State University, East Lansing, MI 48824, USA
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A R T I C L E I N F O

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A B S T R A C T

Occurrence and removal efficiencies of fifteen pharmaceuticals were investigated in a conventional municipal wastewater treatment plant in Michigan. Concentrations of these pharmaceuticals were determined in both wastewater and sludge phases by a high-performance liquid chromatograph coupled to a

**Table 2**
Mass flux of the investigated pharmaceuticals at different treatment units.

| Pharmaceuticals | Mass flux ($g\,d^{-1}$) | | | | | | | | | Mass in effluent (%) | Mass in dewatered sludge, $R_{sor}$ (%) | Mass lost in WWTP, $R_{bio}$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw influent | Pretreatment effluent | Primary effluent | Aeration effluent | Secondary effluent | Final effluent | Primary sludge | Waste sludge | Dewatered sludge | | | |
| CTC | 8.1 ± 8.2 | 7.7 ± 1.8 | 5.5 ± 1.1 | 2.4 ± 0.9 | NA | NA | 0.2 | NA | NA | NA | NA | 100 |
| DMC | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| DOC | 34 ± 25 | 22 ± 16 | 20 ± 16 | 26 ± 25 | 15 ± 18 | 17 ± 17 | 2.3 ± 1.5 | 1.3 ± 1.3 | 1.0 ± 0.5 | 50 | 3.0 | 47 |
| OTC | 1.3 ± 0.8 | 0.9 ± 0.6 | 1.2 ± 0.3 | 0.9 ± 0.2 | 0.6 ± 0.4 | 0.8 ± 0.2 | 0.1 ± 0.01 | 0.1 ± 0.03 | 0.03 ± 0.02 | 61 | 2.2 | 37 |
| TC | 14 ± 4.2 | 5.7 ± 2.0 | 7.0 ± 2.4 | 7.0 ± 3.9 | NA | NA | NA | 3.1 ± 1.7 | 1.0 ± 0.5 | NA | 7.1 | 93 |
| SDZ | 1.7 ± 0.5 | 1.6 ± 0.4 | 1.6 ± 0.3 | 2.0 ± 0.3 | 1.3 ± 0.1 | 1.2 ± 0.6 | 0.2 ± 0.04 | 0.2 ± 0.2 | 0.1 ± 0.03 | 73 | 5.2 | 22 |
| SMR | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| SMZ | 1.2 ± 0.1 | NA | NA | NA | NA | NA | NA | 0.03 ± 0 | 0.01 ± 0 | NA | 0.5 | 99 |
| SMX | 71 ± 26 | 58 ± 24 | 59 ± 23 | 75 ± 32 | 22 ± 3.9 | 8.1 ± 6.9 | 0.1 ± 0.1 | 0.3 ± 0.2 | 0.1 ± 0.03 | 11 | <0.1 | >89 |
| ERY | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| TYL | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| LCM | 2.6 ± 3.6 | 6.1 ± 7.6 | 3.4 ± 5.1 | 2.6 ± 3.5 | 2.6 ± 2.0 | 1.6 ± 0.5 | 0.04 ± 0.05 | 0.2 ± 0.04 | 0.03 ± 0.02 | 60 | 1.0 | 39 |
| CBZ | 5.0 ± 1.2 | 5.4 ± 1.2 | 6.0 ± 1.8 | 7.7 ± 2.7 | 7.1 ± 2.2 | 7.0 ± 2.5 | 0.1 ± 0.1 | 0.1 ± 0.05 | 0.03 ± 0.02 | 141 | 0.6 | -41 |
| AMP | 2800 ± 1493 | 2644 ± 1099 | 2561 ± 1238 | 145 ± 134 | 3.2 ± 1.6 | 4.5 ± 3.9 | 0.3 ± 0.1 | 0.5 ± 0.3 | 0.2 ± 0.1 | <0.2 | <0.01 | >99 |
| CAF | 1871 ± 550 | 1737 ± 538 | 2436 ± 794 | 138 ± 205 | 3.3 ± 2.1 | 3.4 ± 2.7 | 0.3 ± 0.1 | 0.4 ± 0.6 | 0.1 ± 0.05 | <0.2 | <0.01 | >99 |

NA, not currently available. Mass flux was calculated according to Eqs. (1) and (2). $R_{bio}$ and $R_{sor}$ were calculated using Eqs. (4) and (5), respectively.

