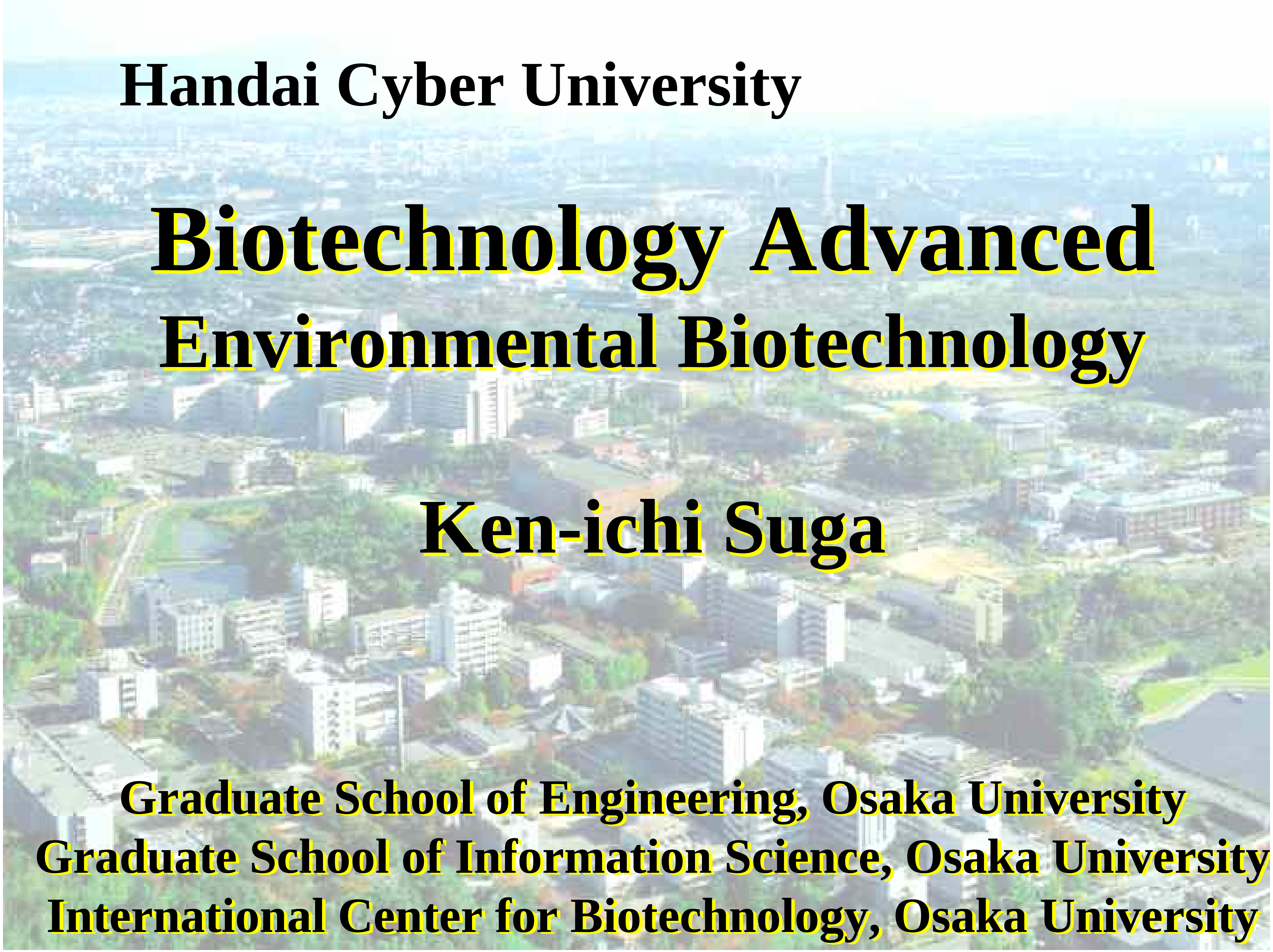

Handai Cyber University

Biotechnology Advanced

Environmental Biotechnology

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Keep water clean!

