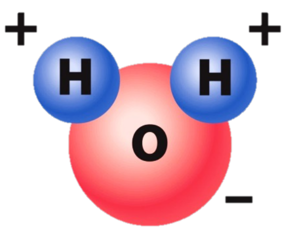
Water and Wastewater Treatment: From Traditional to Advanced Technologies



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Tel Aviv University

How the problem begun??!!

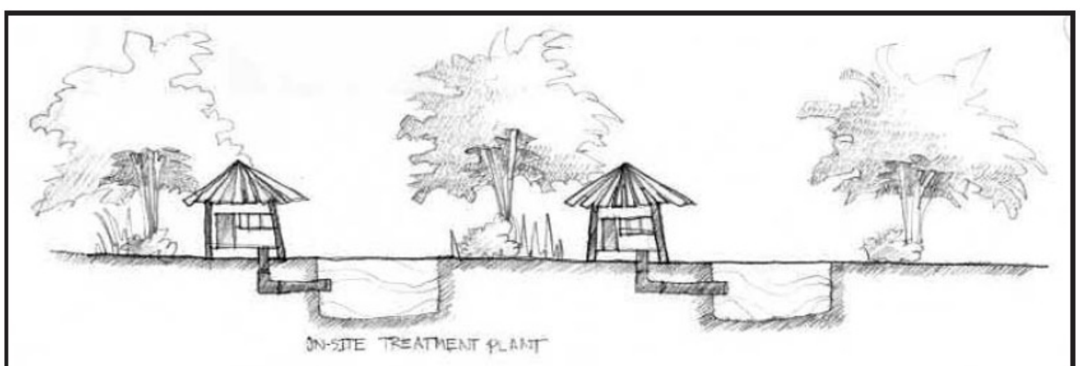


Figure 9: On-Site Wastewater Treatment Systems

S
E
W
A
G
E

Neolithic revolution

small towns and settlements > human excreta control generally non-problematic

"In days of old
When knights were bold
And toilets weren't invented
They'd leave their loads
Upon the roads
And walk away contented"

S
E
W
A
G
E

Post - Neolithic revolution:

- Large towns and cities > human waste control became a problem

- high-density living required technologies for handling human wastes in urban areas:
  - Chamber pots and open gutters
  - Pit privies/trench latrines/outhouses
  - Septic systems and variants
  - Centralized sewage collection and treatment systems

History of Water Treatment

History of Water Treatment (cont.)

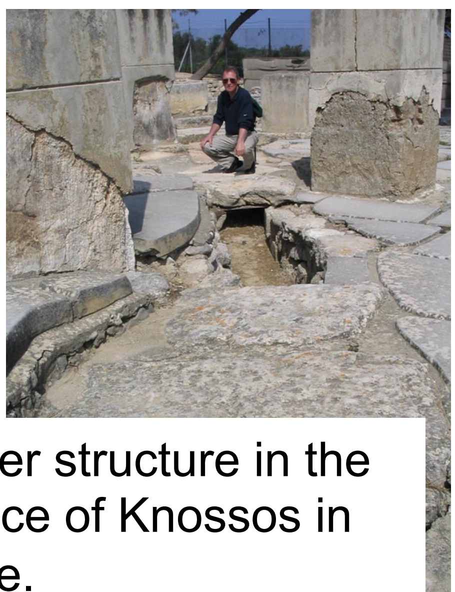
- Question: What is one of the earliest water treatment techniques used to treat water?

  Answer: boiling (conducted in containers)

- 4000 BC ancient Sanskrit (India) recommend "impure water should be purified by being boiled over a fire, or by being heated in the sun, or by dipping heated iron in to it, or it may be purified by filtration through sand and coarse gravel …"

History of Water Treatment (cont.)

3000-1500 B.C. Minoan civilization - Complex open-topped drainage systems carried storm water and sewage. Crete may be the home of the first "flush toilet" with an overhead water reservoir



Sewer structure in the Palace of Knossos in Crete.

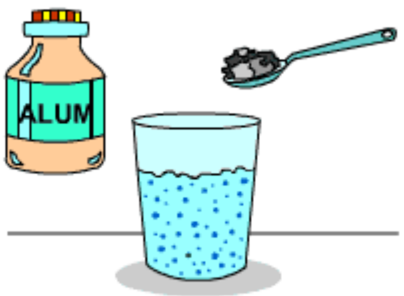
Sewer outfall on a wall outside the palace area

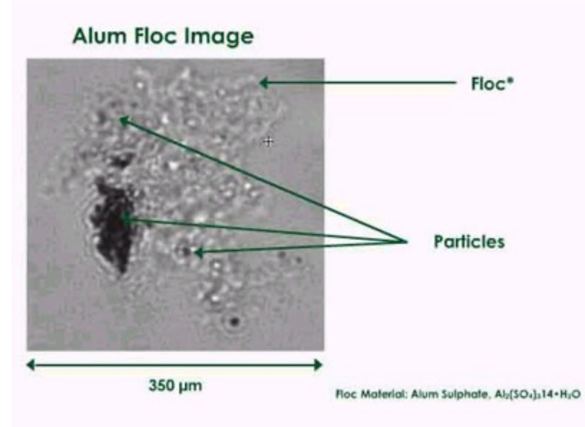
Queen's bathroom, Crete

http://www.sewerhistory.org/grfx/wh_era/minoan1.htm

History of Water Treatment (cont.)

- 1500 B.C. Egyptians used alum to cause suspended particles to settle down





- 5th century (460-377 B.C.) Hippocrates "father of medicine" designed his own crude water filter named "Hippocrates' sleeve" which was a cloth bag, to strain rain water after it had been boiled.

- 3rd century – development of public water systems in Rome, Greece, Egypt…

www.civil.uwaterloo.ca/.../images/fac_dpa2.jpg
resources.emb.gov.hk/.../water_step2.gif

History of Water Treatment (cont.)

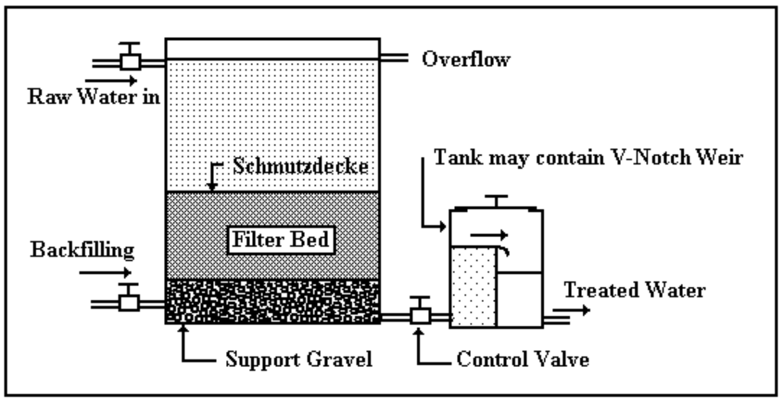
- 340 B.C Roman engineers creates a water supply that delivers water to Rome through aqueducts

- 1703 – French scientist La Hire propose that every household should have a sand filter

- 1746 - French scientist J. Amy granted 1st patent for a filter design composed of sponge, charcoal and wool for home use

History of Water Treatment (cont.)

- 1804 - First municipal water filtration plant in Scotland. Water distributed by a horse and cart
- 1807 – 1st city to pipe treated water to consumers
- 1829 – Installation of slow sand filter in London



- I835 – Dr. Dunlingsen recommends adding chlorine to make contaminated water potable- A REVOLUTIONARY THINKING!!

www.oasisdesign.net/images/SlowSandFilter.gif

History of Water Treatment (cont.)

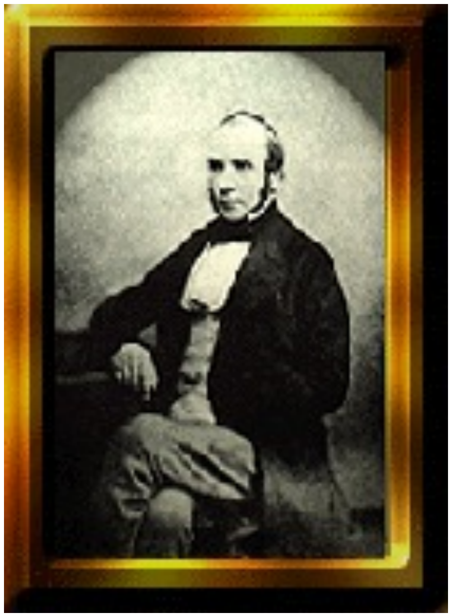
The Flush Toilet's Connection to Disease

- 1800s new flush toilets carried the waste directly into rivers and streams
- London drained its raw sewage into and withdrew its drinking water from the Thames River, both without any treatment.
- In 1850, the microbiologist Hassall wrote of the River Thames water, "...a portion of the inhabitants of the metropolis are made to consume, … a portion of their own excrement, and moreover, to pay for the privilege."

Source: http://ceeserver.cee.cornell.edu/mw24/engri113

History of Water Treatment (cont.)

John Snow – beginning of epidemiology



John Snow (1813-1858)

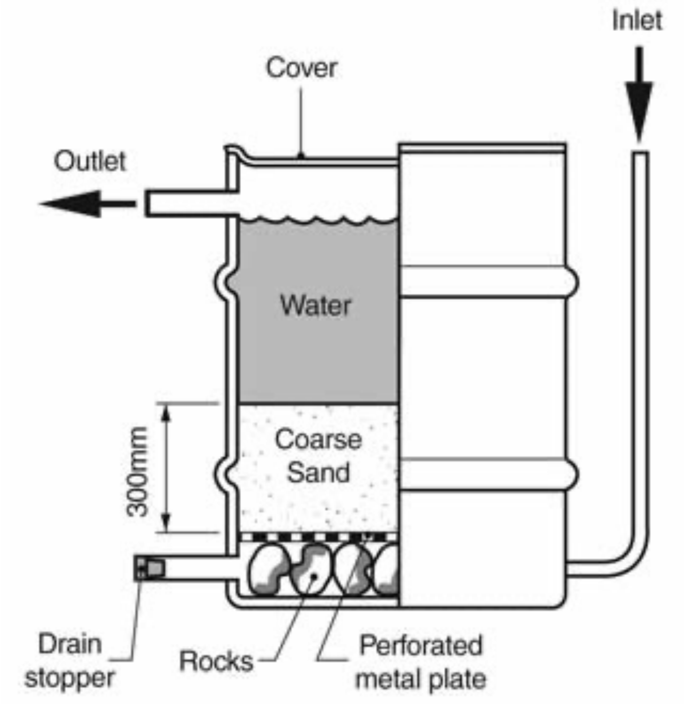
1854 - Snow suggested cholera was a infectious disease caused by a human poison that is found in the vomitus (קיא) and stools (צואה) of cholera patients returned from India. He proved a link between high cholera incidence and water use from Broad Street water pump. The pump was removed and the epidemic was contained.