P. Gao et al. / Chemosphere 88 (2012) 17–24

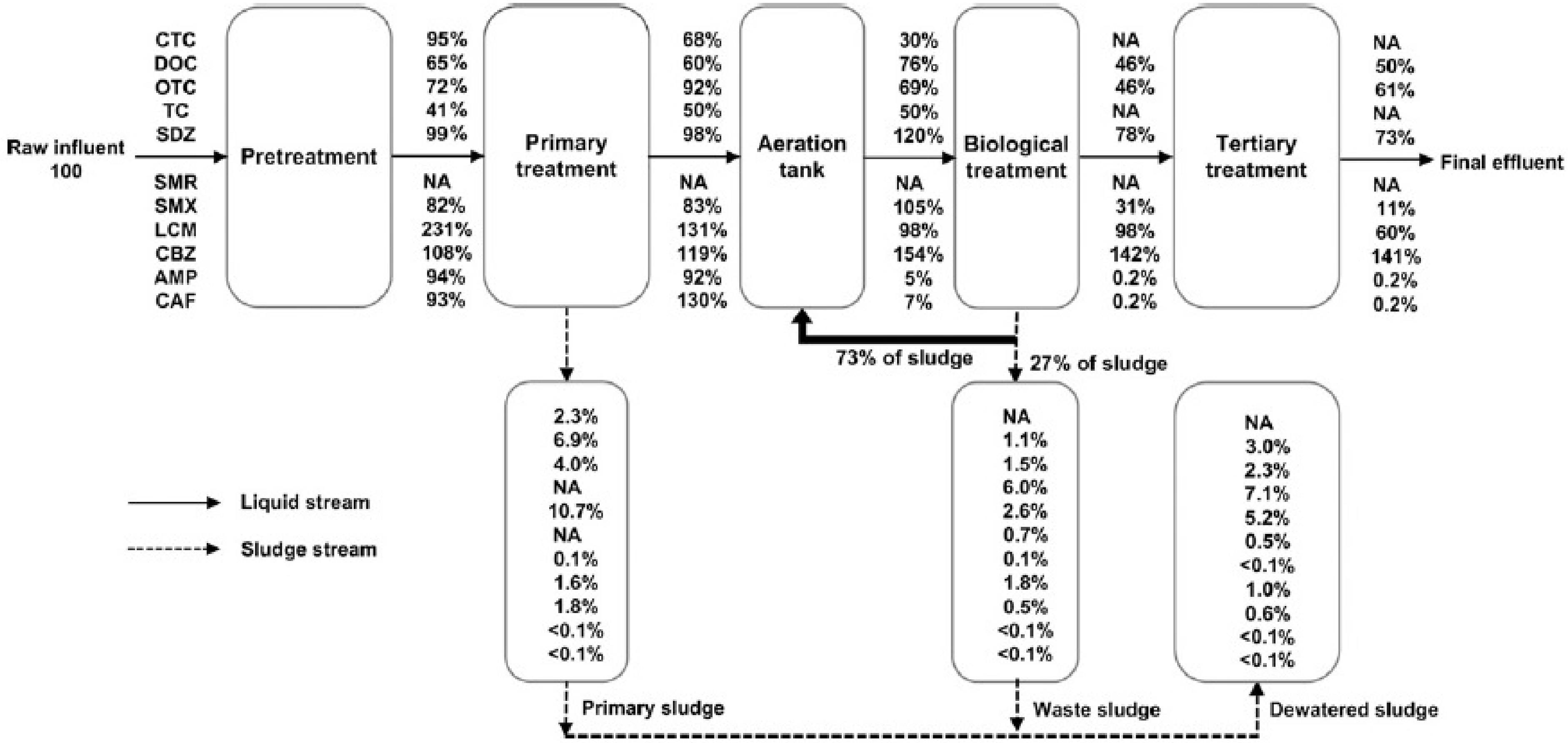


**Fig. 4.** Percentage ($R_i$, %, calculated applying Eq. (6)) of detected pharmaceuticals along the WWTP.

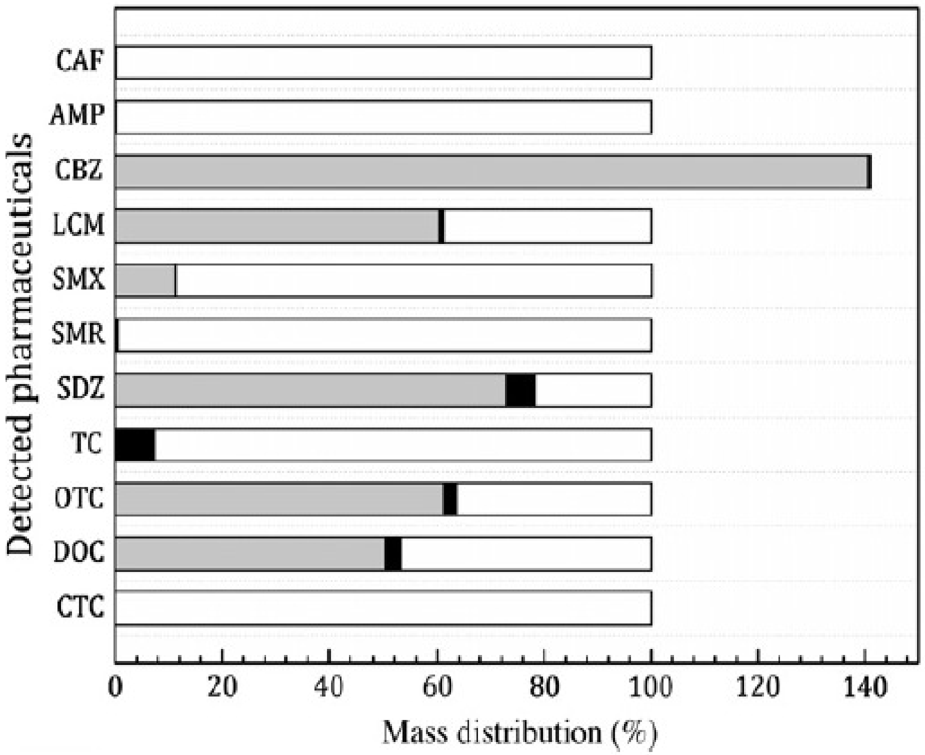


**Fig. 3.** Mass distribution of the detected pharmaceuticals in the WWTP. The grey-colored bar represents the mass fraction in the final effluent, the black-colored bar represents the fraction in the dewatered sludge, and the white bar represents the loss of pharmaceuticals due to biodegradation.

- Write Name entry number on a paper
- Q1: Order chemicals in decreasing order of their potential occurrence in final effluent?
- Q2: Which compound is expected to have smallest $K_{OW}$?

# CVL100:Environmental Science(2-0-0)

**Dr. Arun Kumar**

## Water Treatment-Mass Balance and Big-Picture
Nov 10th 2021 (Part2)

# Recap

## Meta-Analysis of Mass Balances Examining Chemical Fate during Wastewater Treatment

JOCHEN HEIDLER[†] AND ROLF U. HALDEN[*,†,‡]

*Johns Hopkins University Center for Water and Health, Department of Environmental Health Sciences, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, Maryland 21205, and Center for Environmental Biotechnology at The Biodesign Institute, Arizona State University, Tempe, Arizona 85287*

*Received December 3, 2007. Revised manuscript received June 11, 2008. Accepted June 11, 2008.*

Mass balances are an instructive means for investigating the fate of chemicals during wastewater treatment. In addition

composition of biosolids is important because us
sewage sludge as fertilizer in agriculture, f

ere to search

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ARTICLE INFO

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ABSTRACT

Occurrence and removal efficiencies of fifteen pharmaceuticals were investigated in a conventional municipal wastewater treatment plant in Michigan. Concentrations of these pharmaceuticals were determined in both wastewater and sludge phases by a high-performance liquid chromatograph coupled to a

The mass flow calculation can be written as:

$(m_{lost}=m_{biodegradation}+m_{sorbed})$

$$m_{inf} = m_{eff} + m_{bio} + m_{sor} \tag{3}$$

where $m_{inf}$ (kg d$^{-1}$) and $m_{eff}$ (kg d$^{-1}$) are mass input and output of the treatment system. $m_{bio}$ (kg d$^{-1}$) and $m_{sor}$ (kg d$^{-1}$) refer to the mass of pharmaceutical lost due to biodegradation and sorption,

**Table 2**
Mass flux of the investigated pharmaceuticals at different treatment units.

| Pharmaceuticals | Mass flux ($g\,d^{-1}$) | | | | | | | | | (C=100*(B/A)) Mass in effluent (%) | (E=100*(D/A)) Mass in dewatered sludge, $R_{sor}$ (%) | (F=100-(C+E)) Mass lost in WWTP, $R_{bio}$ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw (A) influent | Pretreatment effluent | Primary effluent | Aeration effluent | Secondary effluent | Final (B) effluent | Primary sludge | Waste sludge | Dewatered sludge (D) | (C) | (E) | (F) |
| CTC | 8.1 ± 8.2 | 7.7 ± 1.8 | 5.5 ± 1.1 | 2.4 ± 0.9 | NA | NA | 0.2 | NA | NA | NA | NA | 100 |
| DMC | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
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| OTC | 1.3 ± 0.8 | 0.9 ± 0.6 | 1.2 ± 0.3 | 0.9 ± 0.2 | 0.6 ± 0.4 | 0.8 ± 0.2 | 0.1 ± 0.01 | 0.1 ± 0.03 | 0.03 ± 0.02 | 61 | 2.2 | 37 |
| TC | 14 ± 42 | 5.7 ± 2.0 | 7.0 ± 2.4 | 7.0 ± 3.9 | NA | NA | NA | 3.1 ± 1.7 | 1.0 ± 0.5 | NA | 7.1 | 93 |
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| SMR | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| SMZ | 1.2 ± 0.1 | NA | NA | NA | NA | NA | NA | 0.03 ± 0 | 0.01 ± 0 | NA | 0.5 | 99 |
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| AMP | 2800 ± 1493 | 2644 ± 1099 | 2561 ± 1238 | 145 ± 134 | 3.2 ± 1.6 | 4.5 ± 3.9 | 0.3 ± 0.1 | 0.5 ± 0.3 | 0.2 ± 0.1 | <0.2 | <0.01 | >99 |
| CAF | 1871 ± 550 | 1737 ± 538 | 2436 ± 794 | 138 ± 205 | 3.3 ± 2.1 | 3.4 ± 2.7 | 0.3 ± 0.1 | 0.4 ± 0.6 | 0.1 ± 0.05 | <0.2 | <0.01 | >99 |