Environmental Biotechnology

1. Water quality and pollution

2. Wastewater treatment

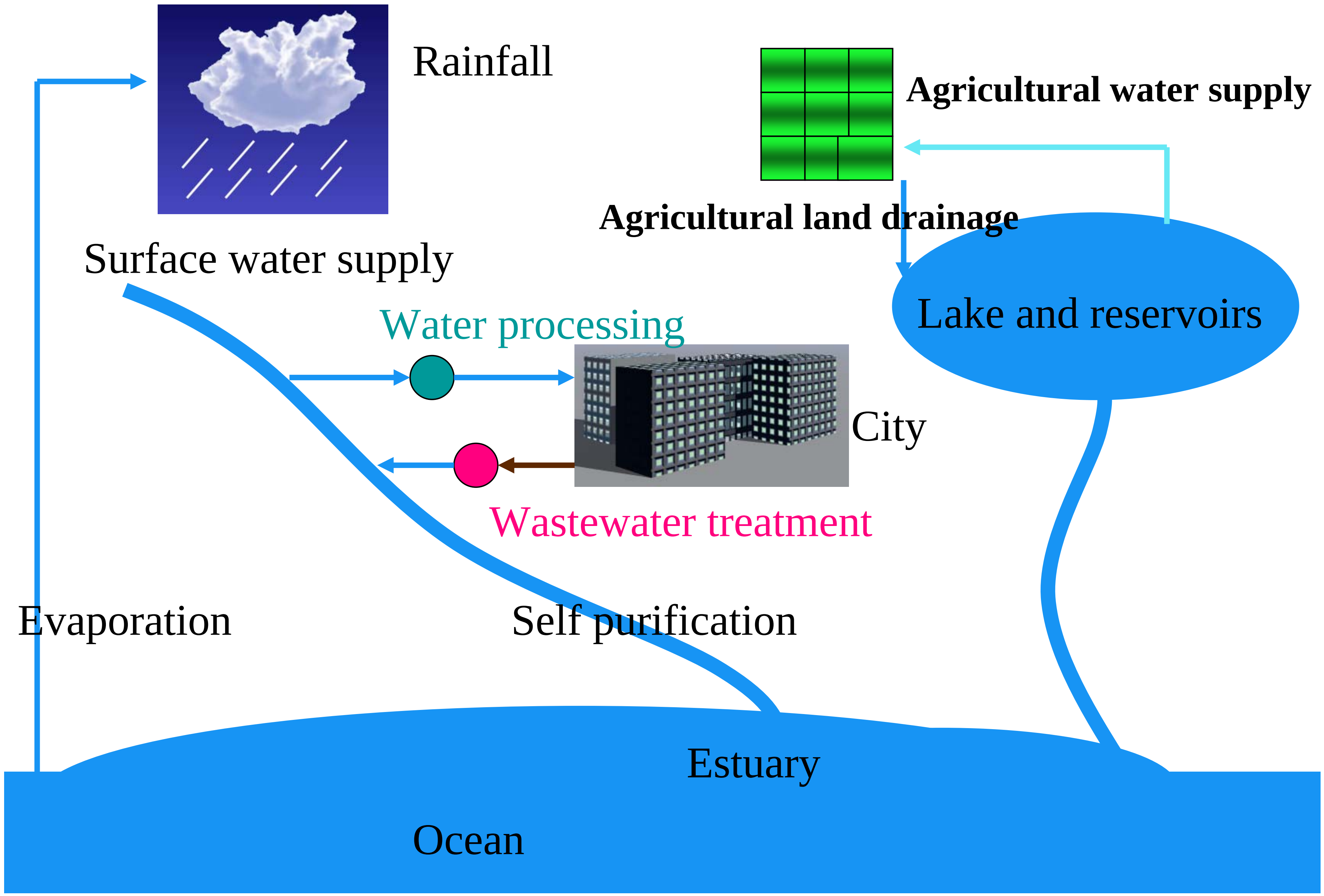
Water quality and pollution

- Introduction
- Stream and self-purification
- Eutrophication

Water quality and pollution

- Introduction

The integration of natural and man-generated water cycle



Rainfall

Agricultural water supply

Agricultural land drainage

Surface water supply

Lake and reservoirs

Water processing

City

Wastewater treatment

Evaporation

Self purification

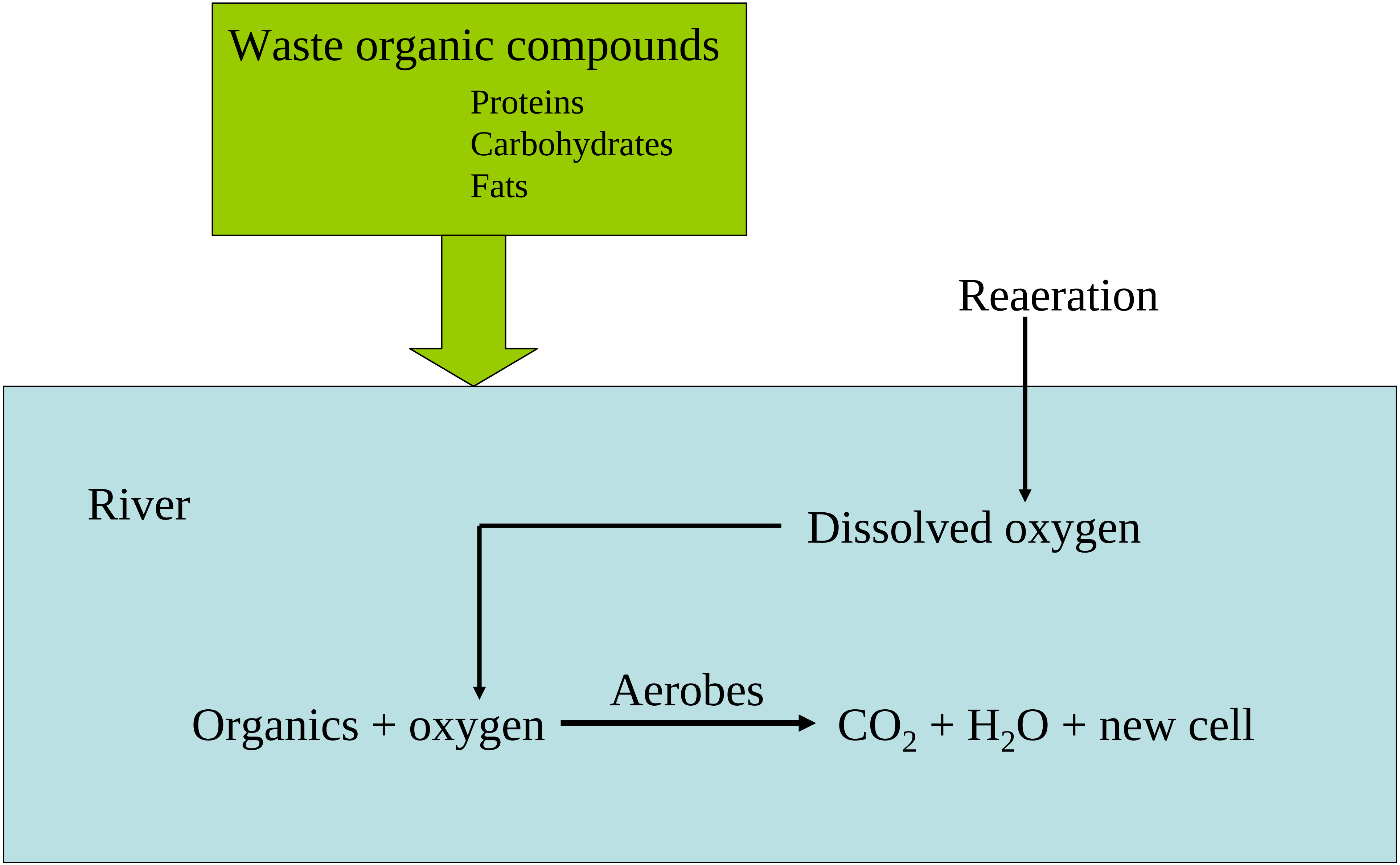
Estuary

Ocean

Water quality and pollution

- Stream pollution and self-purification

Stream pollution and self-purification