History of Water Treatment (cont.)

Success and Challenges

- ✓ 1893 Smith – developed coliform test as means for evaluating presence of sewage contamination in water

- ✓ 1897 Fuller – demonstrated that rapid sand filtration is improved when preceded by coagulation sedimentation

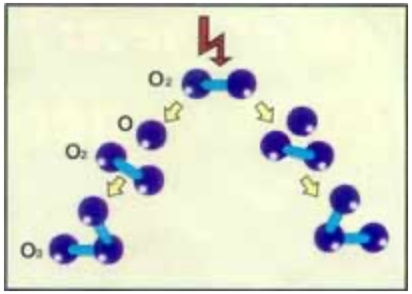


http://doultonusa.com/doulton_water_filters/593SIMUP.jpg

History of Water Treatment (cont.)

Success and Challenges

- 1902 – 1st drinking water supply is chlorinated in Belgium
- 1903 – Iron and lime (סיד) is added to soften water
- 1906 – 1st use of ozone as disinfectant, Nice France



- 1911 – G. Johnson demonstrates that filtration alone is not enough and that adding chlorination to the process reduces risk of bacterial contamination

http://www.creativeconceptsozair.com/gifs/strozn.jpg

History of Water Treatment (cont.)

Success and Challenges

- 1914 – US health service use Smith coliform test to set standards for bacterial tests in water
- 1941 – 85% of water supplies in the states are chlorinated
- 1974 – Dutch and American studies demonstrate that chlorination of water forms trihalomethanes (THM’s)
- Till 1950 most deadly waterborne disease such as Cholera and Typhoid (טיפוס המעיים) are mostly eliminated in developed countries because water were disinfected with chlorine

History of Water Treatment (cont.)

Success and Challenges

- 20th century – shift from acute diseases to chronic diseases caused by trace quantities of man-made contaminants

- Early 21st century – reduce chemicals and microbial contaminants and asses health impacts of trace quantities of chemicals

History of Water Treatment (cont.)

Notes and New Discoveries

- The term poisoning changed to disinfection
- Relationship between water-microorganisms and disease is known for less than 120 years
- Chlorine (oxidant) reacts with organic matter to form disinfection by products
- Pathogenic MO (*Cryptosporidium* and *Giardia*) can be of zoonotic origin (transmission from animals to man)
- Development of membrane filtration technologies for water treatment

Selection of treatment technology

- ✓ What is the type of water subjected to treatment? DW? WW? IDW? SW?
- ✓ What are the specific contaminants we're planning to remove?
- ✓ What is the designated, required water profile to achieve?
- ✓ The future (after treatment) effluent purpose is? Drinking? Irrigation? River rehabilitation?

Treatment Objectives

- ✓ Wastewater treatment systems take human and industrial liquid wastes and make them safe enough (from the public health perspective) to return to the aquatic or terrestrial environment.

- ✓ In some cases, wastewater can be clean enough for reuse for particular purposes.

- ✓ Wastewater treatment systems use the same processes of purification that would occur in a natural aquatic system only they do it faster and in a controlled situation.

Wastewater Treatment

- ✓Sewage or wastewater is composed of sewage or wastewater from:
  - ✓Domestic used water and toilet wastes
  - ✓Rainwater
  - ✓Industrial effluent (**Toxic industrial water is pretreated**)
  - ✓Livestock wastes

Wastewater - Definition

Wastewater: is simply the part of the water supply which has been used for different purposes and has been mixed with solids either suspended or dissolved.

Wastewater is 99.9% water and 0.1% solids. The main task in treating the wastewater is simply to remove most or all of this 0.1% of solids.

Impurities in water

- Sewage
  - 99.9% water
  - 0.1% solids (1000 mg/L)

- Solids
  - Suspended (x< 1μ)
    - Settleable
    - Non-settleable
  - Colloidal (0.001μ <x< 1μ)
  - Dissolved (x<0.001μ) - single molecules or ions

- Characteristics
  - Physical
  - Chemical
    - organic
    - inorganic
  - Biological

Wastewater: Type of wastewater from household

Type of Wastewater	Source of wastewater
Gray water	Washing water from the kitchen, bathroom, laundry (without faeces and urine)
Black water	Water from flush toilet (faeces and urine with flush water)
Yellow water	Urine from separated toilets and urinals
Brown water	Black water without urine or yellow water

Chemical characteristics of wastewater:-

Points of concern regarding the chemical characteristics of wastewater are:

- Organic matter
- Measurements of organic matter
- Inorganic matter
- Gases
- pH

Organic matter ($C_a H_b O_c$).

75% SS ⟶ organic. (Suspended Solids)
25% FS ⟶ organic. (Filtered Solids)

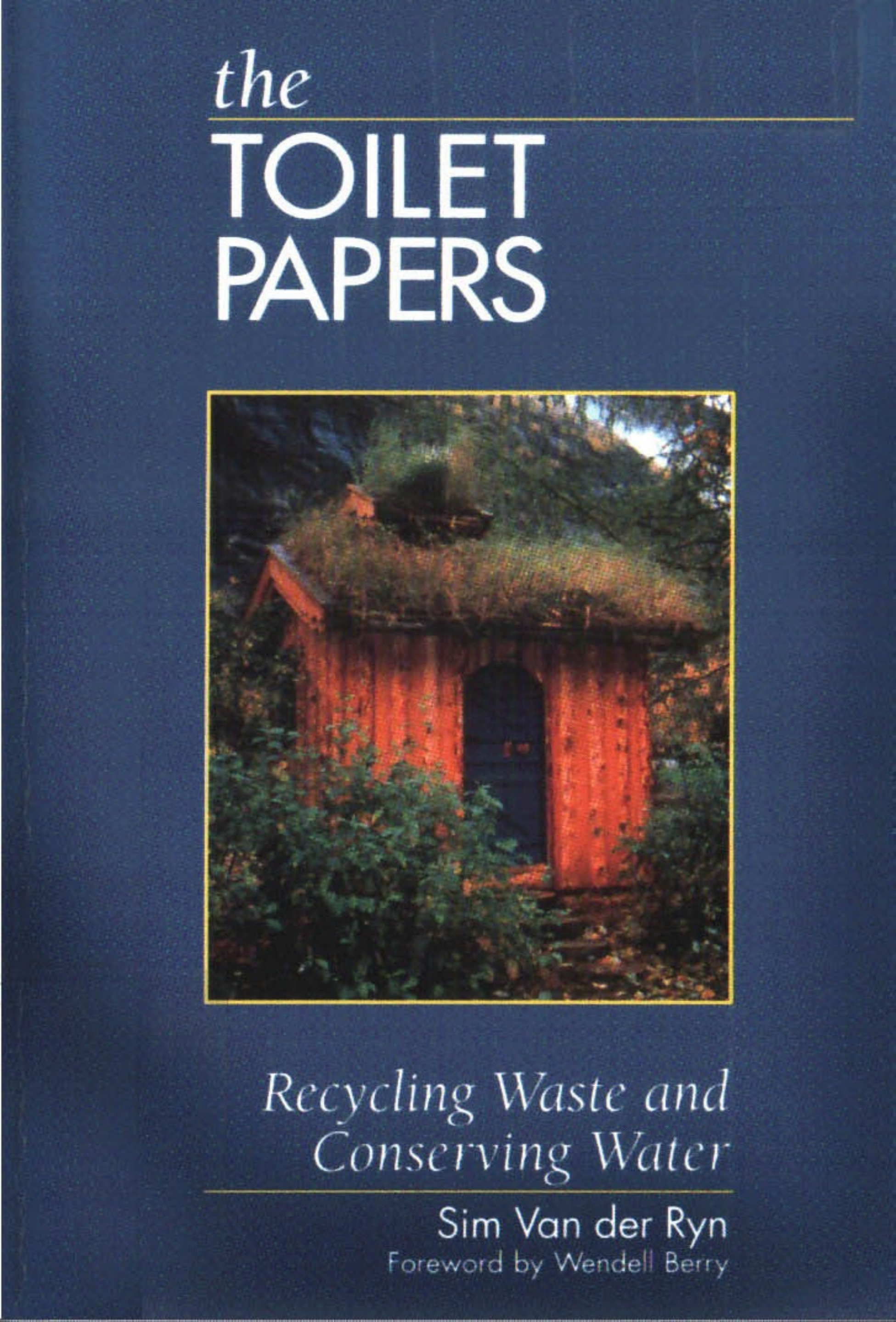
Organic mater is derived from animals & plants and man activities.

Proteins	(40-60%)
Carbohydrates	(25-50%)
Fats, Oils, and Grease	(10%)

W.W. Treatment

"Our excreta--not wastes, but misplaced resources--end up destroying food chains, food supply and water quality in rivers and oceans....How did it come to pass that we devised such an enormously wasteful and expensive system to solve a simple problem?“