NA, not currently available. Mass flux was calculated according to Eqs. (1) and (2). $R_{bio}$ and $R_{sor}$ were calculated using Eqs. (4) and (5), respectively.

tetracycline (TC), demeclocycline (DMC), chlortetracycline (CTC), oxytetracycline (OTC), doxycycline (DOC), meclocycline (MCC), sulfadiazine (SDZ), sulfamerazine (SMR), sulfamethazine (SMZ), SMX, tylosin (TYL), acetaminophen (AMP), erythyromycin (ERY), lincomycin(LCM), carbamazepine (CBZ) and Caffeine (CAF).

P. Gao et al. / Chemosphere 88 (2012) 17–24

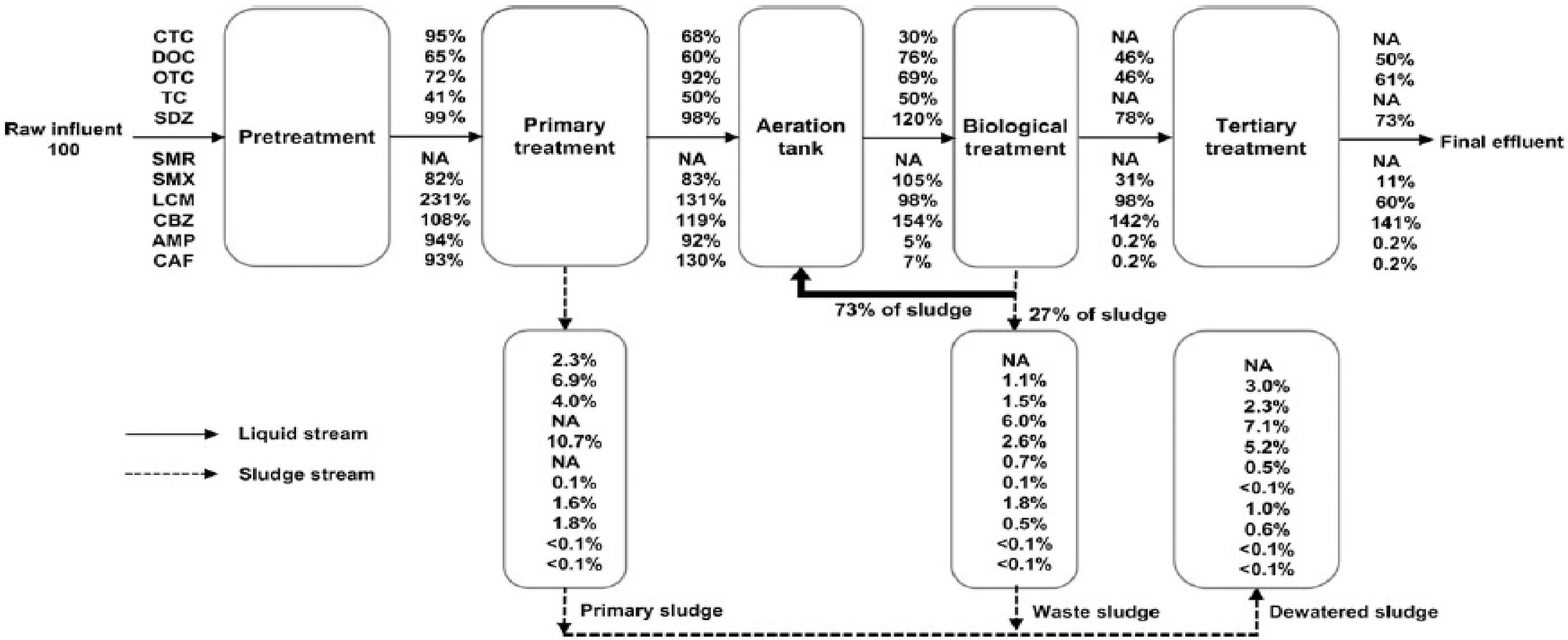


**Fig. 4.** Percentage ($R_i$, %, calculated applying Eq. (6)) of detected pharmaceuticals along the WWTP.

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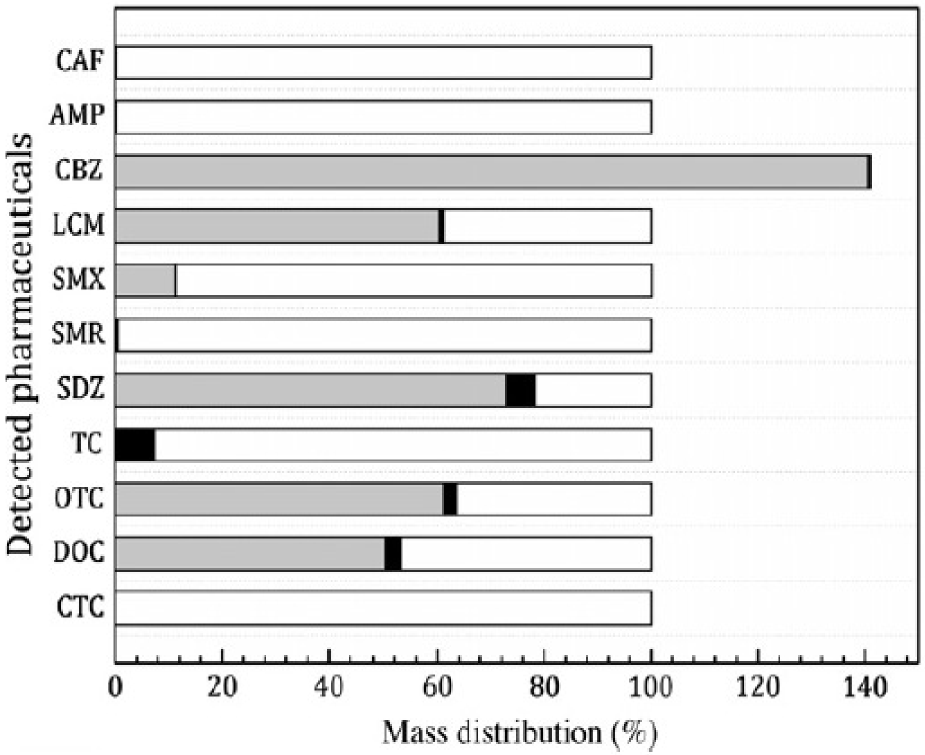
- Comment on removal of different organic compounds in different units.
- Which compound is least detected in final effluent and which is mostly detected in final effluent?
- What does it say about their occurrence in sludge?
- Can we relate this to their $K_{ow}$ and $K_{oc}$ properties?

