FMGN Online Seminar

Leachate Treatment with the Fukuoka Method

in case of Tafaigata Landfill in Samoa

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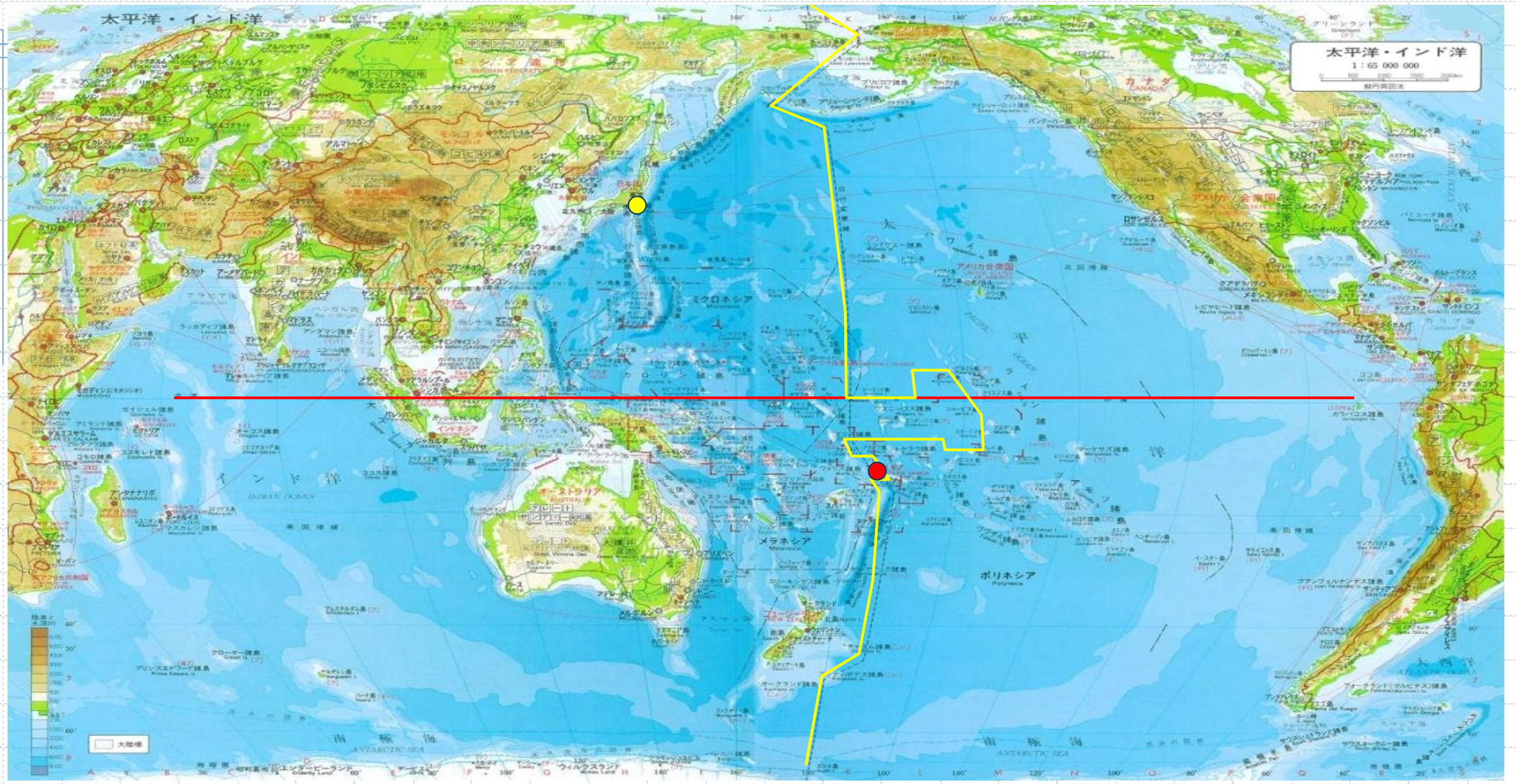
Contents

1. Samoa in the Pacific
2. What is the Fukuoka Method
3. Leachate treatment
4. Fukuoka Method
   for Leachate Treatment in Samoa

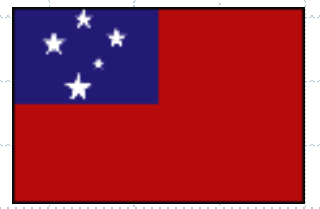
Contents

Geographical Location of Samoa



Independent State of Samoa

as of 2005



Location：14° South latitude、

Climate：Tropical oceanic climate、
average temperature 28℃

Population：170,000 (2004) → 218,000 (2023)

Land area：3,000km² (5 times bigger than Singapore)