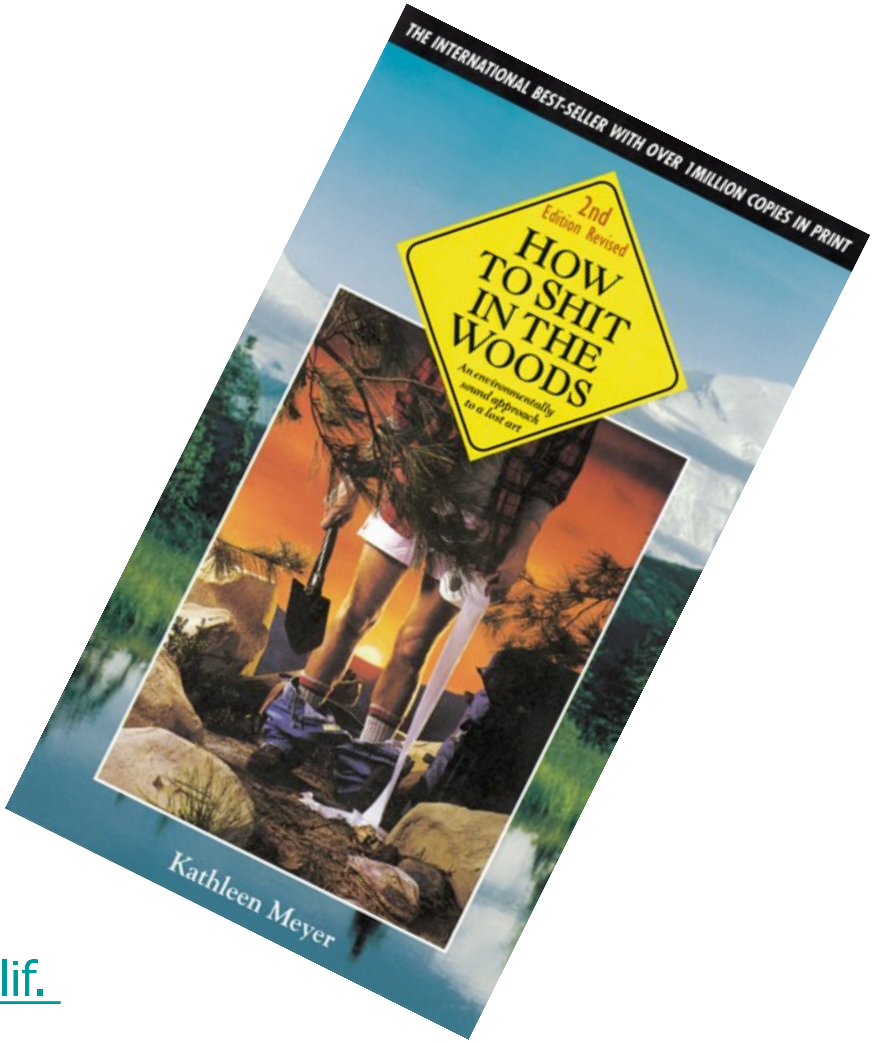
- Sim van der Ryn, ‘The Toilet Papers’ (1978)



Downstream Methods of Managing Sewage: Small scale

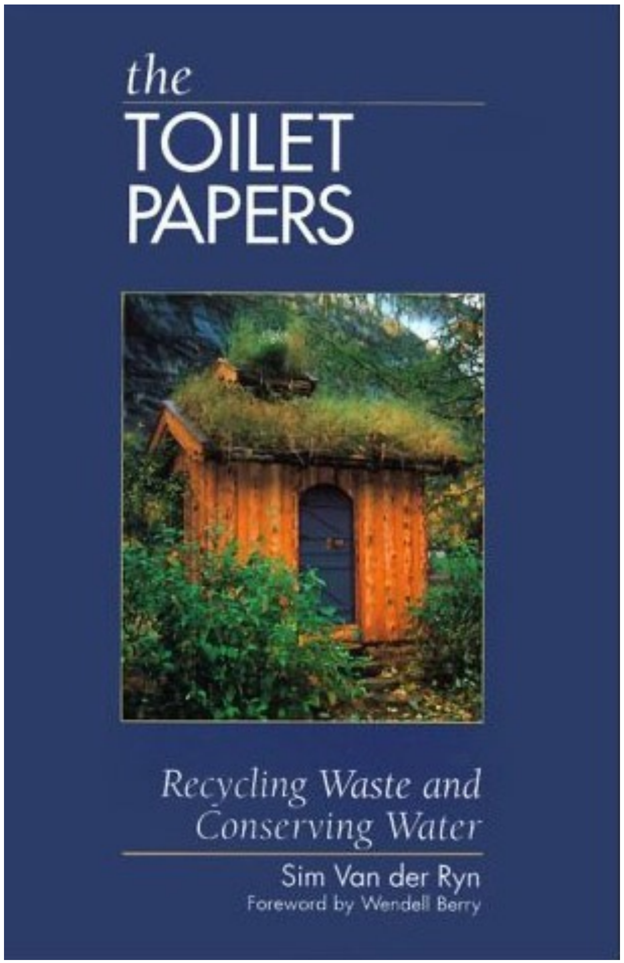
Temporary / short term:

- ✓ packing it out
- ✓ single-use holes
- ✓ pit privies
- ✓ trench latrines



Meyer, Kathleen. 1989.
How to shit in the woods :
an environmentally sound approach
to a lost art. Ten Speed Press, Berkeley, Calif.

Downstream Methods of Managing Sewage: Small scale

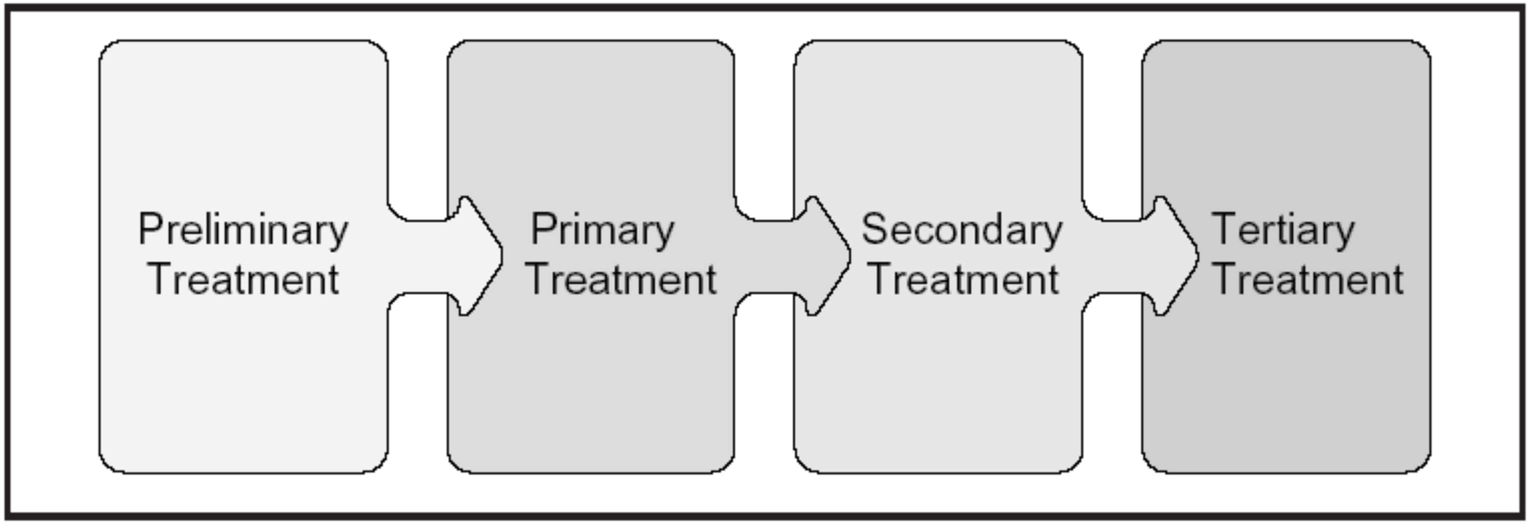


Long-term

- ✓ outhouses
- ✓ settling ponds
- ✓ septic tanks
- ✓ septic fields
- ✓ composting toilets

van der Ryn, Sim. 1978 (republished and revised 1999). The Toilet Papers: Recycling Waste and Conserving Water. Chelsea Green Publishing, Vermont. Online edition available at www.brocku.ca/tren/courses/tren3p14/2006/ToiletPapers.pdf

Downstream Methods of Sewage Treatment: Large Scale



W.W. Treatment - 1

Three main categories:

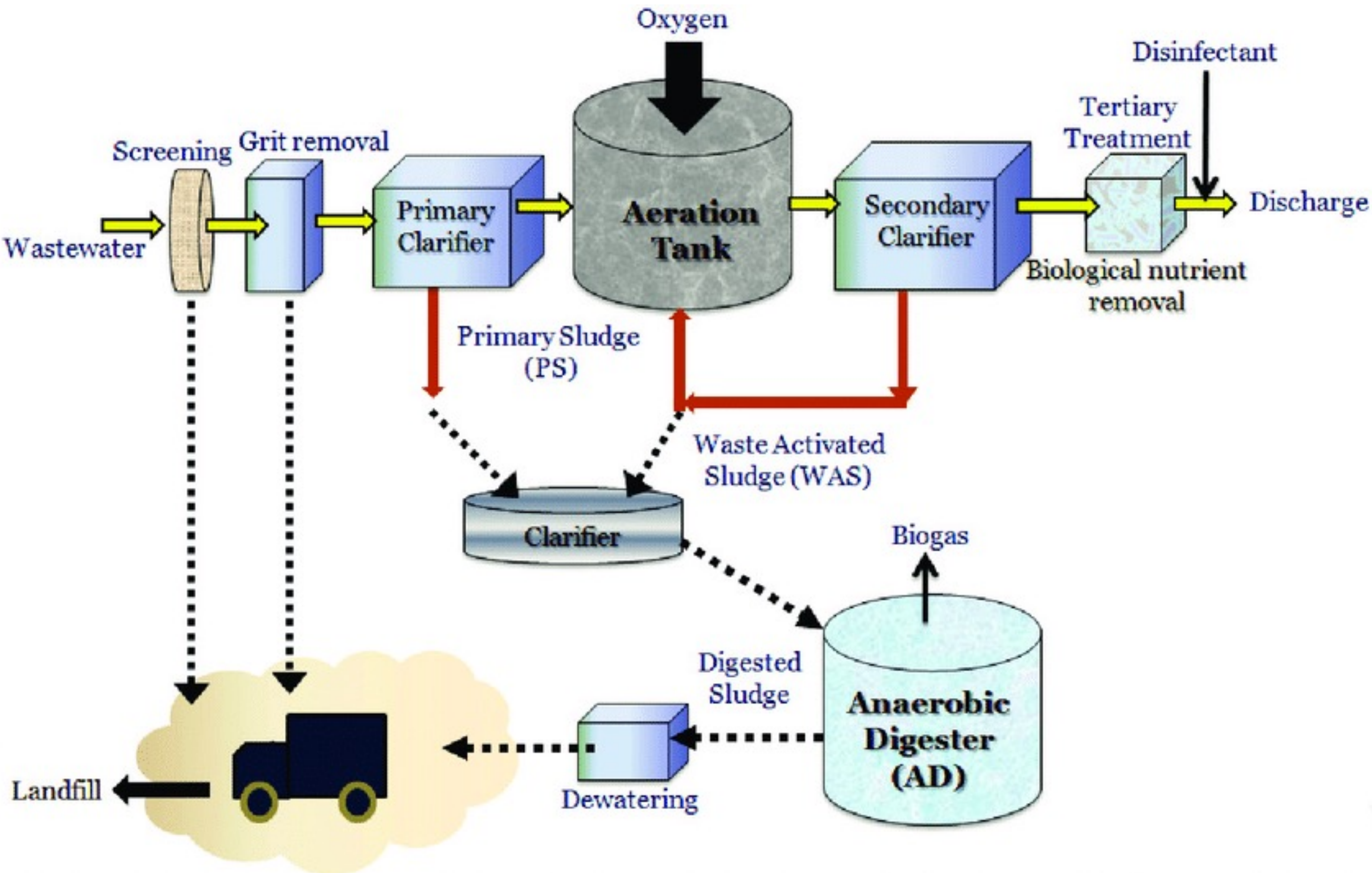
- Primary treatment: primary settling of solids, mechanical treatment- Screening and removal of large contaminants
- Secondary treatment: biological treatment- removal of biodegradable OM and nutrients include the related problem of disposal of WW sludge
- Tertiary treatment: removal of residual dissolved nutrients and persistent pollutants- include advanced treatment.