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- Q1: Order chemicals in decreasing order of their potential occurrence in final effluent?
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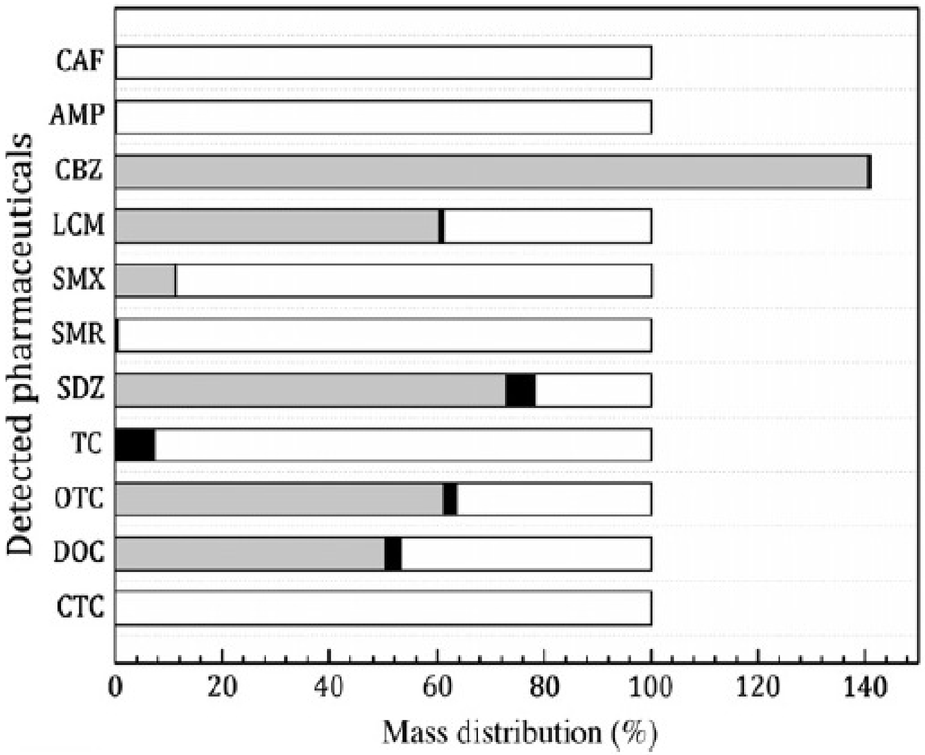


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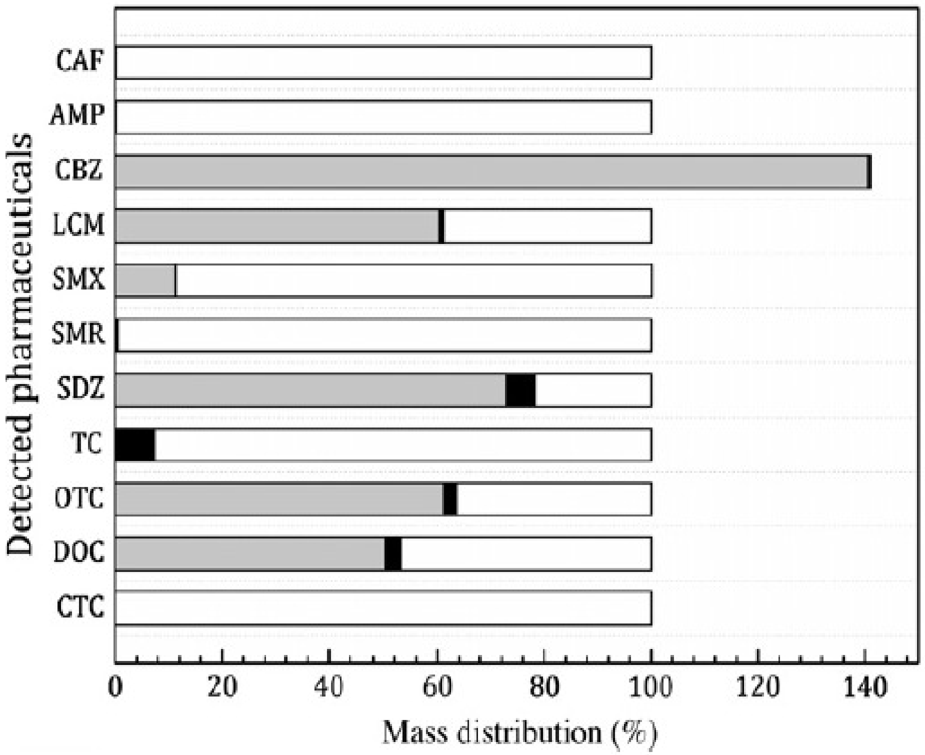
**Presence in final effluent**

oxytetracycline (OTC),
doxycycline (DOC),
sulfadiazine (SDZ),
sulfamethoxazole(SMX),
lincomycin(LCM),
carbamazepine (CBZ)

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**Check presence in surface water if wastewater effluent is mixed with surface water**

oxytetracycline (OTC),
doxycycline (DOC),
sulfadiazine (SDZ),
sulfamethoxazole(SMX),
lincomycin(LCM),
carbamazepine (CBZ)

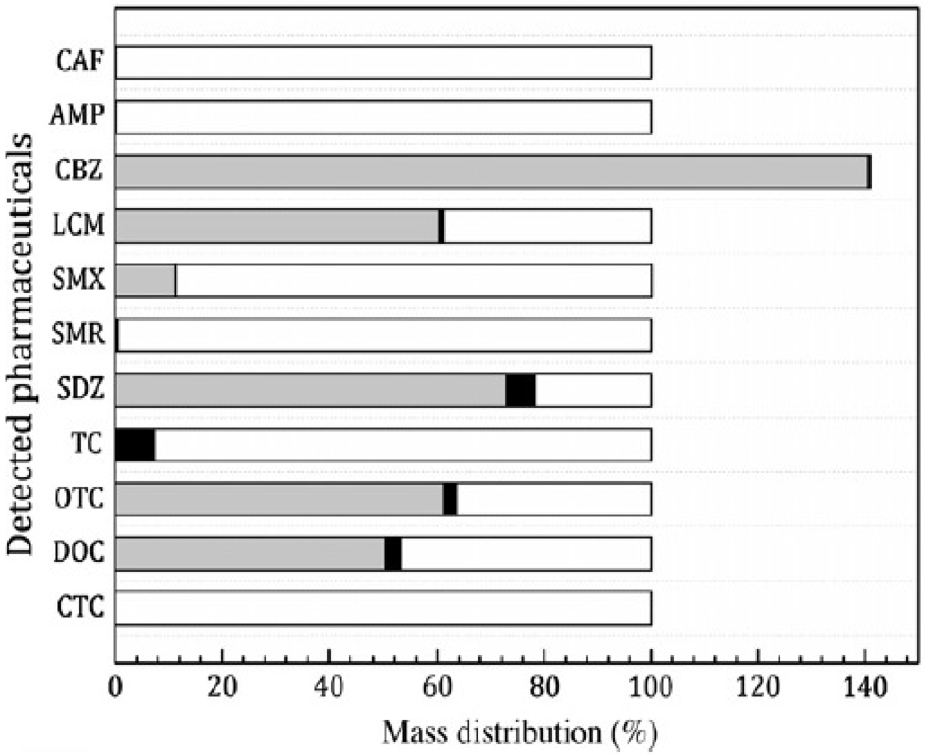



**Fig. 3.** Mass distribution of the detected pharmaceuticals in the WWTP. The grey-colored bar represents the mass fraction in the final effluent, the black-colored bar represents the fraction in the dewatered sludge, and the white bar represents the loss of pharmaceuticals due to biodegradation.