Waste organic compounds

Proteins
Carbohydrates
Fats

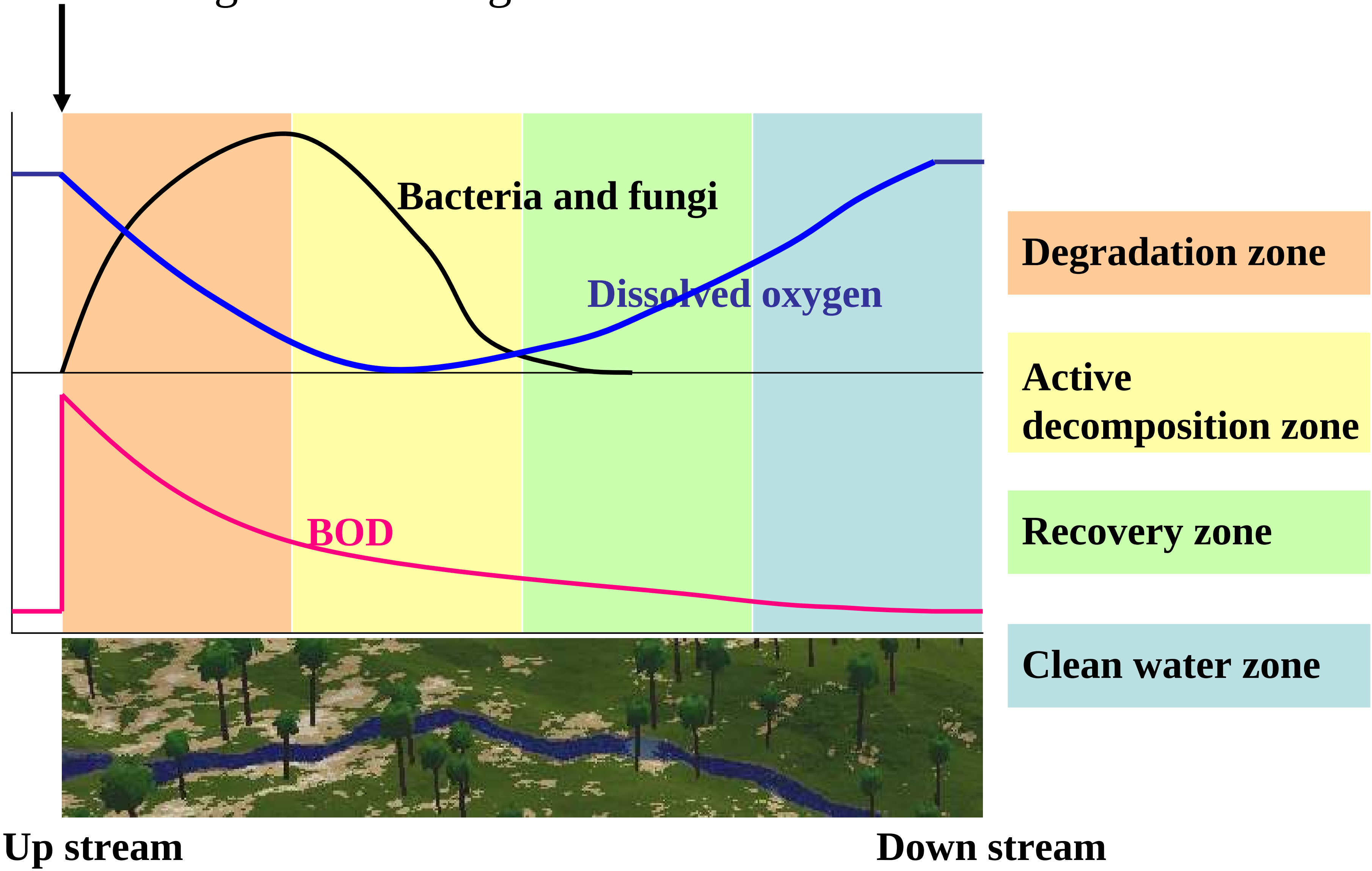
Reaeration

River

Dissolved oxygen

Organics + oxygen $\xrightarrow{\text{Aerobes}}$ CO_2 + H_2O + new cell

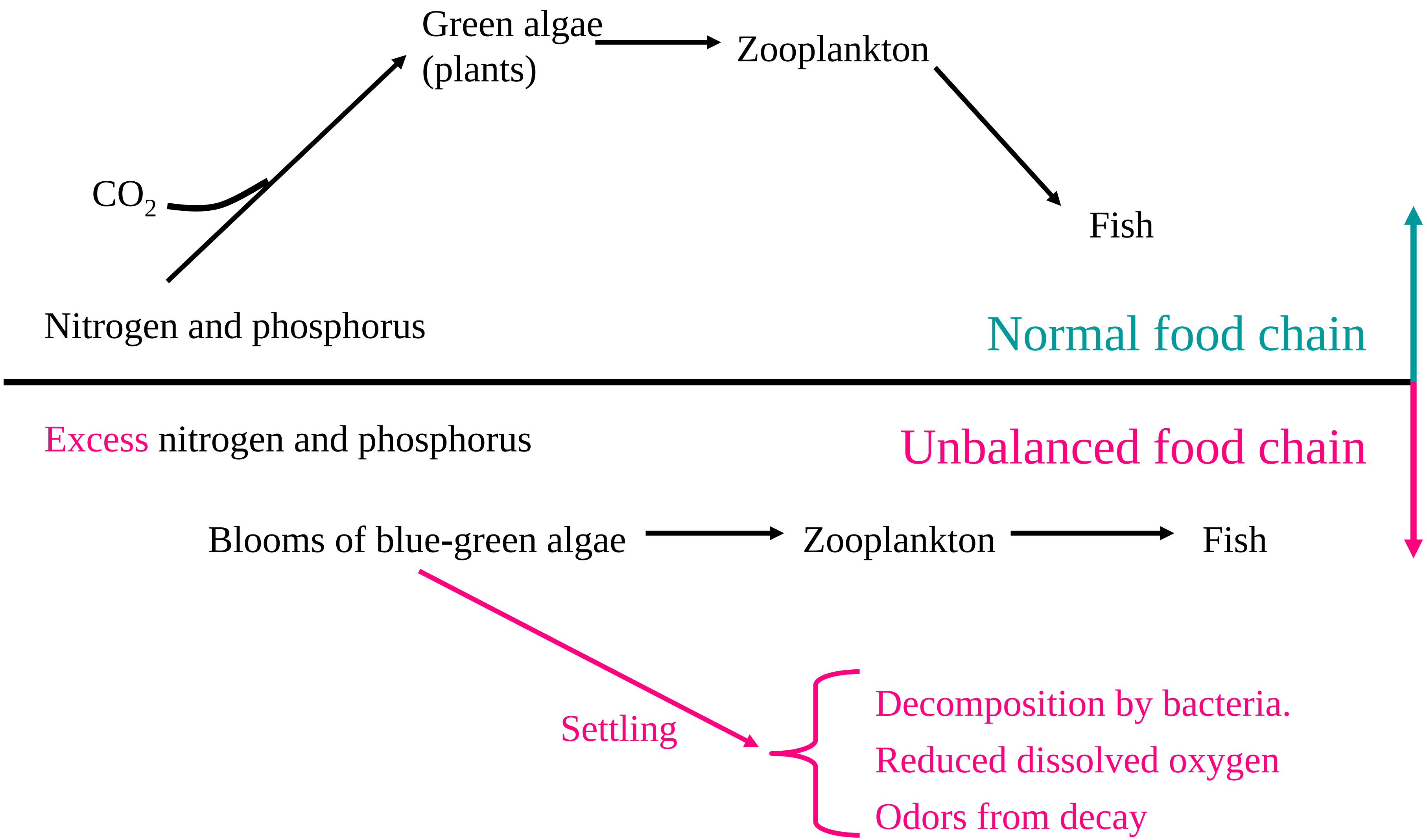
Discharge of waste organic matter



Effect of organic pollution and self-purification on a stream.

Water quality and pollution

- Eutrophication



Green algae (plants)

Zooplankton

Fish

CO_2

Nitrogen and phosphorus

Normal food chain

Excess nitrogen and phosphorus

Unbalanced food chain

Blooms of blue-green algae

Zooplankton

Fish

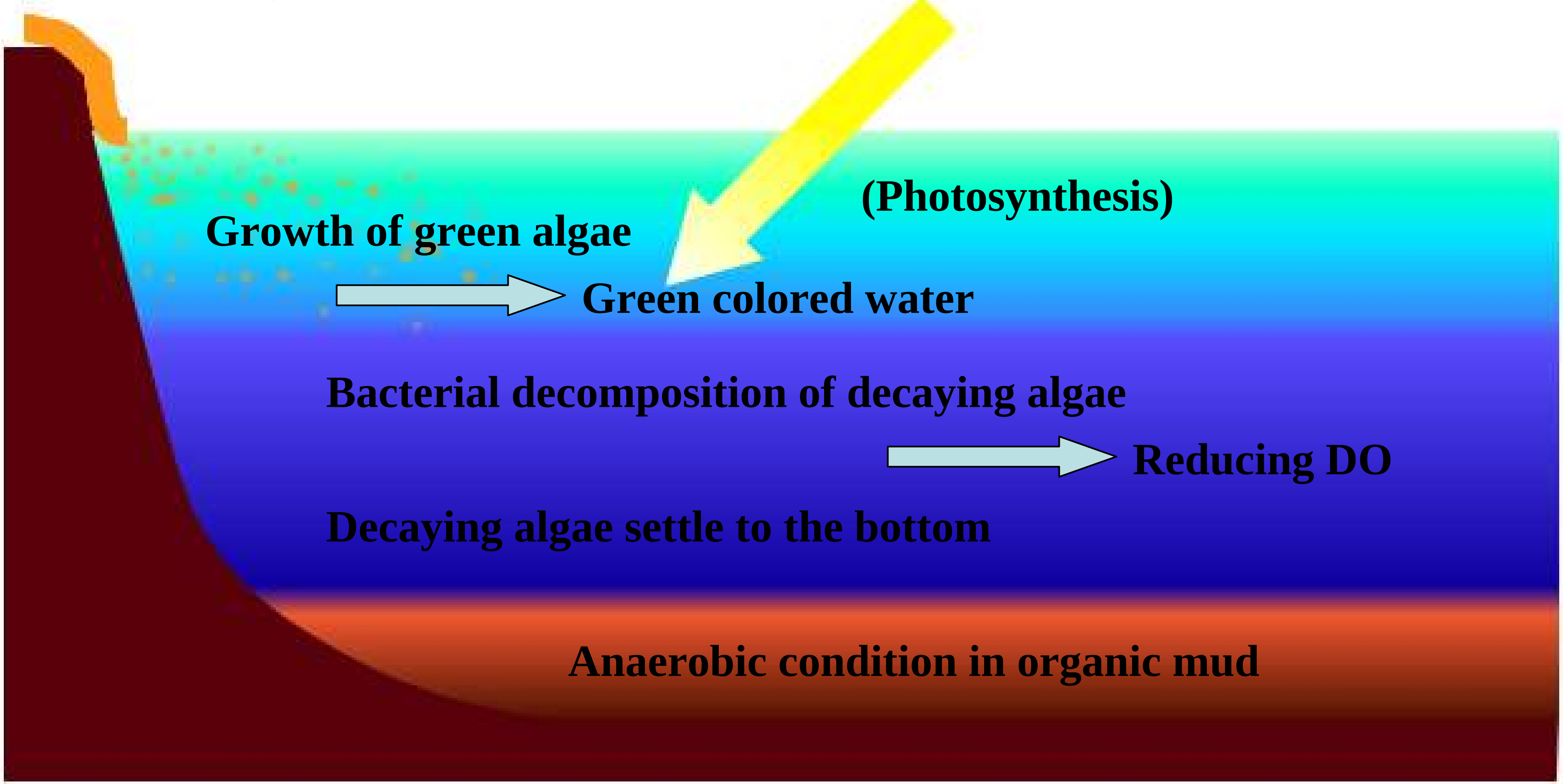
Settling

Decomposition by bacteria.