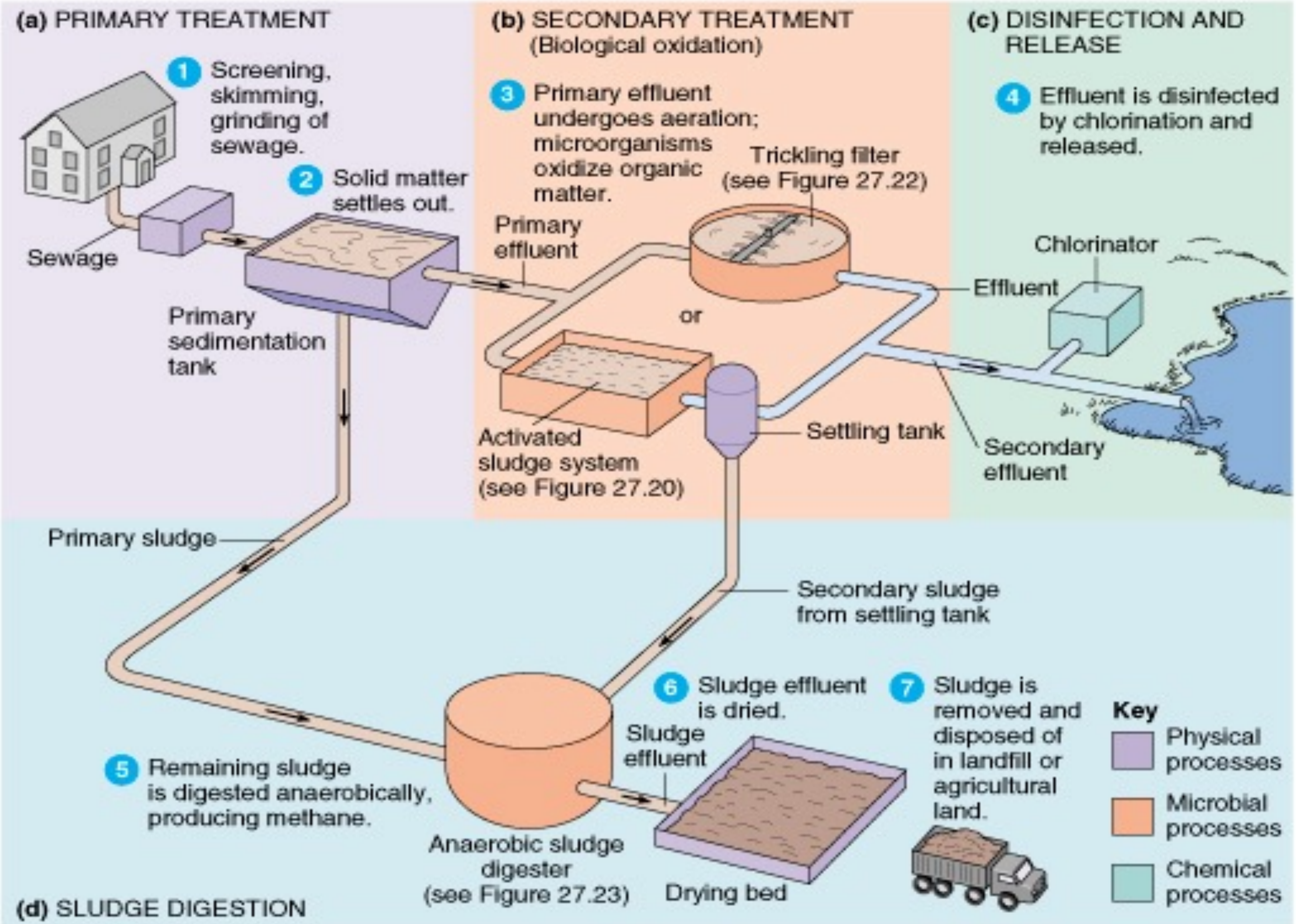
Wastewater Treatment

Purpose:

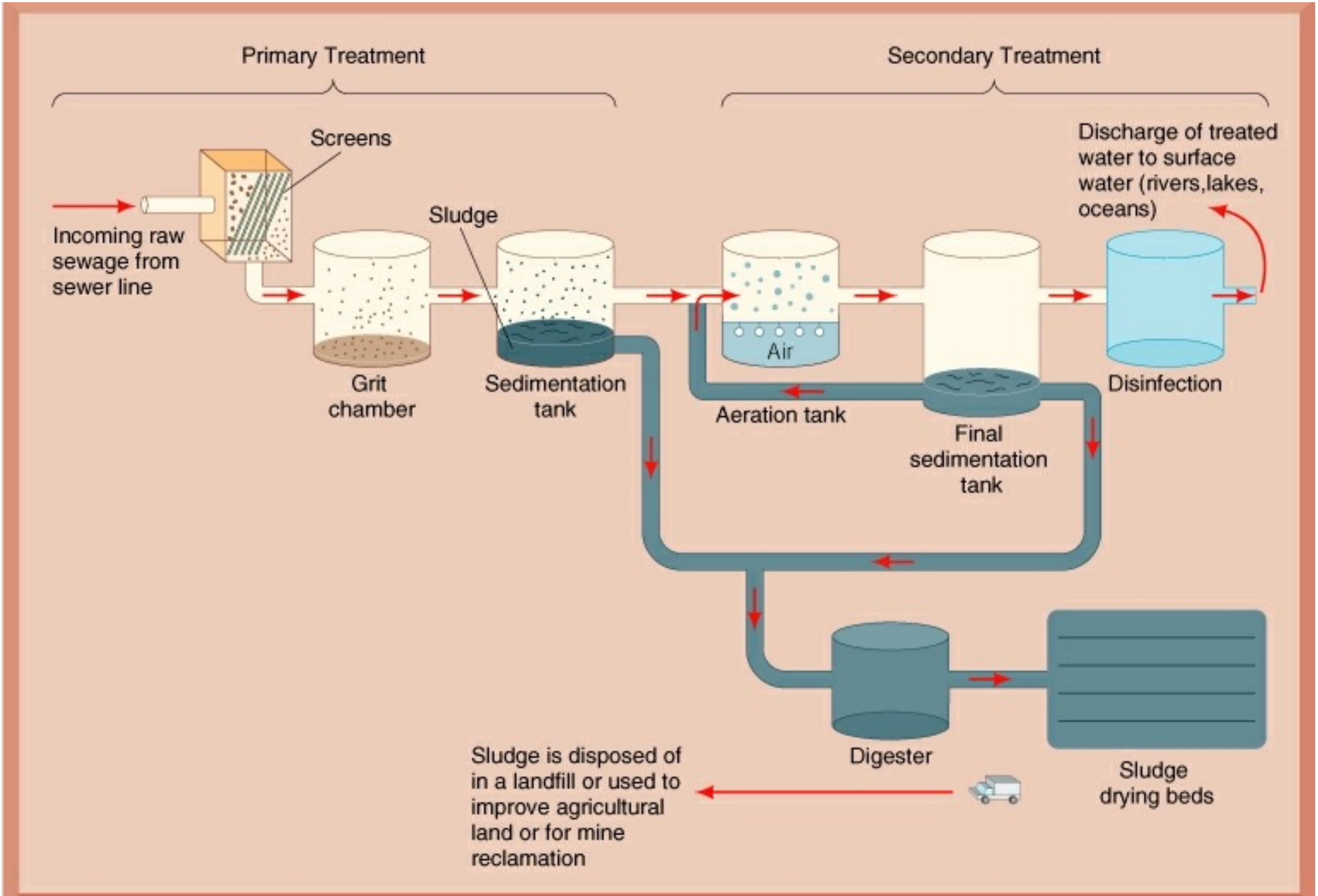
To manage water discharged from homes, businesses, and industries to reduce the threat of water pollution.