**Check further removal in drinking water treatment plant if surface water is used as raw source water for making drinking water**

oxytetracycline (OTC),
doxycycline (DOC),
sulfadiazine (SDZ),
sulfamethoxazole(SMX),
lincomycin(LCM),
carbamazepine (CBZ)

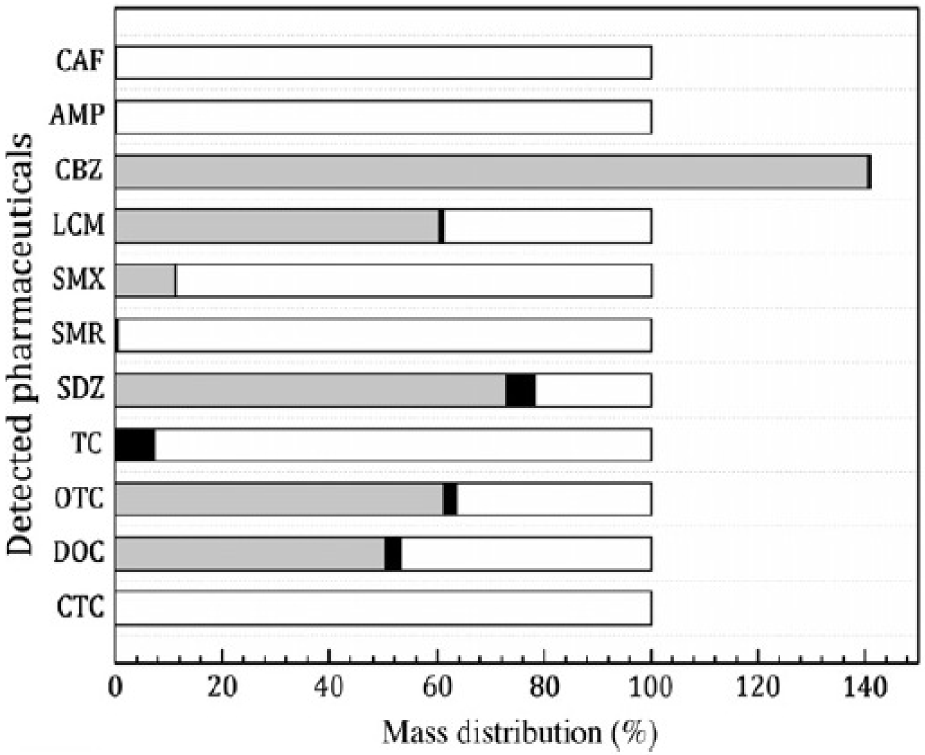



**Fig. 3.** Mass distribution of the detected pharmaceuticals in the WWTP. The grey-colored bar represents the mass fraction in the final effluent, the black-colored bar represents the fraction in the dewatered sludge, and the white bar represents the loss of pharmaceuticals due to biodegradation.

**Presence in sludge**

oxytetracycline (OTC),
doxycycline (DOC),
sulfadiazine (SDZ),
lincomycin(LCM),
Tetracycline(TC)

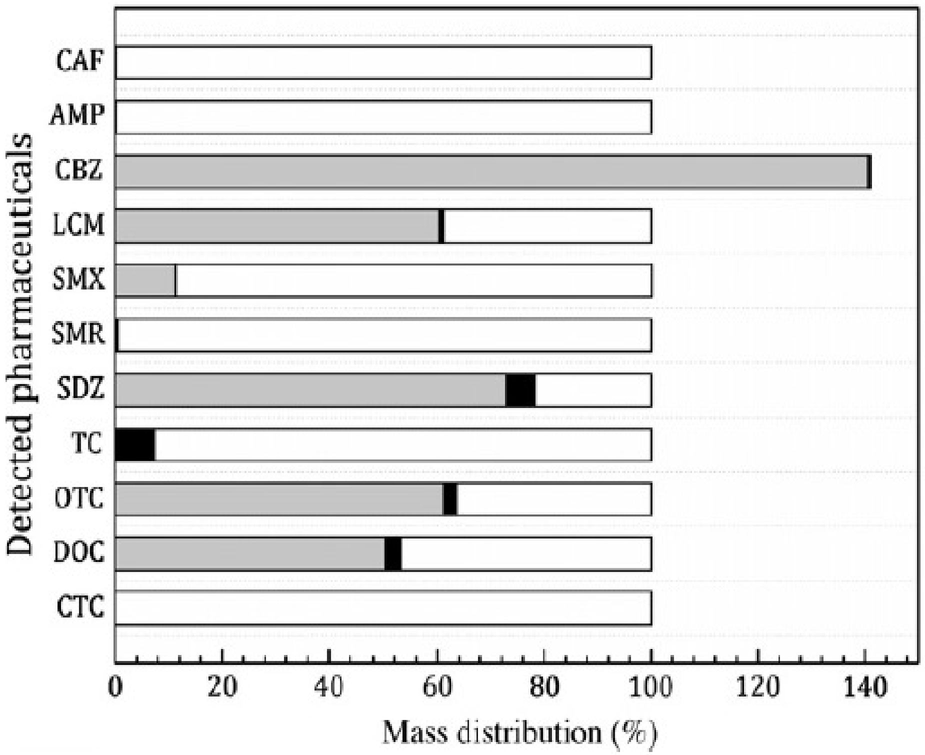



**Fig. 3.** Mass distribution of the detected pharmaceuticals in the WWTP. The grey-colored bar represents the mass fraction in the final effluent, the black-colored bar represents the fraction in the dewatered sludge, and the white bar represents the loss of pharmaceuticals due to biodegradation.