Reduced dissolved oxygen

Odors from decay

Aquatic food chain unbalanced by eutrophication compared with normal chain



Excess nitrogen and phosphorus

Sunlight

(Photosynthesis)

Growth of green algae → Green colored water

Bacterial decomposition of decaying algae → Reducing DO

Decaying algae settle to the bottom

Anaerobic condition in organic mud

Eutrophic lake

- The accepted upper limits for lakes free of algal blooms

(Ammonia + Nitrate)-N	0.3 mg/l
Orthophosphate-P	0.02 mg/l

- Lakes will exhibit algal blooms

Total-N	0.8 mg/l
Total-P	0.1 mg/l

Biological treatment systems

Activated sludge process

Advanced wastewater treatment

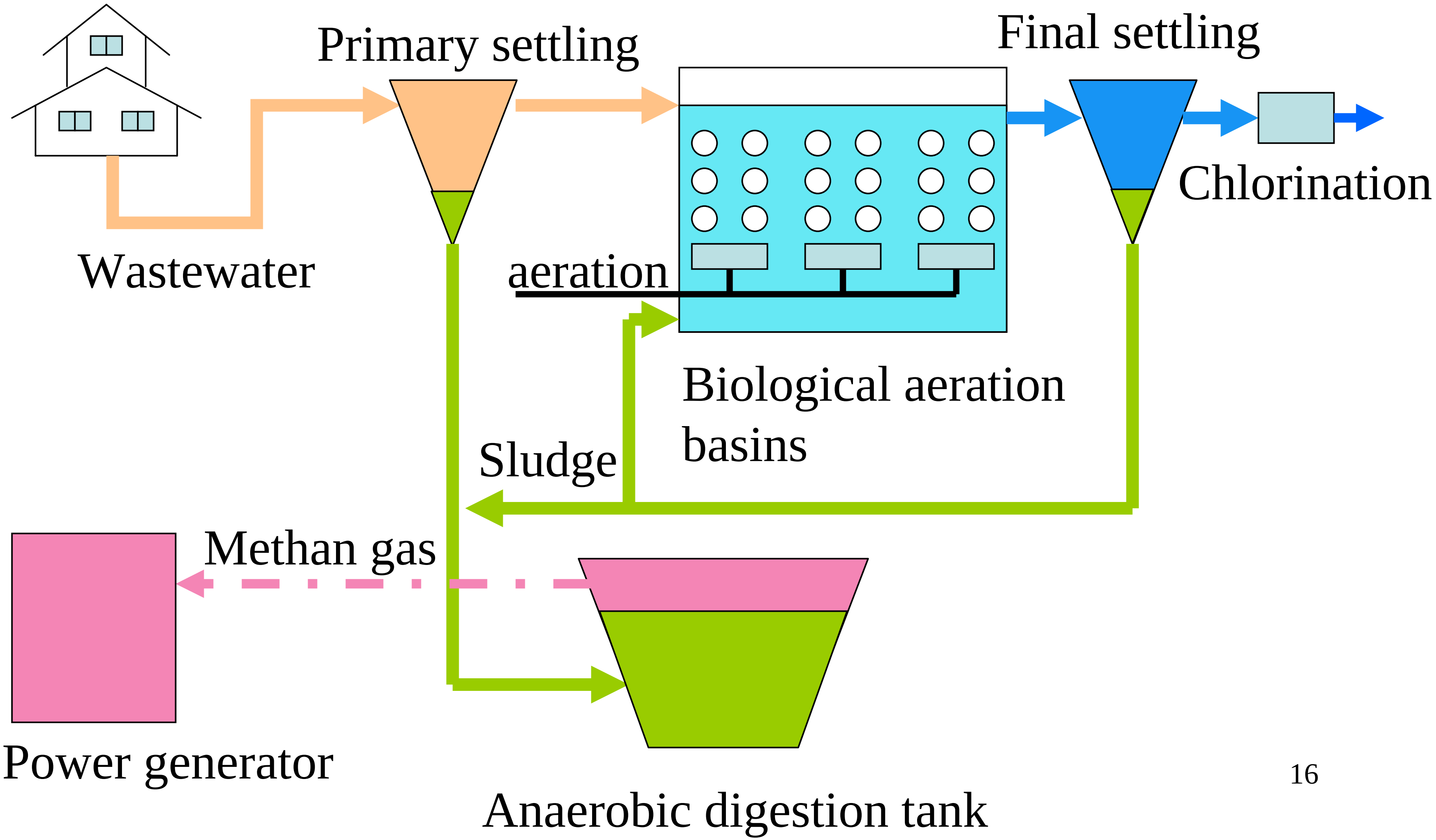
- Biological nitrogen removal
- Biological phosphorus removal