Wastewater Treatment Process

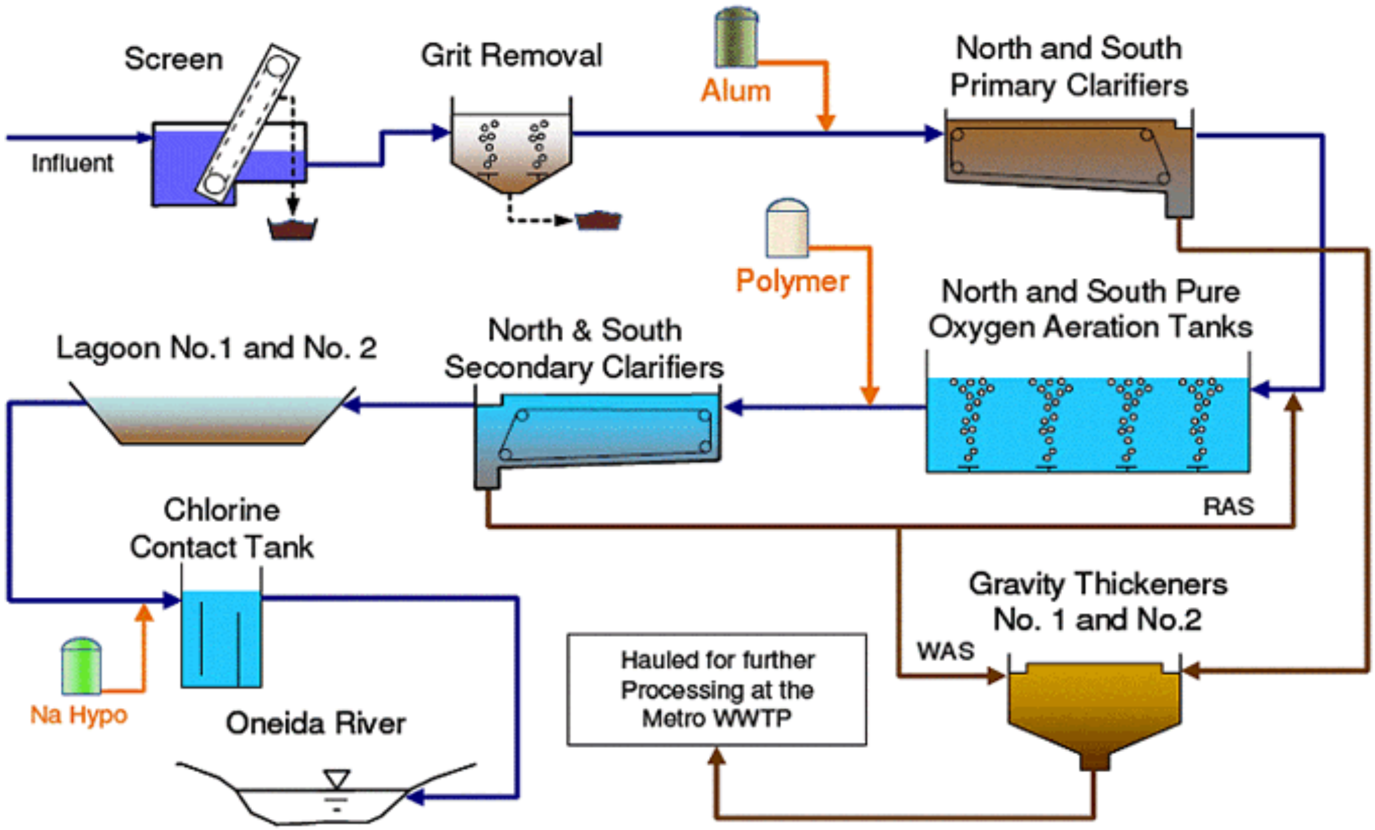



(a) PRIMARY TREATMENT
(b) SECONDARY TREATMENT
(Biological oxidation)
(c) DISINFECTION AND RELEASE
1 Screening, skimming, grinding of sewage.
2 Solid matter settles out.
3 Primary effluent undergoes aeration; microorganisms oxidize organic matter.
4 Effluent is disinfected by chlorination and released.
Sewage
Primary sedimentation tank
Primary effluent
Trickling filter (see Figure 27.22)
or
Activated sludge system (see Figure 27.20)
Settling tank
Chlorinator
Effluent
Secondary effluent
Primary sludge
Secondary sludge from settling tank
5 Remaining sludge is digested anaerobically, producing methane.
6 Sludge effluent is dried.
7 Sludge is removed and disposed of in landfill or agricultural land.
Sludge effluent
Anaerobic sludge digester (see Figure 27.23)
Drying bed
(d) SLUDGE DIGESTION
Key
Physical processes
Microbial processes
Chemical processes

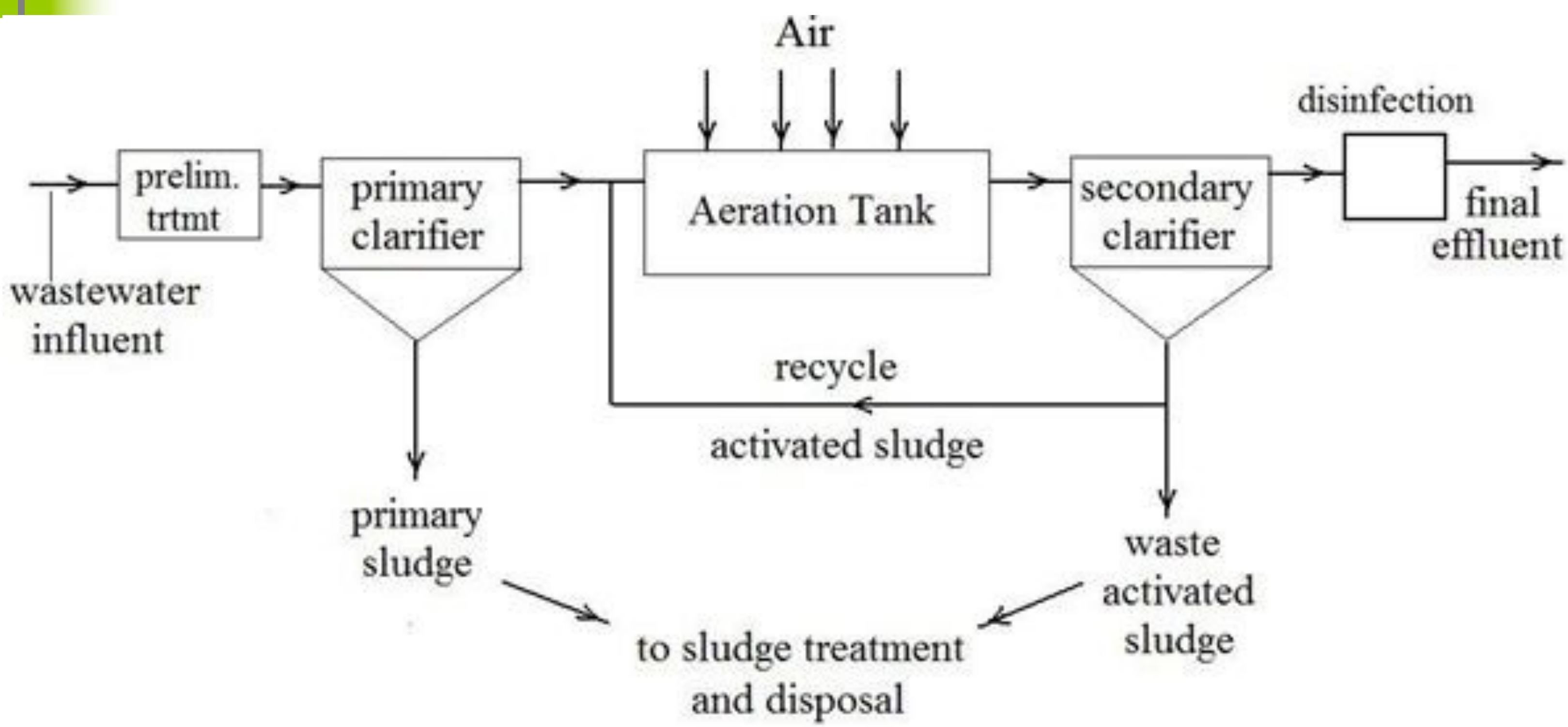
Wastewater Treatment



Wastewater treatment processes



Wastewater treatment processes



Activated Sludge Wastewater Treatment Flow Diagram

Wastewater Treatment

Pre-treatment

- Occurs in business or industry prior to discharge
- Prevention of toxic chemicals or excess nutrients being discharged in wastewater

- Water discharged from homes, businesses, and industry enters sanitary sewers
- Water from rainwater on streets enters storm water sewers only
- Combined sewers carry both sanitary wastes and storm water – not allowed
- Wastewater moves toward the WWTP primarily by gravity flow
- Lift stations pump water from low lying areas over hills

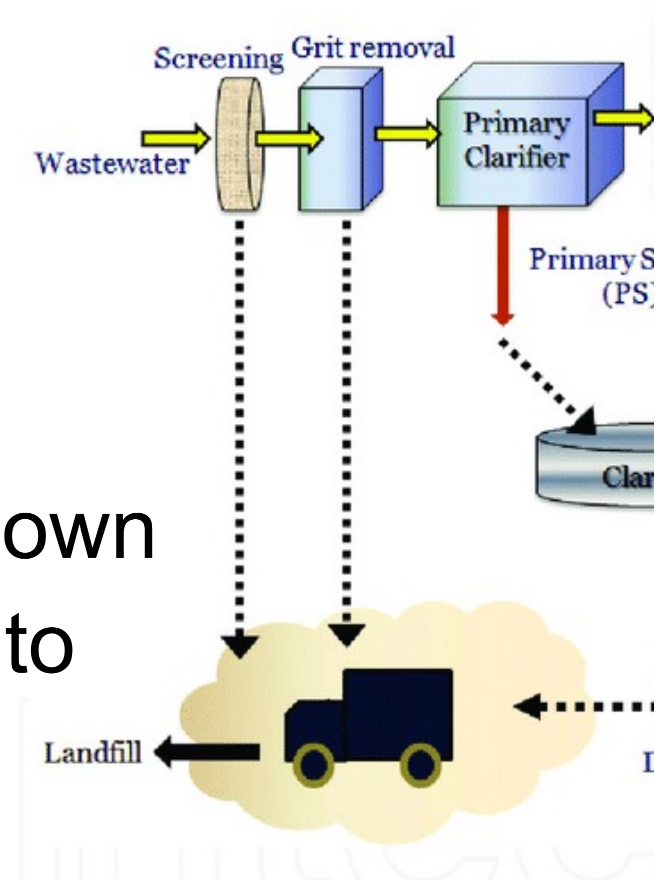
Primary wastewater Treatment

- Removes large objects and non-degradable materials

A physical process -

- Wastewater flow is slowed down and suspended solids settle to the bottom by gravity

- The material that settles is called sludge or bio-solids



Effluent After Primary Treatment:

Primary Treatment - 1

Primary treatment of waste water consists of the removal of insoluble matter such as grit, soil, grease and scum from water.