**Check presence in land if sludge is applied there as nutrient source**

oxytetracycline (OTC),
doxycycline (DOC),
sulfadiazine (SDZ),
lincomycin(LCM),
Tetracycline(TC)

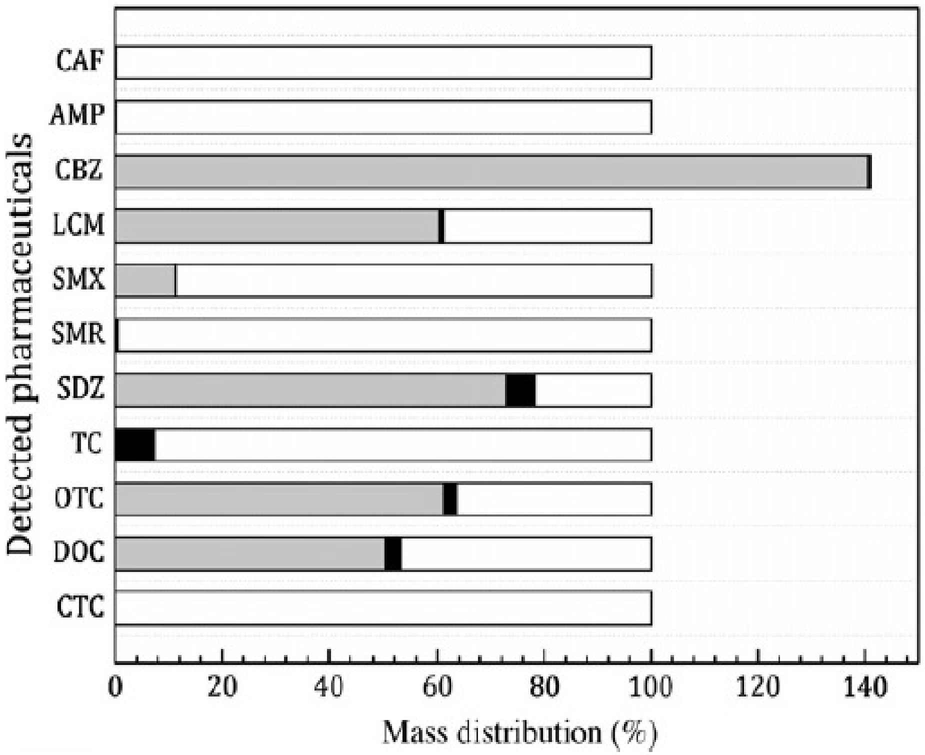
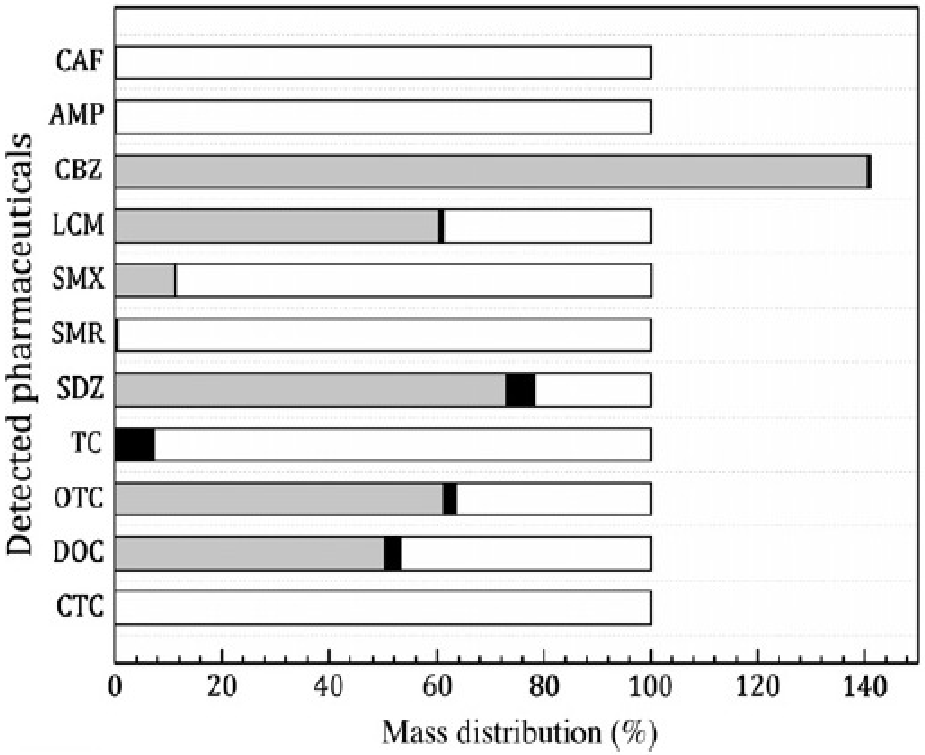



**Fig. 3.** Mass distribution of the detected pharmaceuticals in the WWTP. The grey-colored bar represents the mass fraction in the final effluent, the black-colored bar represents the fraction in the dewatered sludge, and the white bar represents the loss of pharmaceuticals due to biodegradation.

**Check chance of contamination of soil, surface water through runoff and groundwater through percolation if sludge is applied on land as nutrient source**

oxytetracycline (OTC),
doxycycline (DOC),
sulfadiazine (SDZ),
lincomycin(LCM),
Tetracycline(TC)

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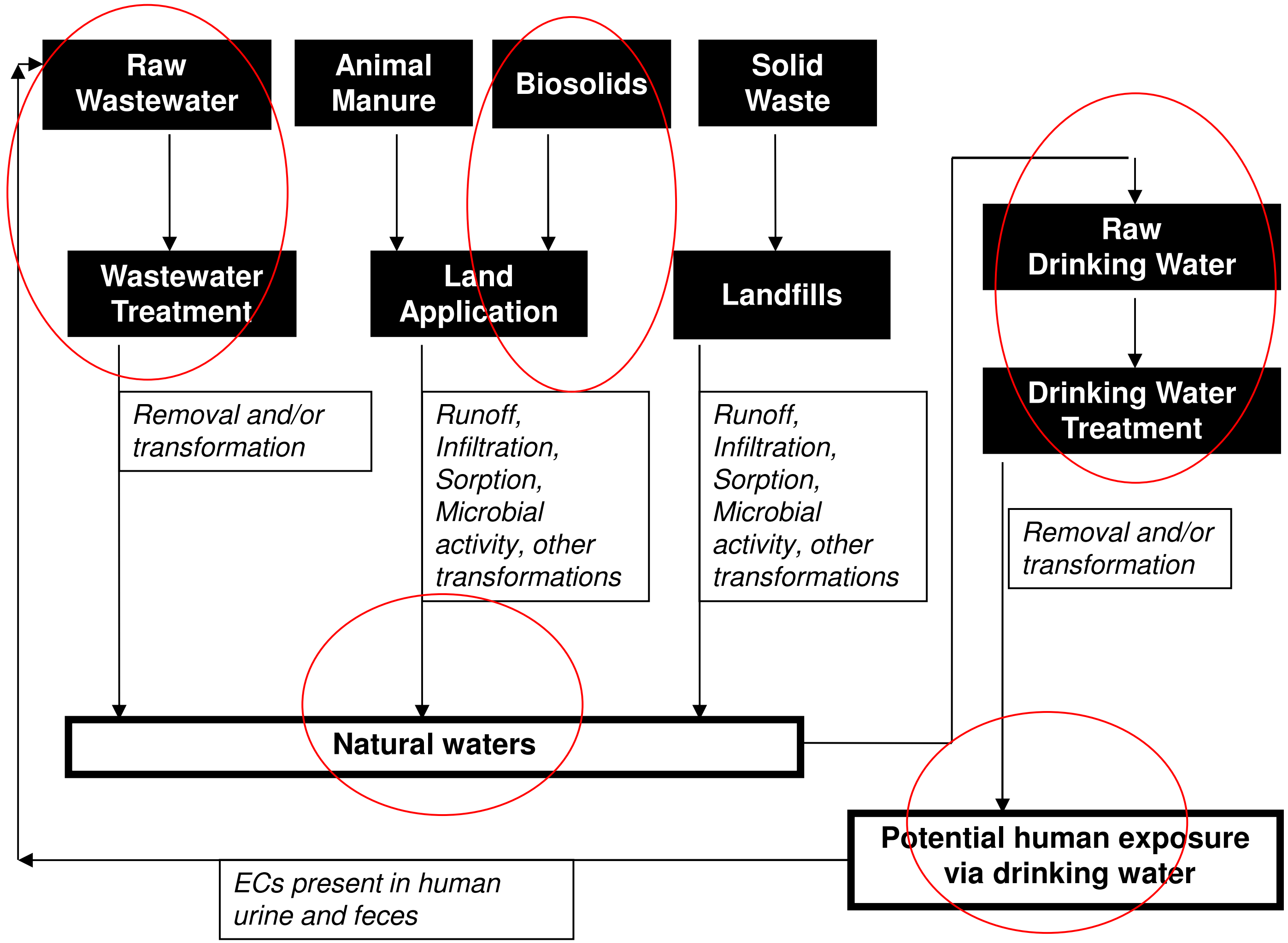
**Lost due to biodegradation (i.e., compound can be degraded by bacteria)**