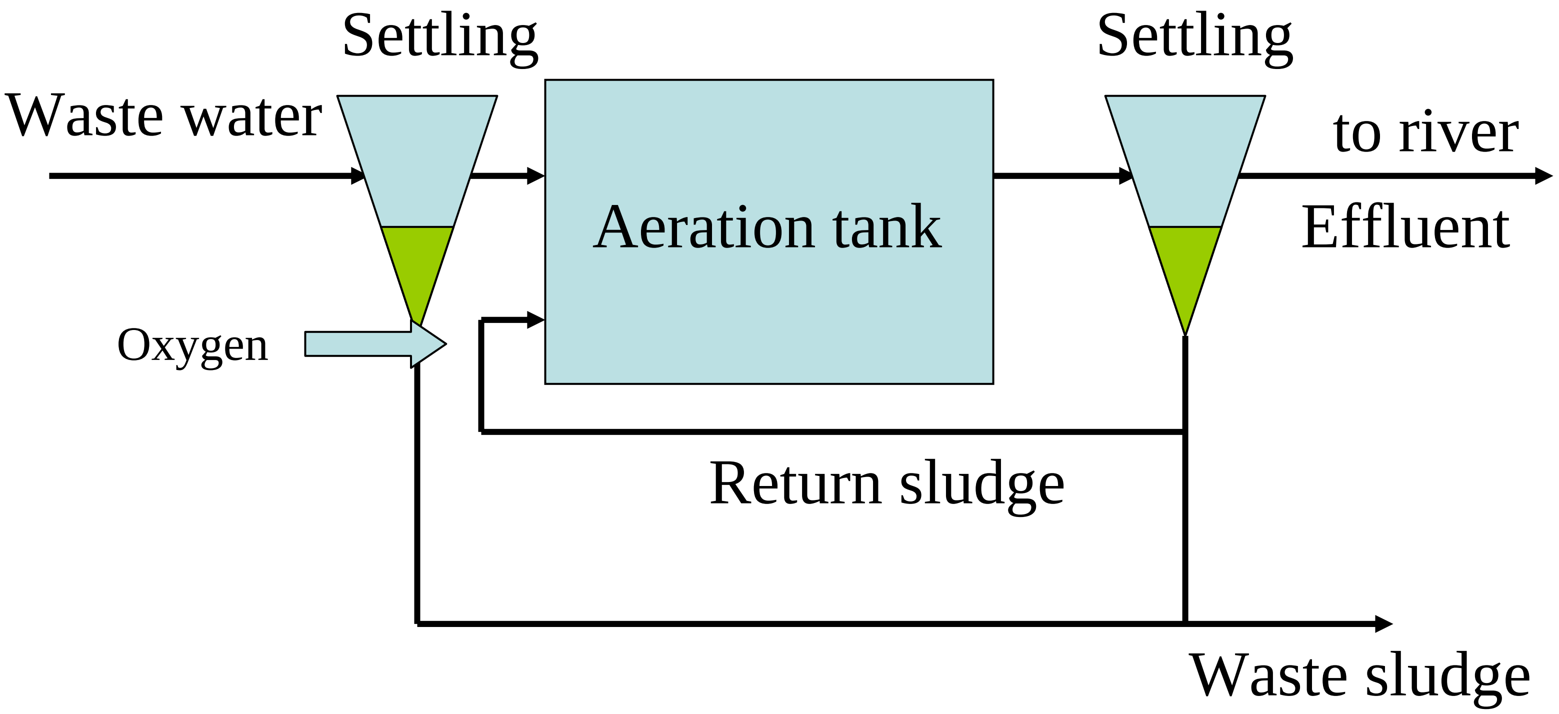
Biological treatment systems

Activated sludge process

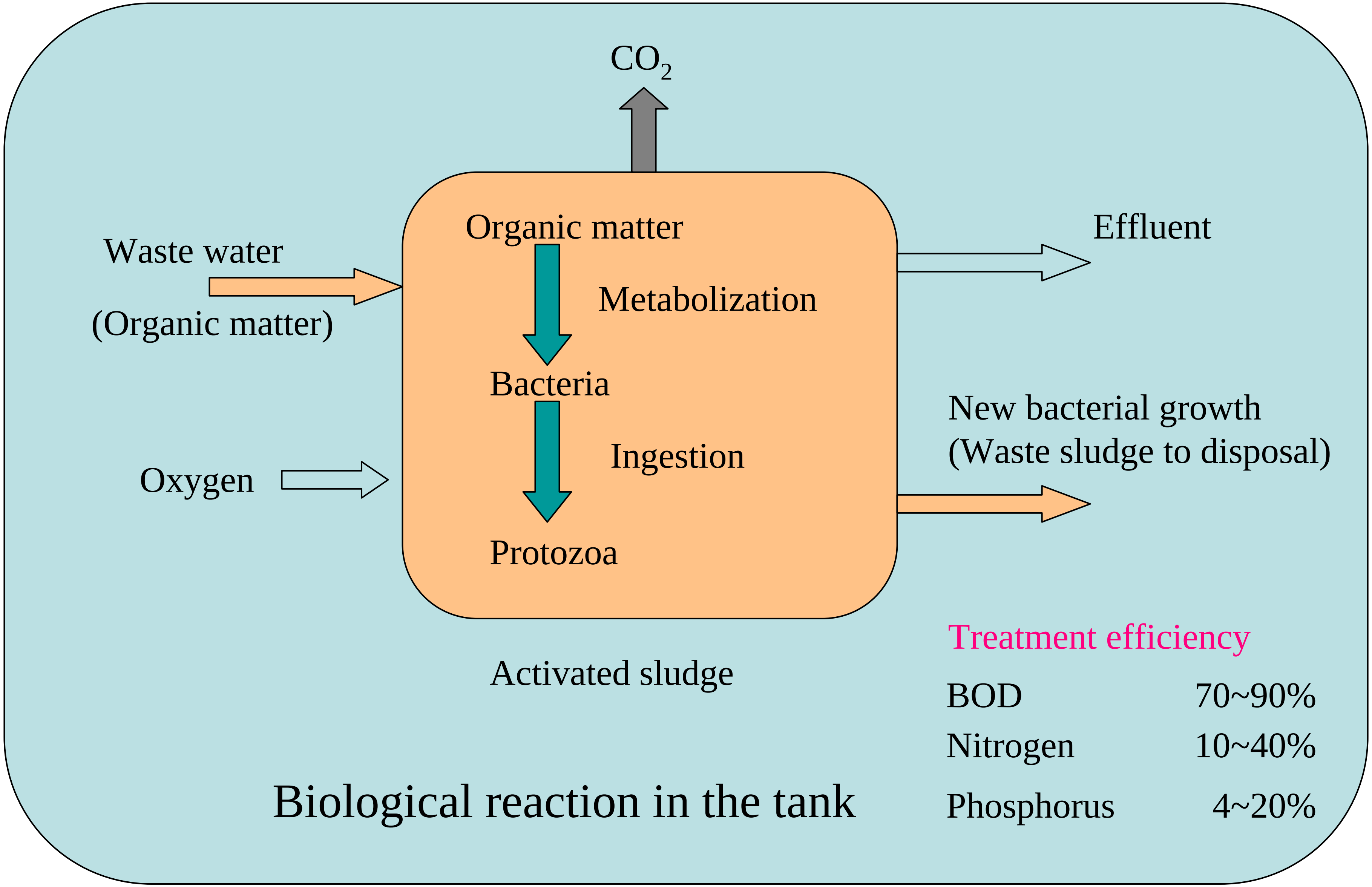
Biological treatment

1. Activated sludge process





Waste water treatment by activated sludge system



CO_2

Waste water

(Organic matter)

Oxygen

Organic matter

Metabolization

Bacteria

Ingestion

Protozoa

Activated sludge

Effluent

New bacterial growth
(Waste sludge to disposal)

Treatment efficiency

BOD	70~90%
Nitrogen	10~40%
Phosphorus	4~20%

Biological reaction in the tank

Waste water treatment by activated sludge system

Design of activated sludge process

Kinetics of biological growth

Application of kinetics to wastewater treatment systems

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Design of activated sludge process

Kinetics of biological growth

$$\left[\frac{dX}{dt}\right]_{grow} = Y\left[\frac{dS}{dt}\right]_{con} - k_d X \qquad (1)$$

- $\left[\frac{dX}{dt}\right]_{grow}$ = net growth rate of microorganisms

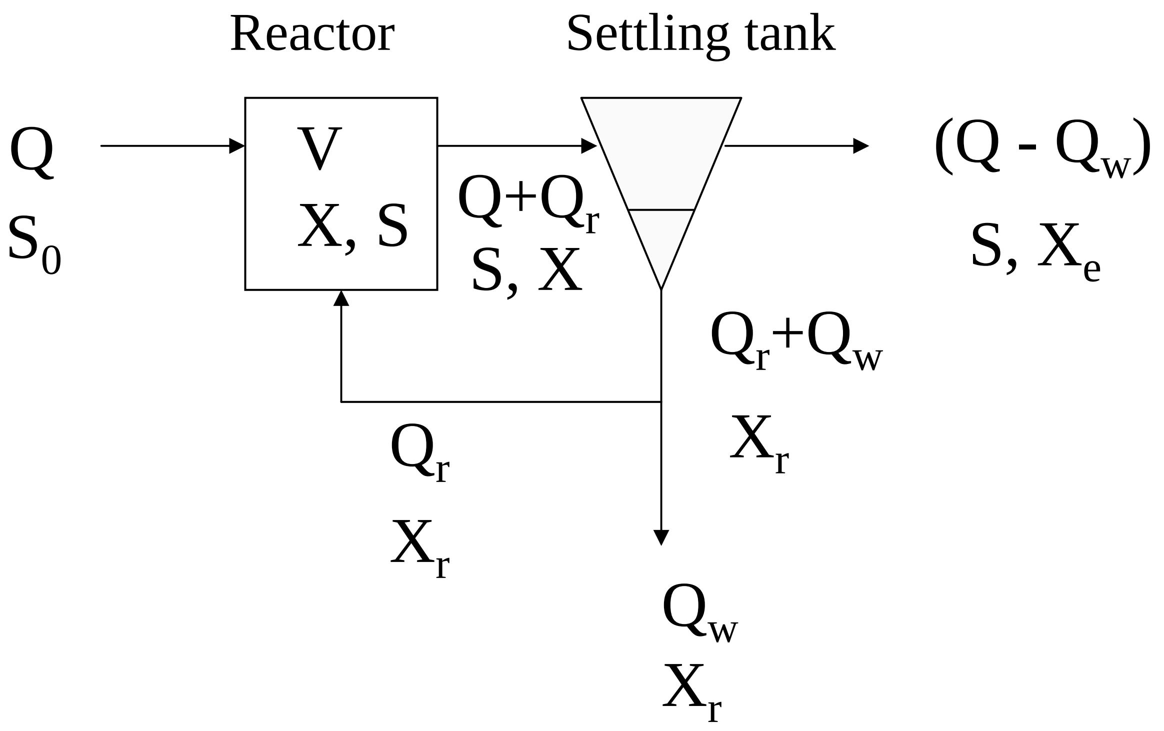
$\left[\frac{dS}{dt}\right]_{con}$ = rate of BOD utilization by microorganisms