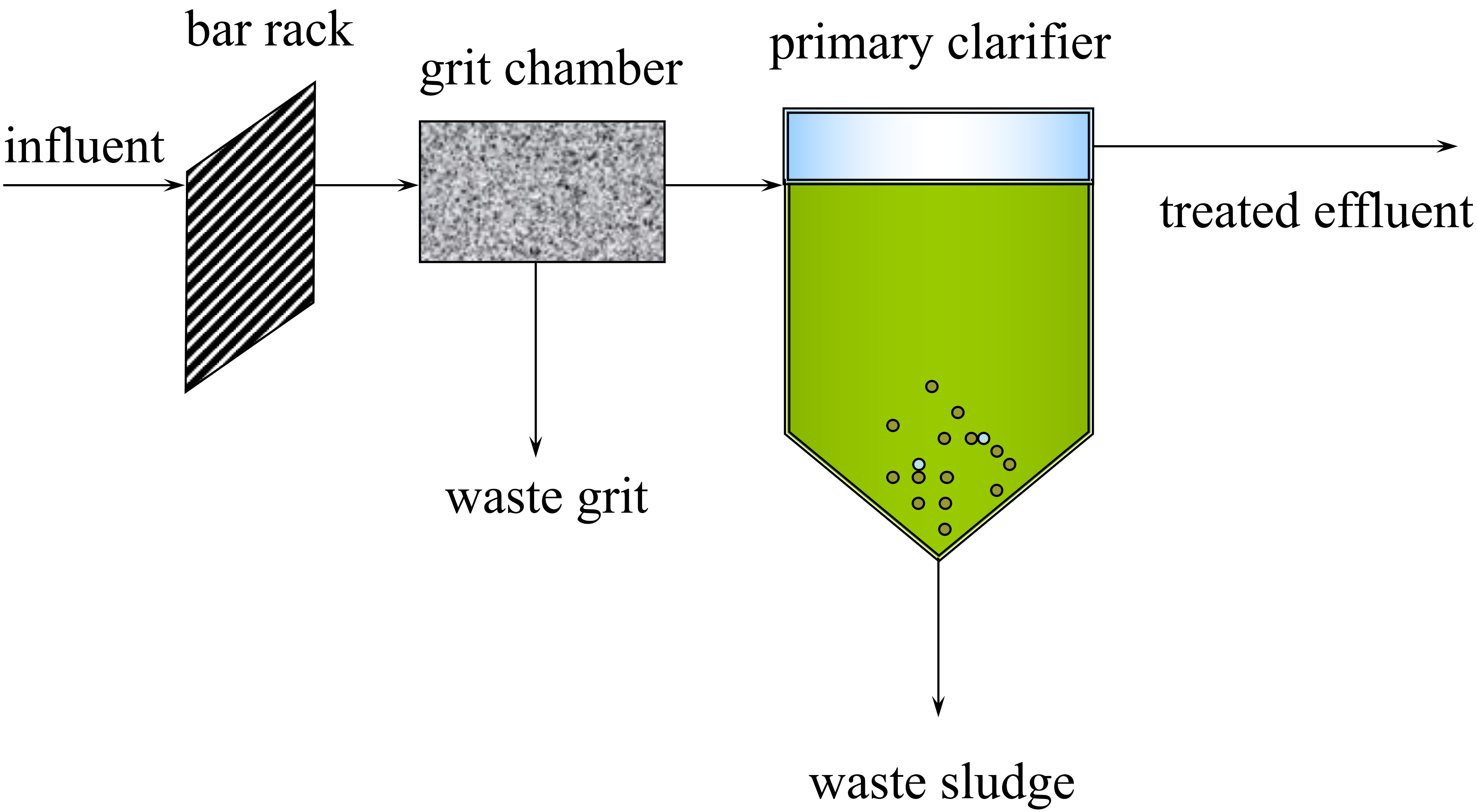
First step: screening to remove or reduce the size of trash and large solids that get into the sewage system. The solids are collected on screens and scraped off for subsequent disposal.

Second step: Grit removal.

Primary Treatment - 2

- In the second step the sewage enters a large lagoon/tank and moves through slowly enough that any solid particles settle down and sink down gravitationally.
- Some materials float at the surface of the sewage (Those materials are called grease). They are removed by a skimming device.
- The effluent form the primary settler is almost clear, but has a high BOD (several hundred milligrams per liter).

Primary Treatment

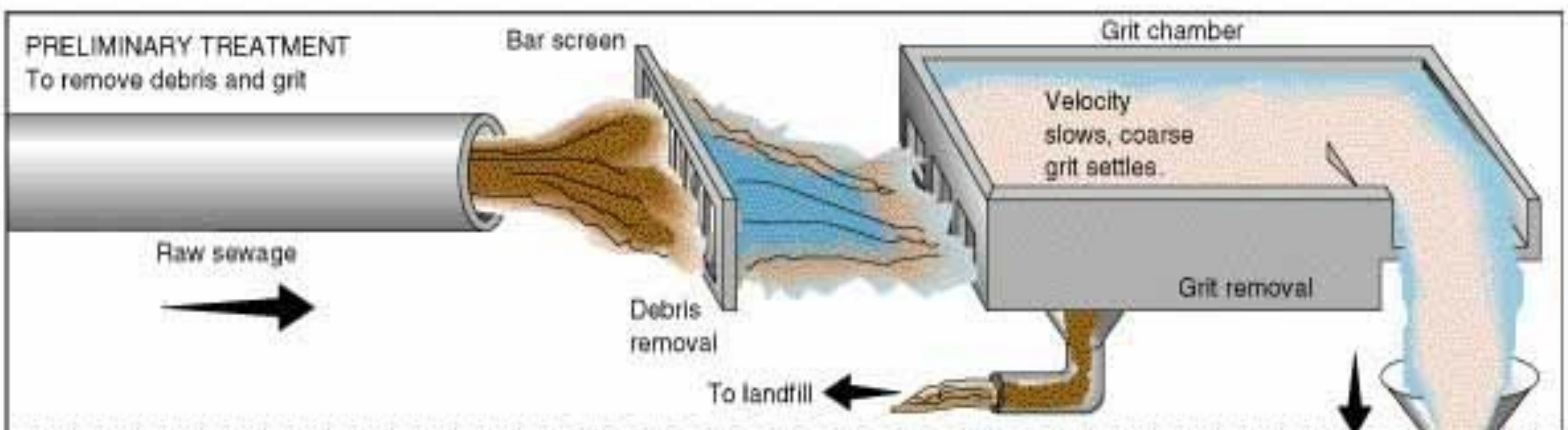


Settling tank

Saha Pat Industrial Park, Laem Chabang, Thailand

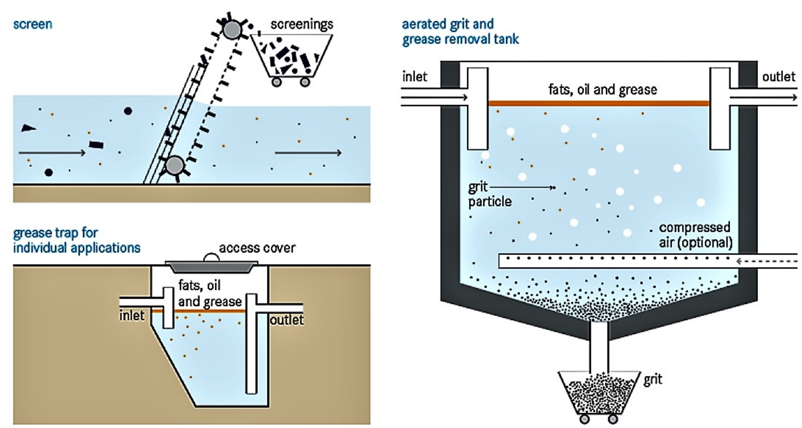
Bar Screen

- catches large objects that have gotten into sewer system such as bricks, bottles, pieces of wood, etc.



Grit Chamber

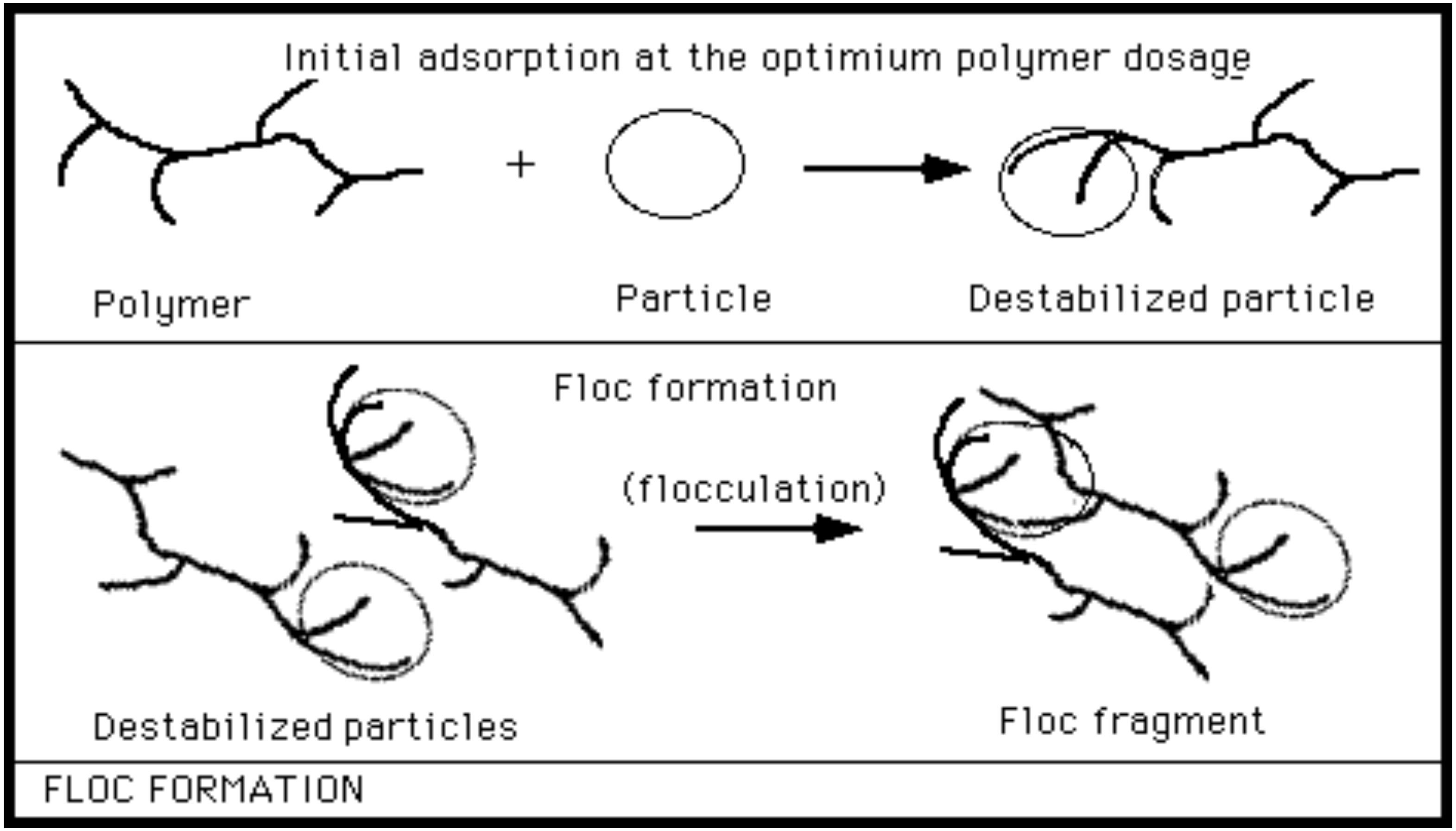
- removes sand gravel, grease and oil.



Mesh Screen

- removes diapers, combs, towels, plastic bags, syringes, etc.