CAF
AMP
LCM
SMX
SMR
SDZ
TC
OTC
DOC
CTC

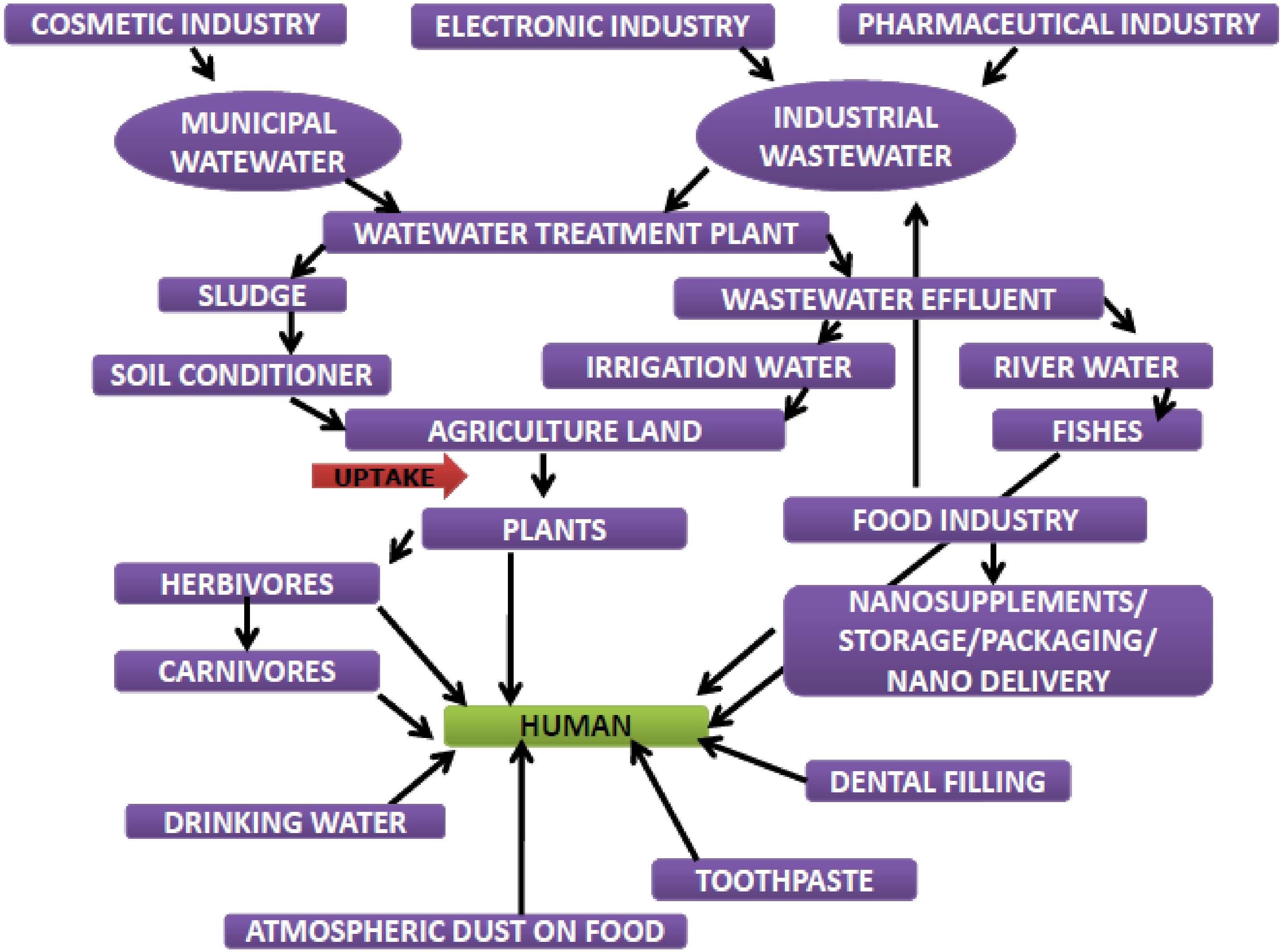
Some can be biodegraded more
And some can be biodegraded less.