k_d = microorganisms decay constant

Y = growth yield coefficient,

mass of microorganism /mass BOD utilized

Application of kinetics to treatment system



Reactor

Settling tank

Q

S_0

V

X, S

$Q+Q_r$

S, X

$(Q - Q_w)$

S, X_e

Q_r+Q_w

X_r

Q_r

X_r

Q_w

X_r

Schematic of an activated sludge reactor with sludge recycle

A material balance for the mass of cells in the entire system can be written as

$$\begin{bmatrix} Rate\ of\ change \\ of\ cells \\ concentration \\ in\ reactor \end{bmatrix} = \begin{bmatrix} Net\ rate\ of \\ cells\ growth \\ in\ reactor \end{bmatrix} - \begin{bmatrix} Rate\ of\ cells \\ outflow \\ from\ reactor \end{bmatrix}$$

$$V\left(\frac{dX}{dt}\right) = \left(Y\left(\frac{dS}{dt}\right)_{con} - k_d X\right)V - \left(Q_w X_r + \left(Q - Q_w\right)X_e\right) \qquad (2)$$

Y : growth yield coefficient, mass of cells / mass BOD utilized

k_d : cells decay coefficient

X : the concentration of cells in the reactor

X_e : the concentration of cells in the effluent

X_r : the concentration of cells in the recycle flow

Q_w: the cell-wasting rate.

$$\left(\frac{dS}{dt}\right)_{con} = consumption\ rate\ of\ BOD$$

At steady state, *dX/dt* equals 0, Eq. (2) can be rewritten as

$$\left(Q_w X_r + \left(Q - Q_w\right) X_e\right) = \left(Y \left(\frac{dS}{dt}\right)_{con} - k_d X \right) V \qquad (3)$$

In a system with a properly operating settling units, the concentration of the cells in the effluent, X_e is very small, Eq. (3) can be simplified to give

$$Q_w X_r = \left(Y \left(\frac{dS}{dt}\right)_{con} - k_d X \right) V \qquad (4)$$

Dividing both sides of Eq. (4) by *XV* gives

$$\frac{Q_w X_r}{XV} = \left(\frac{Y}{X} \left(\frac{dS}{dt}\right)_{con} - k_d \right) \qquad (5)$$

The mean cell residence time θ_c is defined as

$$\theta_c = \frac{XV}{Q_w X_r} \qquad (6)$$

The mean hydraulic retention time θ for the reactor is defined as

$$\theta = \frac{V}{Q} \qquad (7)$$

where,

V : the volume of the reactor

Q : the flow rate of waste water to the reactor

-

Eq.(5) can be simplified

or

$$\frac{1}{\theta_c} = Y\left(\frac{\left(\frac{dS}{dt}\right)_{con}}{X}\right) - kd \qquad (8)$$

$$\frac{1}{\theta_c} = Y\nu - k_d \qquad (9)$$

where,

$$\nu = \frac{\left(\frac{dS}{dt}\right)_{con}}{X}$$

ν is commonly known as the specific BOD consumption rate or specific waste removal rate.

The waste removal rate in the reactor can be evaluated,

$$V\left(\frac{dS}{dt}\right)_{con} = Q\left(S_0 - S\right) \qquad (10)$$

Using Eqs. (6), (7) and (10), the cell concentration *X* in the reactor can be obtained,

$$X = \frac{\theta_c}{\theta}\frac{Y\left(S_0 - S\right)}{1 + k_d\theta_c} \qquad (11)$$

Sludge production rate, R_s can be calculated by using Eq. (6)

$$R_s = Q_w X_r = \frac{XV}{\theta_c} \qquad (12)$$

Oxygen requirements

The theoretical oxygen requirement can be calculated by knowing BOD of wastewater and the amount of organisms wasted from the system.

$$O_2\left(\frac{g}{day}\right)=\begin{bmatrix} BOD\ utilized \\ per\ day \end{bmatrix}-\begin{bmatrix} BOD\ of\ organisms \\ wasted\ per\ day \end{bmatrix} \qquad (13)$$

The BOD of a mole of cells is assumed as follows,

$$C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + 2H_2O + NH_3 \quad (14)$$

Cells

(113g) (5x32g)

$$\frac{O_2}{cells} = \frac{160}{113} = 1.42\left(\frac{g\ O_2}{g - cell}\right) \quad (15)$$

Consequently, the BOD of cells is equal to

$$\text{BOD} = 1.42(\text{cells}) \quad (16)$$

Therefore, the theoretical oxygen requirement for an activated sludge system can be calculated as

$$O_2\left(\frac{g}{day}\right)=\left[\begin{array}{l}BOD\ utilized\\ per\ day\end{array}\right]-1.42\left[\begin{array}{c}organisms\\ wasted\ \ per\ day\end{array}\right] \tag{17}$$

$$O_2\left(\frac{g}{day}\right)=\left(\frac{dS}{dt}\right)_{con}-1.42\left(\frac{dX}{dt}\right)_{gr} \tag{18}$$

$$=Q(S_0-S)-1.42Q_wX_r \tag{19}$$

Then, if the oxygen transfer efficiency of the aeration system is known, the actual air requirement can be determined.

Advanced wastewater treatment

Biological nitrogen removal

Nitrogen content in municipal wastes

4 - 6kg of nitrogen per person per year.

Common form of nitrogen

organic, ammonia, nitrate and nitrite.

Decomposition of nitrogenous organic matter

$$\text{Organic nitrogen compounds} \xrightarrow{\text{Bacterial decomposition}} NH_3$$

Advanced wastewater treatment

- Nitrification and nitrogen removal

Bacterial nitrification (autotrophic bacteria)