Coagulation and Flocculation



Measurements

Measurement and sampling are taken continuously at the inlet and after Preliminary treatment

- a flow meter records the volume of water entering the treatment plant

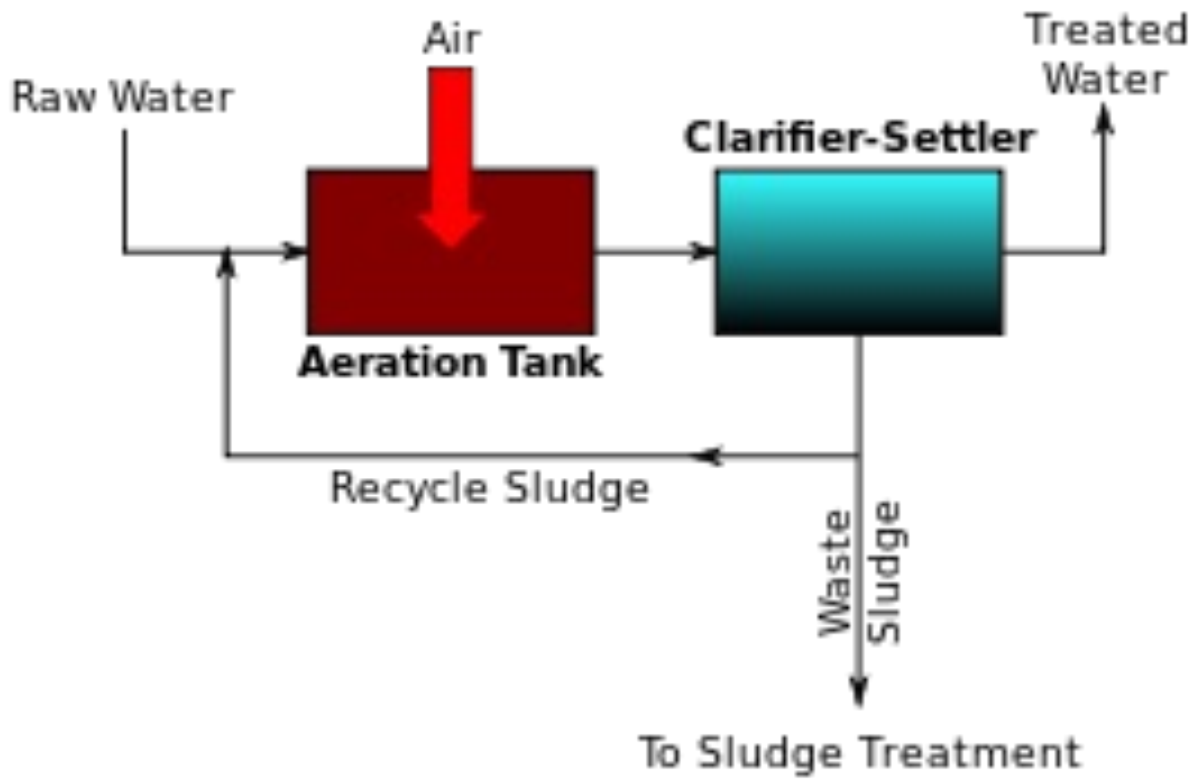
- water samples are taken for determination of total suspended solids TSS,BOD: Both Suspended Solids and BOD. decrease as water moves through the wastewater treatment processes

- ✓ Primary treatment reduces the suspended solids and the BOD of the wastewater.
- ✓ From the primary treatment tanks water is pumped to the trickling/aeration filter for secondary treatment.
- ✓ Secondary treatment will further reduce the suspended solids and BOD of the wastewater.

Secondary Treatment

❖ Secondary treatment is a biological process

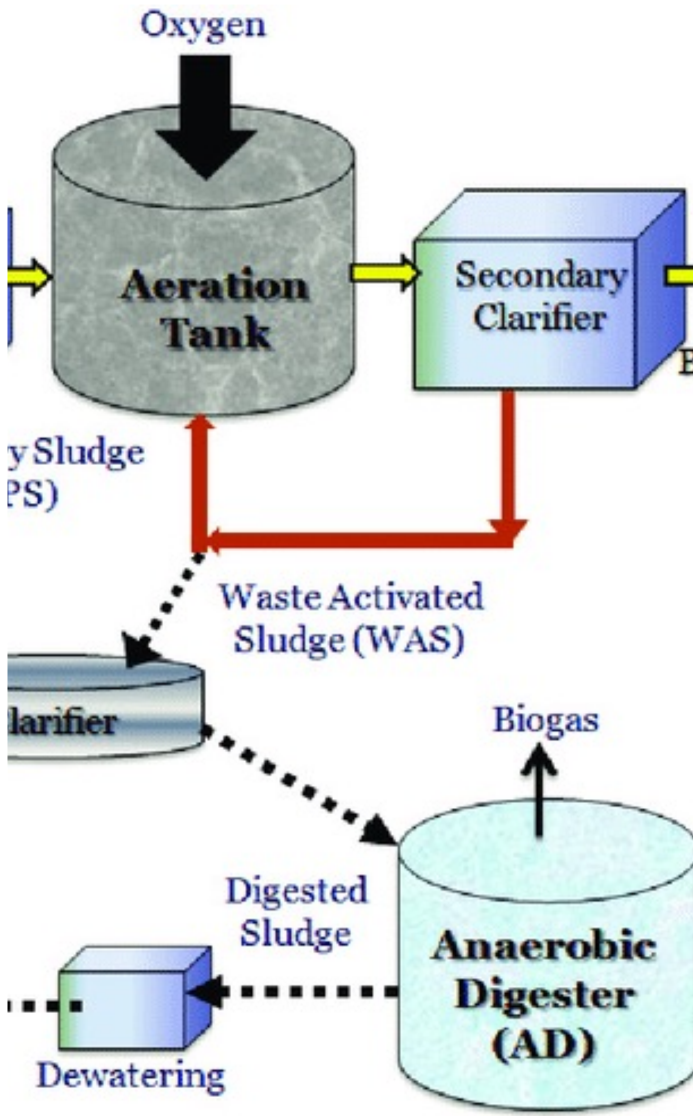
❖ Utilizes bacteria and algae to metabolize organic matter in the wastewater



The final clarifiers remove additional sludge and further reduce suspended solids and BOD

Secondary Sewage Treatment

Effluent After Primary treatment:



To tertiary Treatment

Secondary Treatment

Objective of the secondary treatment: ✓

To reduce the BOD to acceptable level (below 10 mg/L).

- ✓ The basic principle consists of the action of microorganisms provided with added oxygen degrading organic material in solution or in suspension.
- ✓ Two main systems:
  - ✓Activated sludge
  - ✓Trickling filter

The main objectives of biological wastewater treatment are:

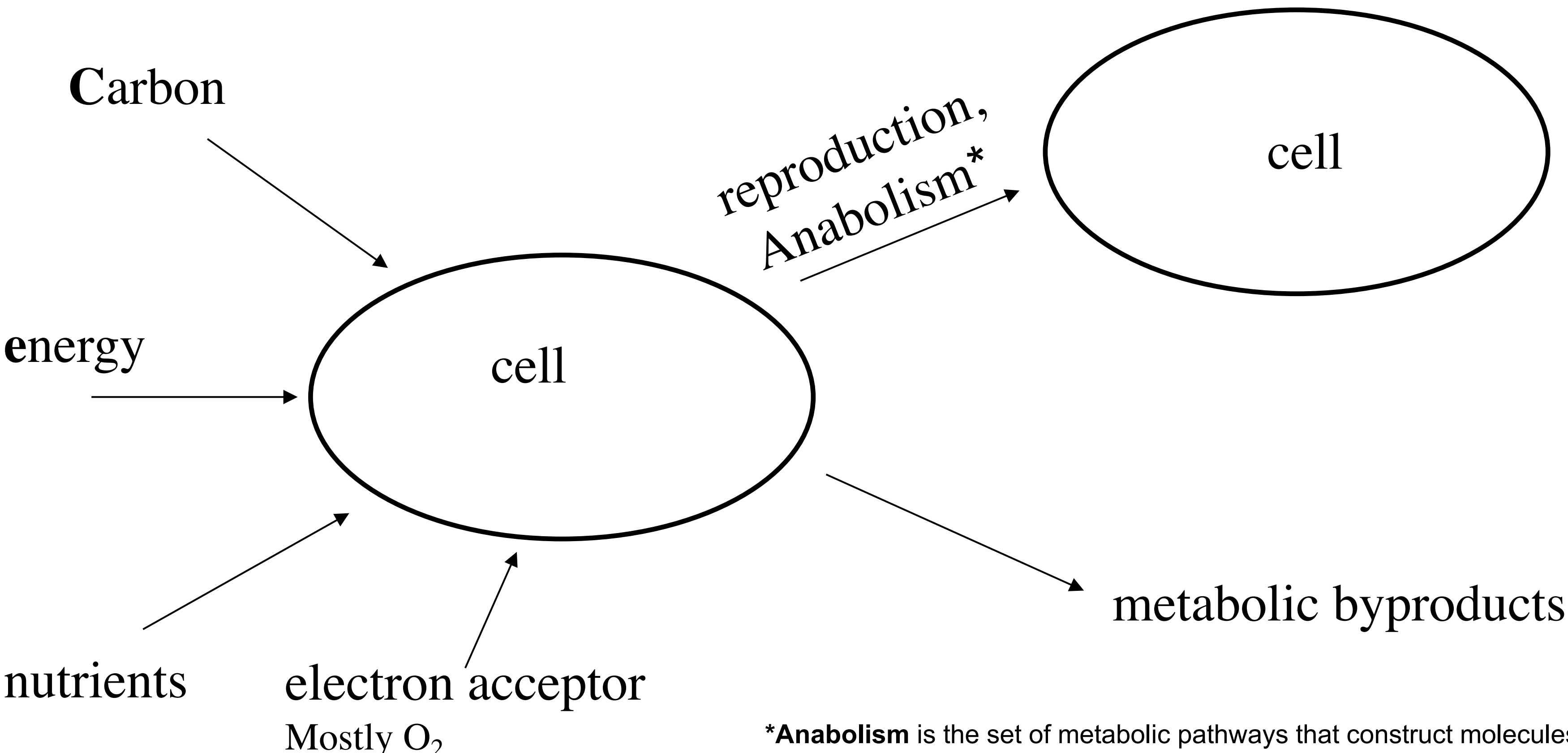
To promote microbes and microbial activity that transform biodegradable constituents into acceptable end products, while promoting microbial conditions that are easily separated from the wastewater or readily settle out of solution as suspended solids and capture colloidal solids.

Biological treatment units are designed to oxidize carbon and remove nutrients such as nitrogen and phosphorus.