# Fate of pharmaceuticals in environment and our exposure



# A big picture overview

# A big picture overview




**Singh, D**. and Kumar, A. (2015)

# Big-picture

## *Emerging Water Contaminants (EWCs)*

1. Pharmaceuticals, Endocrine-disrupting chemicals(ex: triclosan; Bisphenol-A)

2. Nanoparticles (nanosilver, nanoparticles: $TiO_2$, CuO, Carbon nanotubes)

3. Micro-plastics

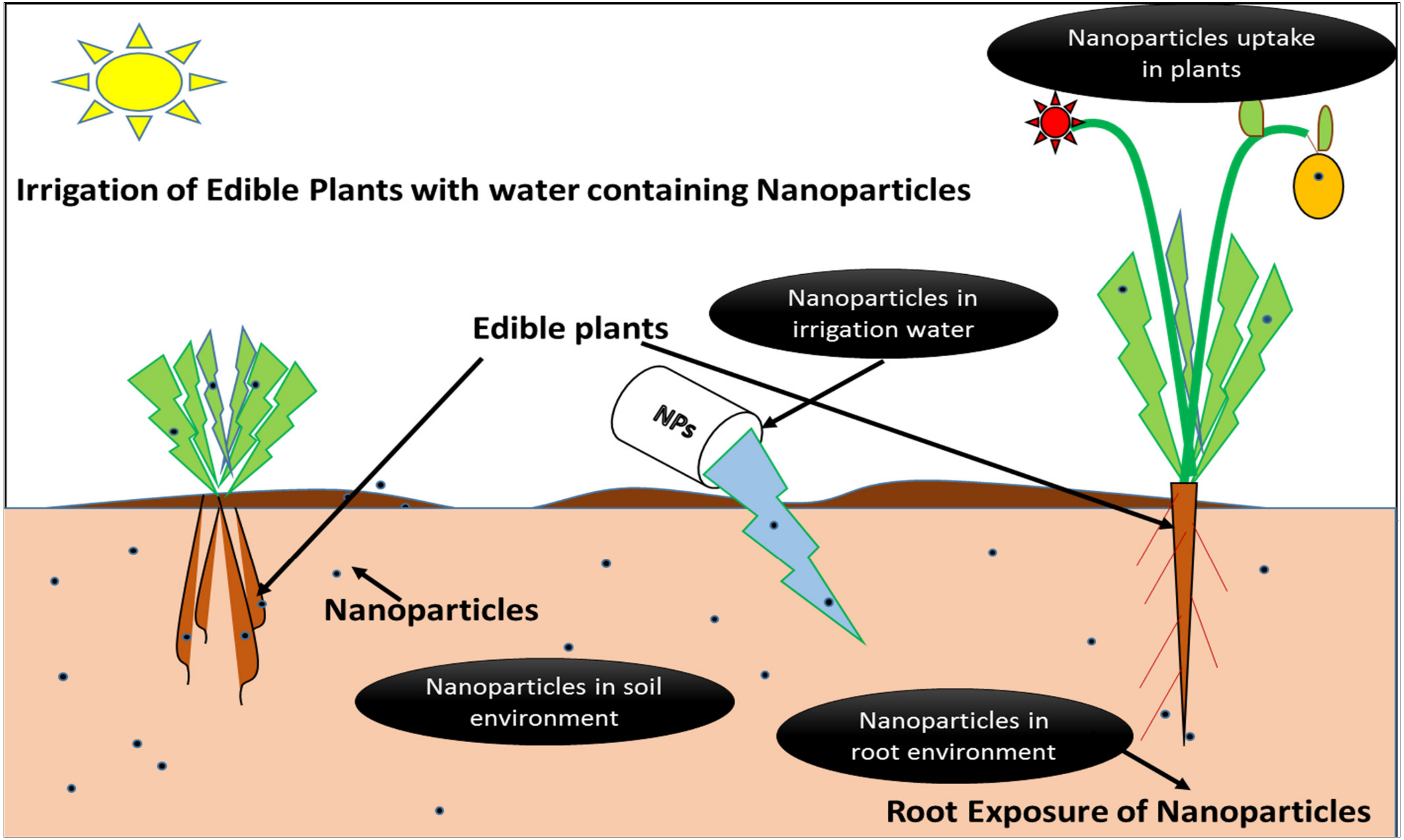
4. Viruses and bacterial pathogens

5. Bioaerosols

**Some of these are not regulated**

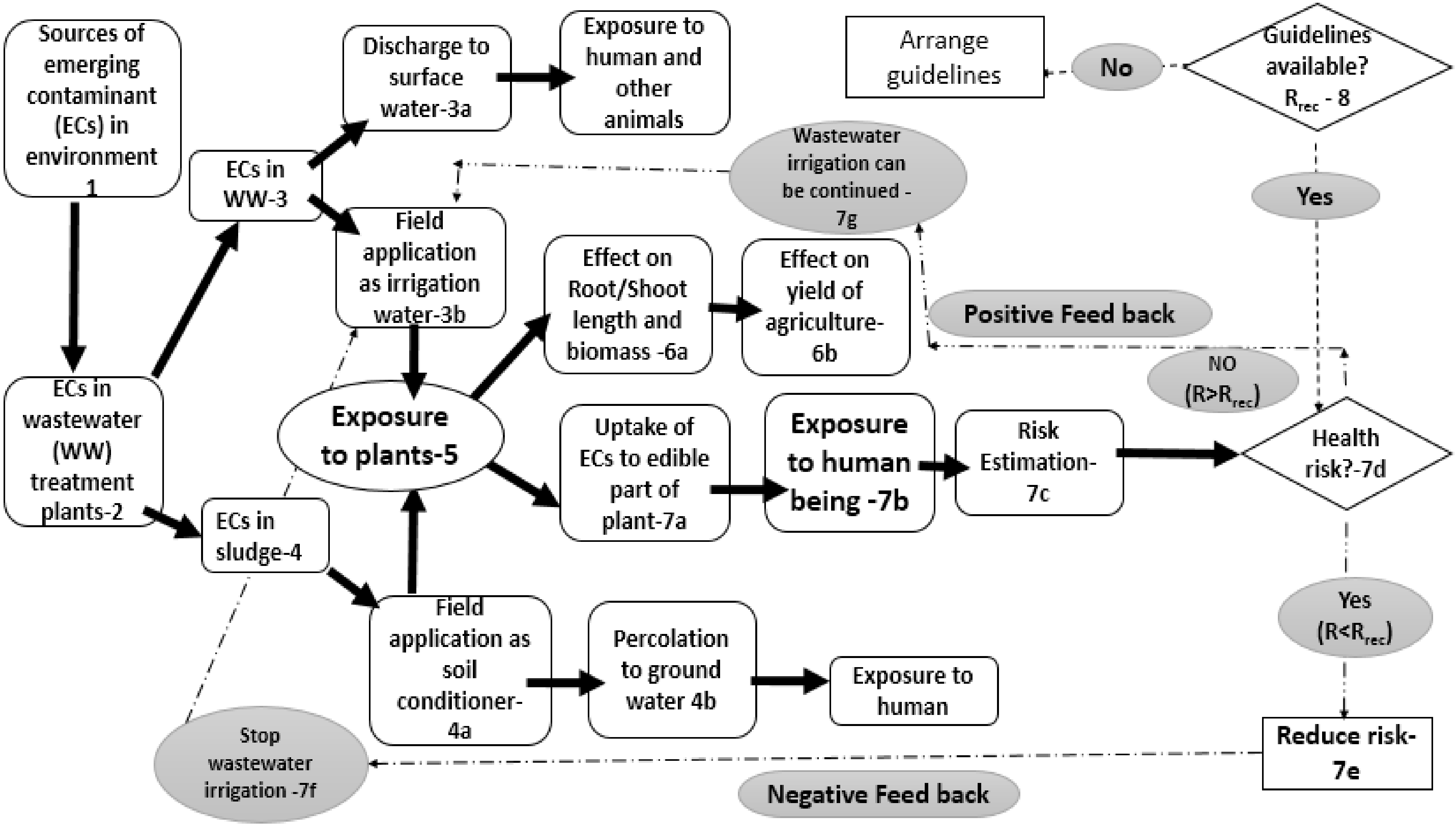
Snyder et al. (2007); Kumar and Xagoraraki (2010a); Boone and Gerba (2007)

# Big- Picture Overview




Adapted from the Singh, D. and Kumar, A. **Understanding effect of interaction of nanoparticles with roots on uptake in plants**" Environmental Nanotechnology (Book Chapter - (in press)*

# Pieces




Singh and Kumar (2014)

# *EWCs: Why to worry now?*

1. Occurrence (although low concentration)

2. Toxic nature (long-term toxicity unknown)

3. Long-term implications unknowns

4. How to go about? Additional costs? Additional benefits? Cost-benefit? Can we afford?

Solution:

Environmental solutions with the help of all areas