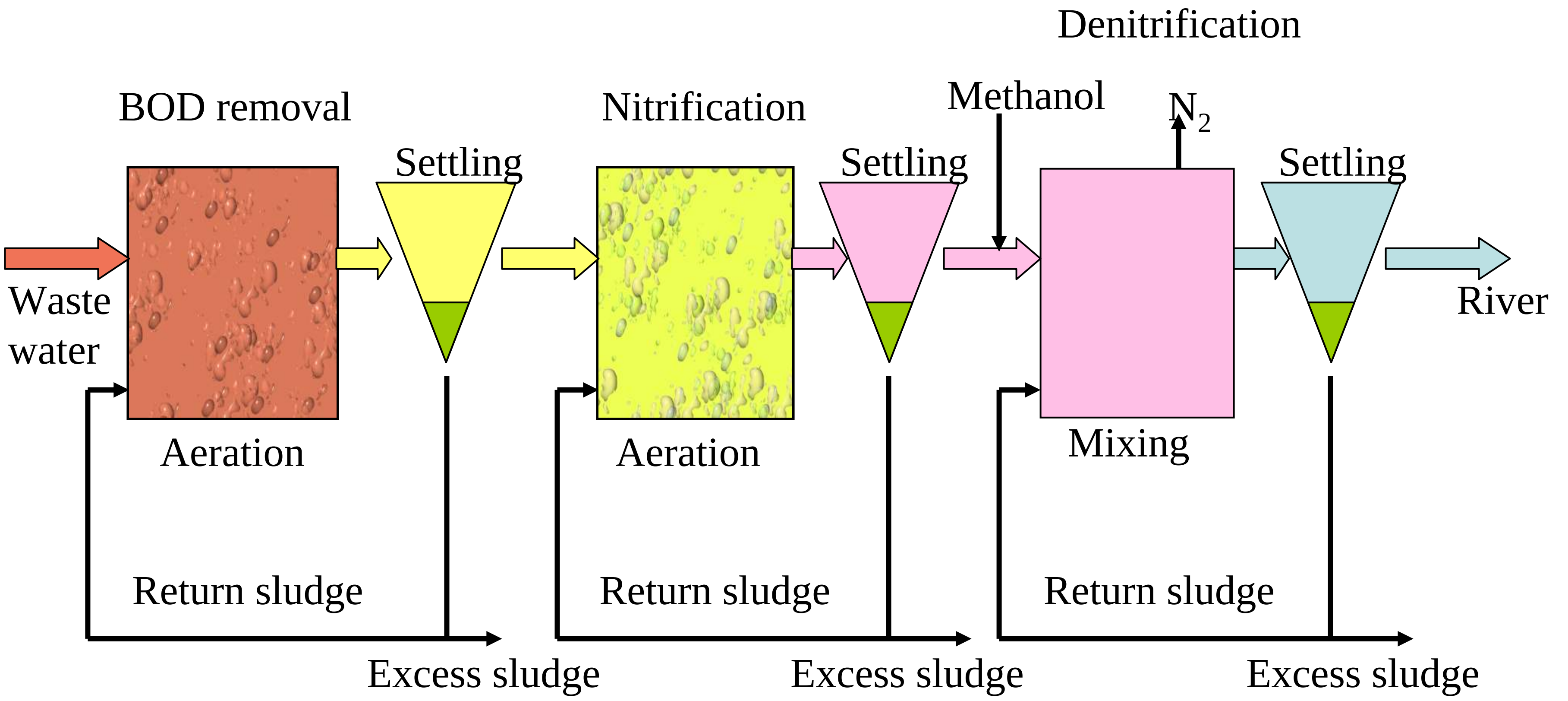
$$NH_4^+ + \frac{3}{2} O_2 \xrightarrow{\textit{Nitrsomonas}} NO_2^- + 2H^+ + H_2O$$

$$NO_2^- + \frac{1}{2} O_2 \xrightarrow{\textit{Nitrobacter}} NO_3^-$$

Bacterial denitrification (hetrotrophic bacteria)

$$\text{dissolved organic -C} + NO_x$$

$$\longrightarrow N_2 \uparrow \text{, } CO_2\text{, } H_2O\text{, biomass}$$



Advanced waste water treatment by three activated sludge system (Nitrogen removal)