What cells need and do

Environmental conditions: pH, moisture, temperature, salinity

$$Food + O_2 + nutrients \xrightarrow{Bacteria} CO_2 + NH_3 + new \cdot biomass + other \cdot end \cdot products$$



***Anabolism** is the set of metabolic pathways that construct molecules from smaller units. These reactions require energy, known also as an endergonic process. **Anabolism** is the building-up aspect of metabolism, whereas catabolism is the breaking-down aspect.

www.bren.ucsb.edu/academics/ courses/214/Lectures/Lecture_2_ESM214_05.ppt -

Carbon and energy source

Organisms that use organic carbon for C source are called **Heterotrophs**

Organisms that derive cell carbon from CO_2 are called **Autotrophs**

Those that use light as energy sources are **Phototrophs** (and can be either **Heterotrophic** or **Autotrophic**)

Those that derive energy from chemical reactions are **Chemotrophs** (and can be either **Heterotrophic** or **Autotrophic**)

Chemoautotrophs obtain energy from oxidation of reduced inorganic carbon as ammonia, nitrite etc…

- Ninety-five percent or more of all types of living organisms are heterotrophic.

Energy source

- Reduction: The gain of electrons by a compound
- Oxidation: The loss of electrons by a compound
- The energy producing chemical reactions by chemotrophs are oxidation-reduction from an electron donor (compound loses e-) and to the electron acceptor (compound gains e-)
- **When O_2 is used as electron acceptor reaction** is **Aerobic**
- When **other electron acceptors are used the reaction** is **Anaerobic**
- When **nitrite ($N0_2^-$) or nitrate ($N0_3^-$) are used as electron acceptor the reaction** is **Anoxic**

Energy source

CO_2 + $2H_2O$ + Photons → $[CH_2O]$ + O_2 + H_2O (photosynthesis)

Carbon dioxide	water	light energy	carbohydrate	oxygen	water

Aerobic respiration is an oxidation reaction in which carbon in organic matter is oxidized to carbon dioxide with the release of energy. Respiration by microorganisms decomposing organic matter in pond soil consumes oxygen faster than it can penetrate the soil mass, and only the surface layer is aerobic.

<u>Organic carbon oxidation to carbon dioxide</u>

$$CH_2O + H_2O = CO_2 + 4e^-$$

- The most prevalent electron acceptor is O_2 (g), and is the sole electron acceptor in aerated systems (**aerobic systems**).

$$O_2 + 4e^- + 4H^+ = 2H_2O$$

- Living compounds create energy by oxidizing carbohydrates and reducing oxygen. That is, organisms take electrons from the organic carbon, run it through their metabolic cycles, and then dump the electron to an electron acceptor (O_2). When oxygen is not present, microorganisms must seek alternate electron acceptors. The energy gain for the organisms is the energy difference between reduced carbon and the electron acceptor.
- **In order of favorability, electron acceptors are**:

$$O_2 > NO_3^- > Mn(VI) > Fe(III) > AsO_4^{3-} > SO_4^{2-}$$

Nitrogen Removal - 1

- Organic nitrogen is converted to ammonium (NH_4^+) ion and nitrate ($NO_3{-}$)
- Ammonia (NH_3^+) is the primary nitrogen product produced by most biological waste treatment processes
- One method is to strip ammonia in the form NH_3 gas from the water by air
- Another method is nitrification followed by denitrification

Nitrogen Removal - 2

Nitrification - denitrification:

First step: conversion of ammonia and organic nitrogen to nitrate under strongly aerobic conditions:

$$2\ NH_4^+ + 3\ O_2 \xrightarrow{\text{Nitrosomonas bacteria}} 4\ H^+ + 2\ NO_2^- + 2H_2O$$

$$2\ NO_2^- + O_2 \xrightarrow{\text{Nitrobacter}} 2\ NO_3^-$$

These reactions occur in the aeration tank of the activated sludge plant.

Nitrogen Removal - 3

Nitrification-denitrification (cont.)

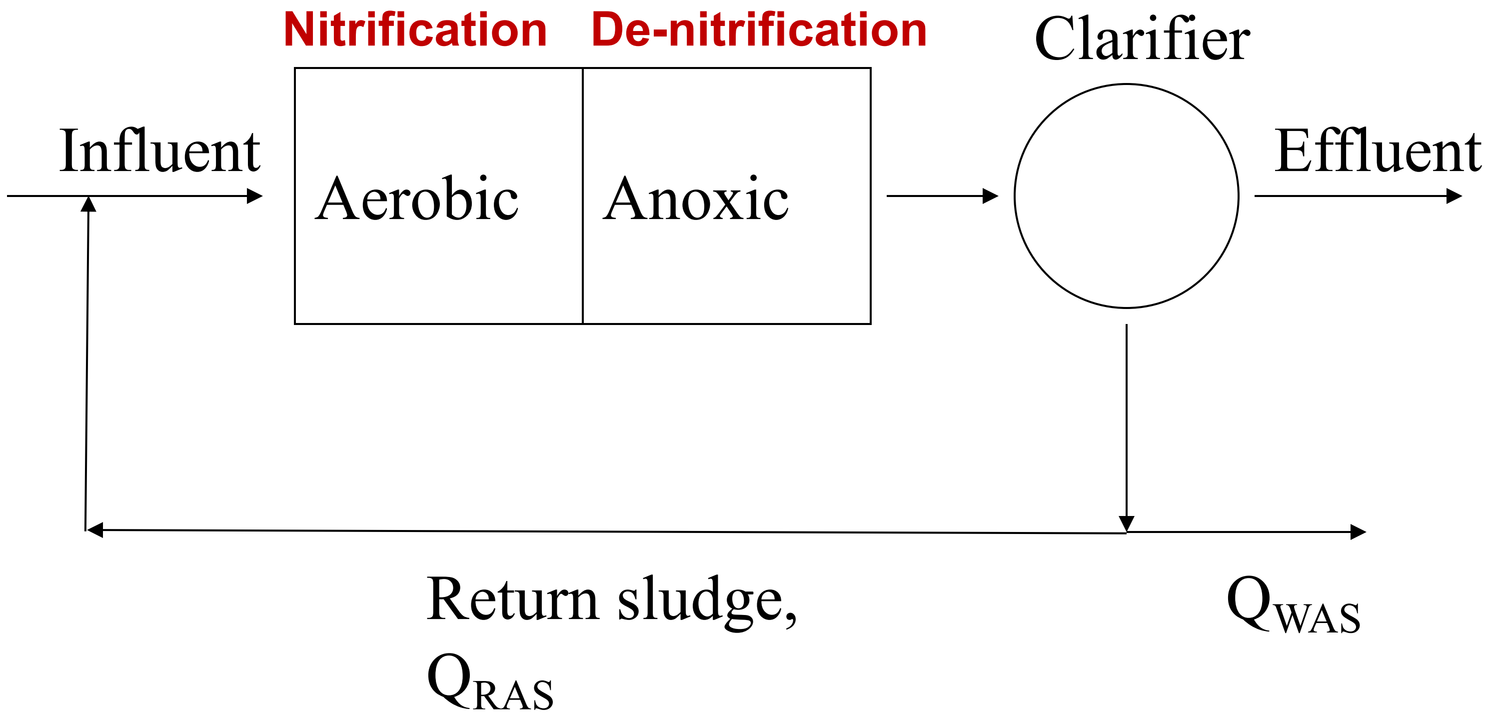
- Second step: reduction of nitrate to nitrogen gas. This reaction is also bacterially catalyzed and requires a carbon source and a reducing agent such as methanol, CH_3OH: **(Anoxic condition*)**

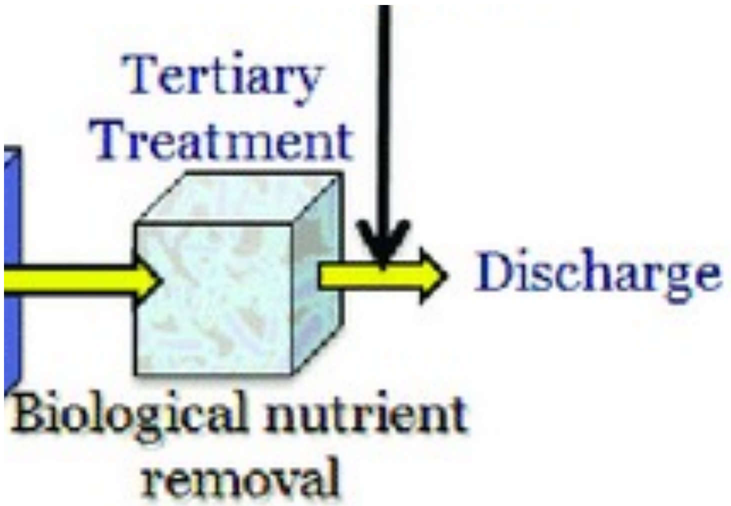
$$6\,NO_3^- + 5\,CH_3OH + 6\,H^+ \text{ (denitrifying bacteria)} \rightarrow 3\,N_2(g) + 5\,CO_2 + 13\,H_2O$$

- In pilot plant operation, conversions of 95% of the ammonia to nitrate and 86% of the nitrate to nitrogen have been achieved

* Nitrite ($N0_2^-$) or Nitrate ($N0_3^-$) are used as electron acceptor the reaction

Biological nitrogen removal





Polishing the effluent

Treating Persistent Compound

Tertiary Treatment

Tertiary Treatment (Physicochemical Process)

- Precipitation
- Chlorination
- SAT
- Filtration
- **AOP's**

Tertiary Treatment

- Wastewater receiving tertiary treatment is unable to support microbial growth, and can be of such high quality that it can be pumped directly into the water supply.
- The most popular means of removing BOD is with biological treatment.
- Physiochemical processes are used to remove inorganic nutrients, especially phophate and nitrate.

Tertiary Treatment - 1

- In some cases a portion of the water using for agricultural irrigation, GW artificial recharge and rivers rehabilitation, is actually water that has been discharged from a municipal WW treatment.
- Tertiary waste treatment (also called advanced wastewater treatment): term used to describe a variety of processes performed on the effluent from the secondary waste treatment.

Tertiary Treatment - 2

- The contaminants removed by tertiary treatment fall into three general categories:
  - suspended solids: responsible for residual biological oxygen demand in secondary WW effluent waters.
  - dissolved organic compounds: they are potentially the most toxic
  - dissolved inorganic materials: the major problem: nitrates and phosphates (nutrient for algae). Also, potentially hazardous toxic metals may be found among the dissolved inorganics.

Q & A

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