Treatment efficiency

Conventional activated sludge process

BOD	70 – 80%
Nitrogen	10 – 40%

Advanced activated sludge process

BOD	80 - 90%
Nitrogen	60 – 70%

Advanced wastewater treatment

Biological phosphorus removal

Phosphorus content in the cell

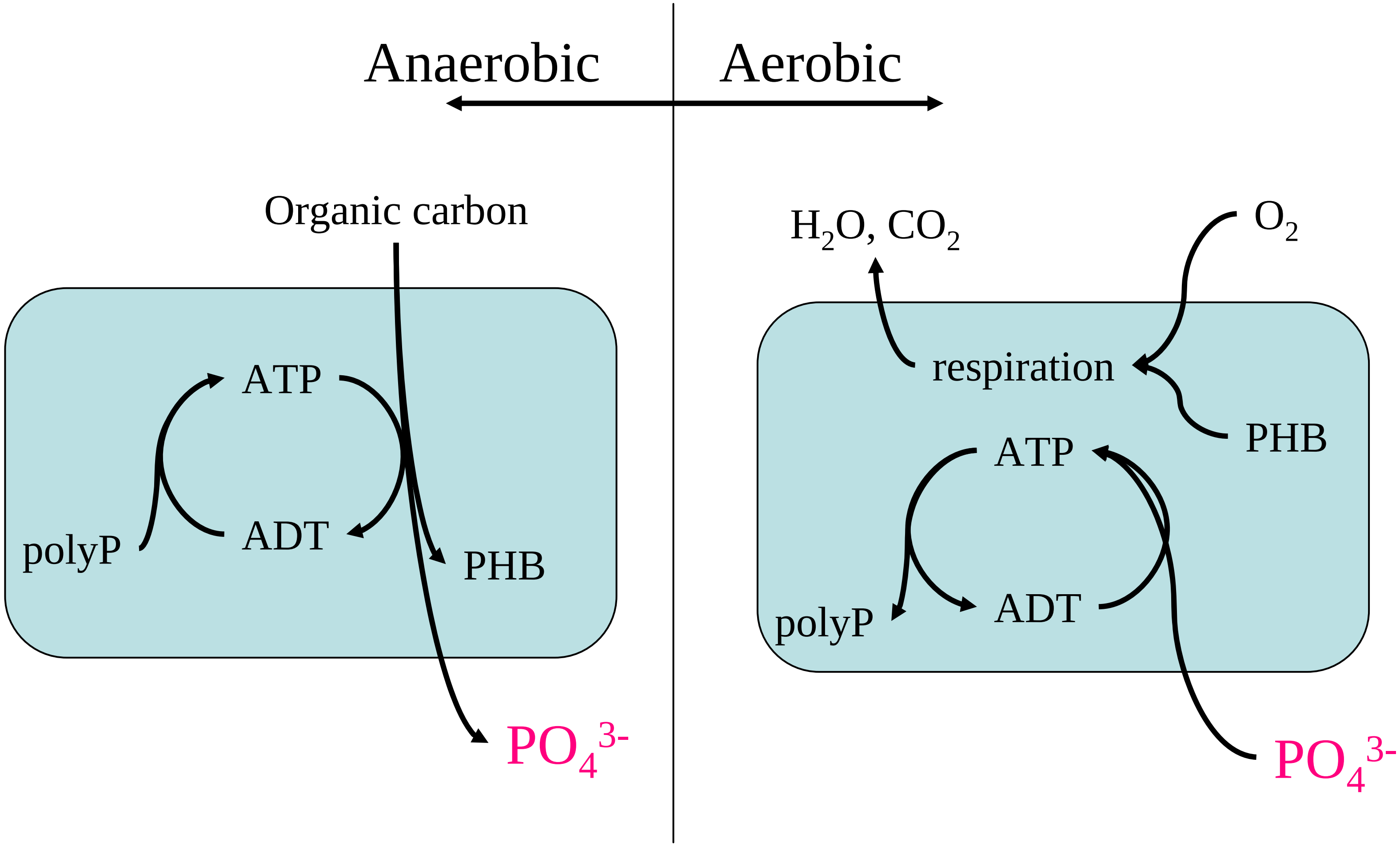
Conventional activated sludge

about 3% of the cell dry mass

Polyphosphate accumulating activated sludge bacteria

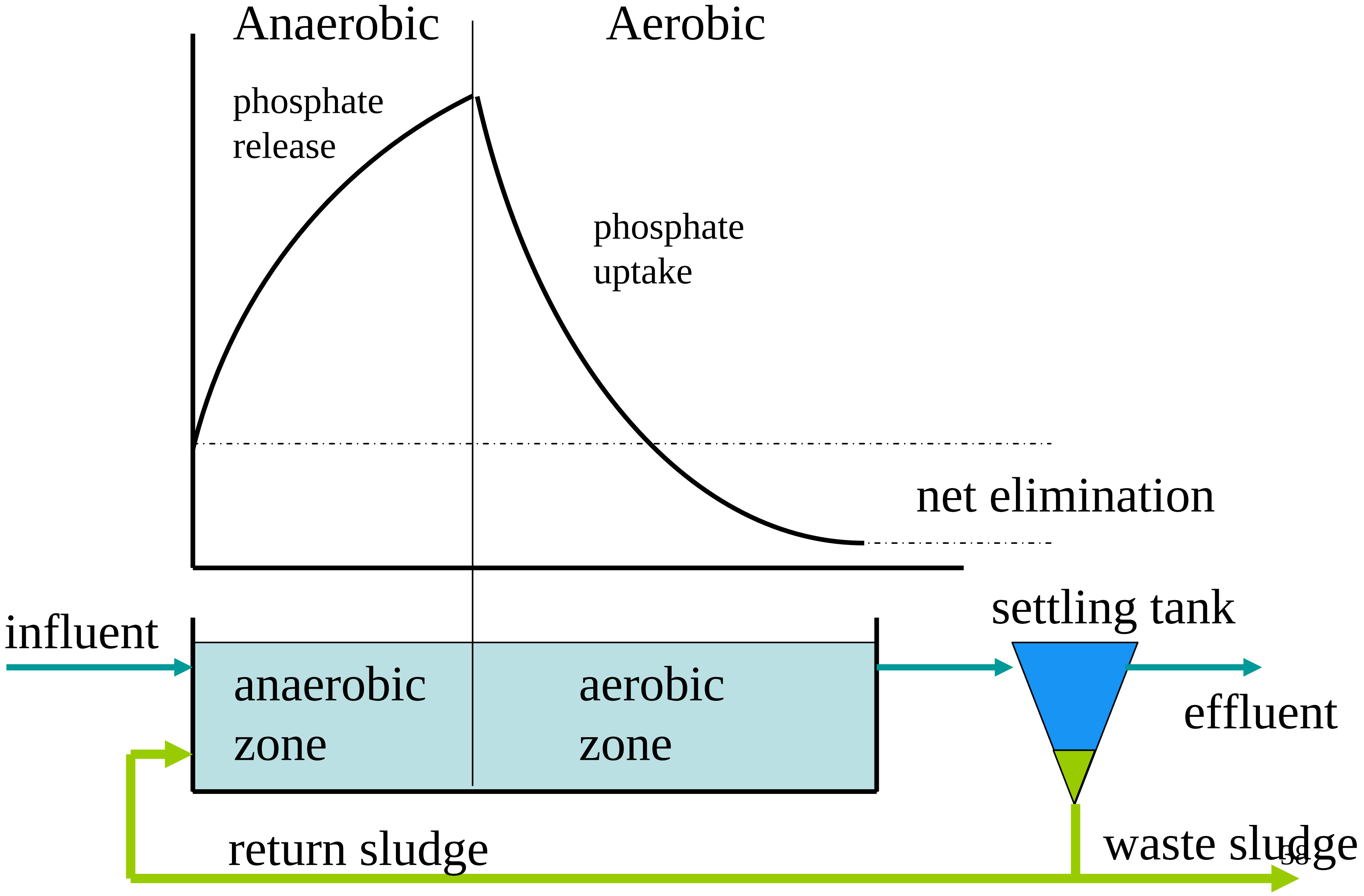
more than 12% of the cell dry mass

Biochemical model of enhanced phosphorus uptake and release



PHB : poly-β-3 hydroxy butyric acid
polyP : poly phosphate

Biological phosphorus removal



Anaerobic

Aerobic

phosphate
release

phosphate
uptake

net elimination

influent

anaerobic
zone

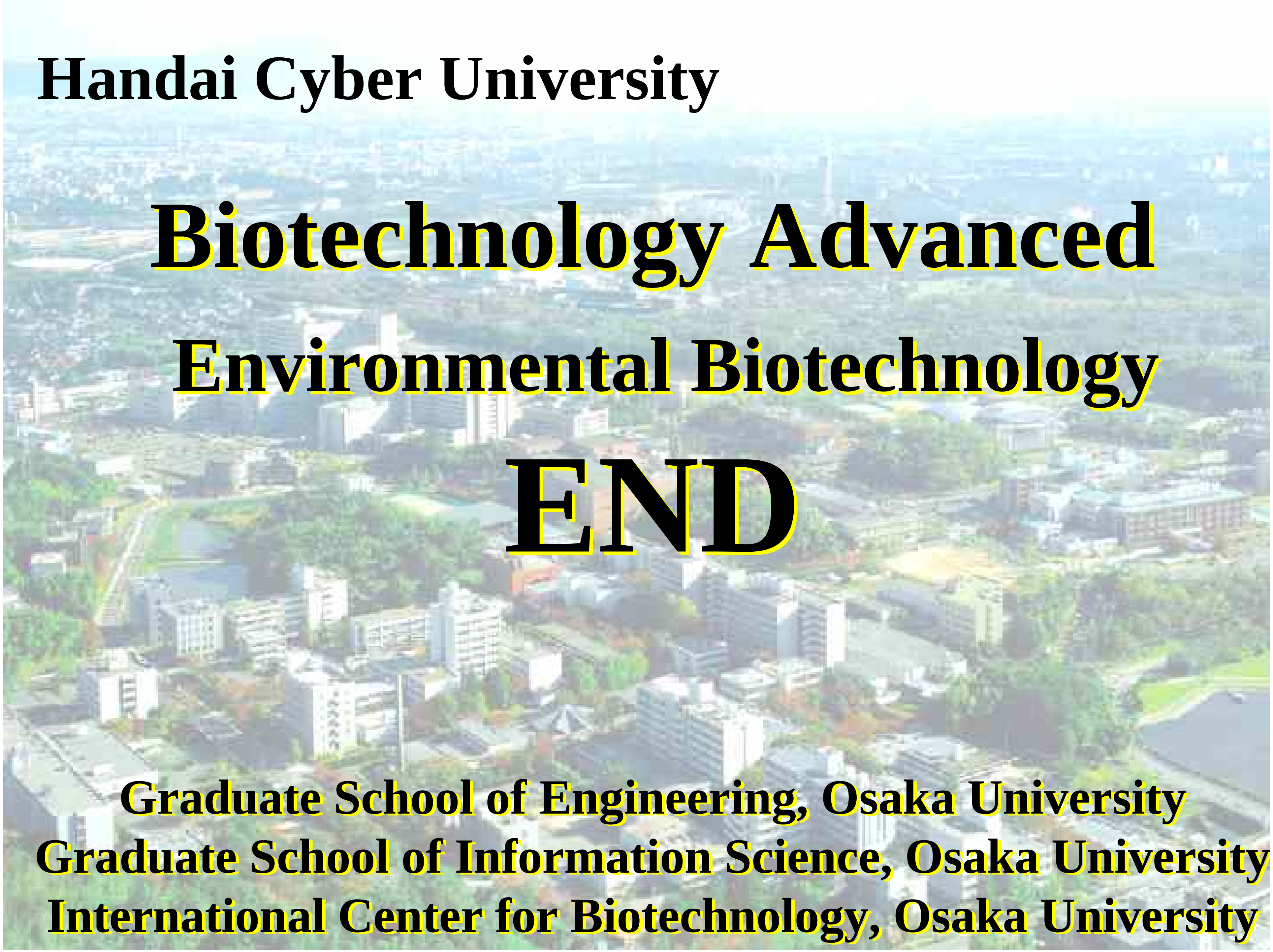
aerobic
zone

settling tank

effluent

return sludge

waste sludge



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