Main industry：Agriculture（coconuts、cocoa）

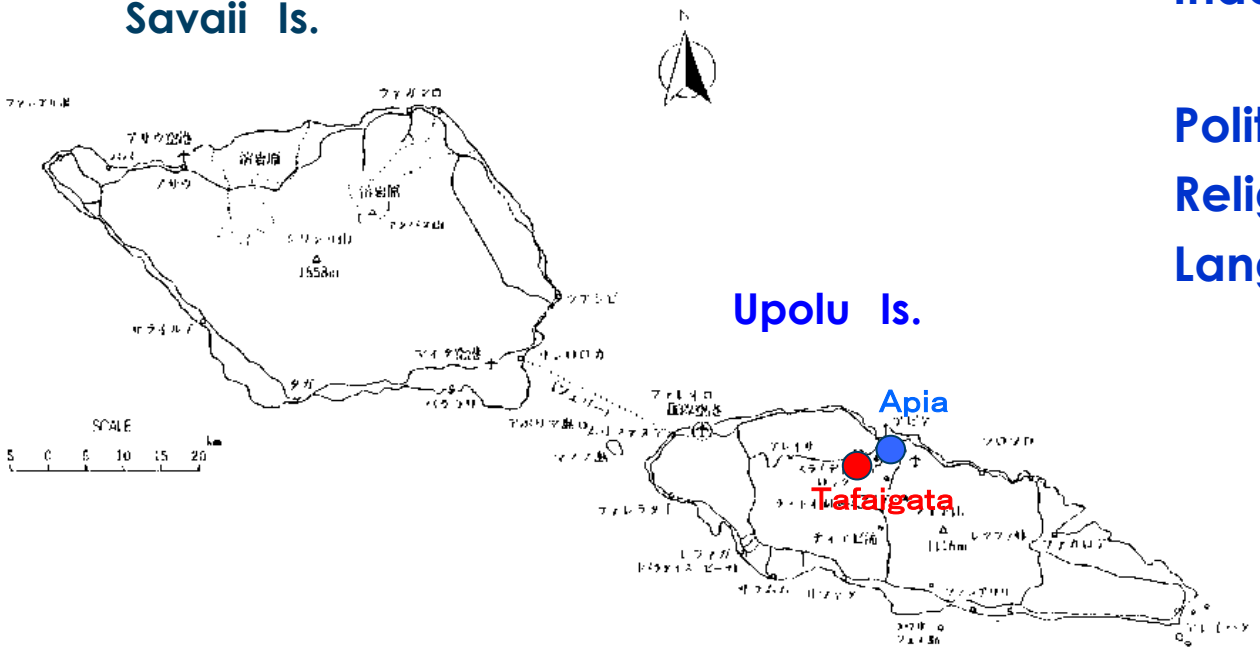
GDP：US$843 million (2021)

Independence：German territory、
independent after NZ trusteeship in 1962

Political framework：Limited monarchy

Religion：Christianity

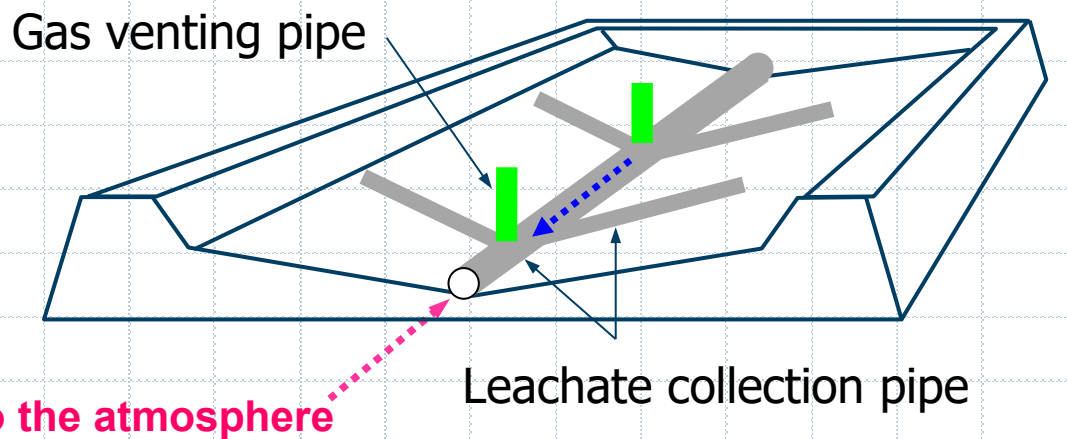
Language：Samoan, English



Contents

1. Samoa in the Pacific
2. What is the Fukuoka Method
3. Leachate treatment
4. Fukuoka Method for Leachate Treatment in Samoa

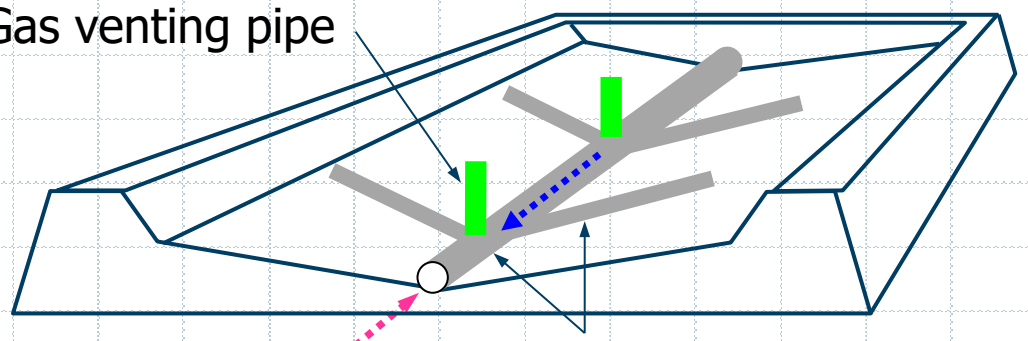
The Fukuoka Method (semi-aerobic landfill) structure



Aperture of the pipe is always open to the atmosphere

- Leachate is collected through perforated pipe embedded in graded boulders and goes to leachate collection pond .
- As the aperture of main leachate collection pipe is always open to the atmosphere, fresh air is down into the layers thereby introducing an aerobic condition around the pipes.
- Since leachate is removed as quick as it is formed, the internal waste layer have lower water contents.

The Fukuoka Method (semi-aerobic landfill) structure



Aperture of the pipe is always open to the atmosphere

Main collection pipe (under construction)

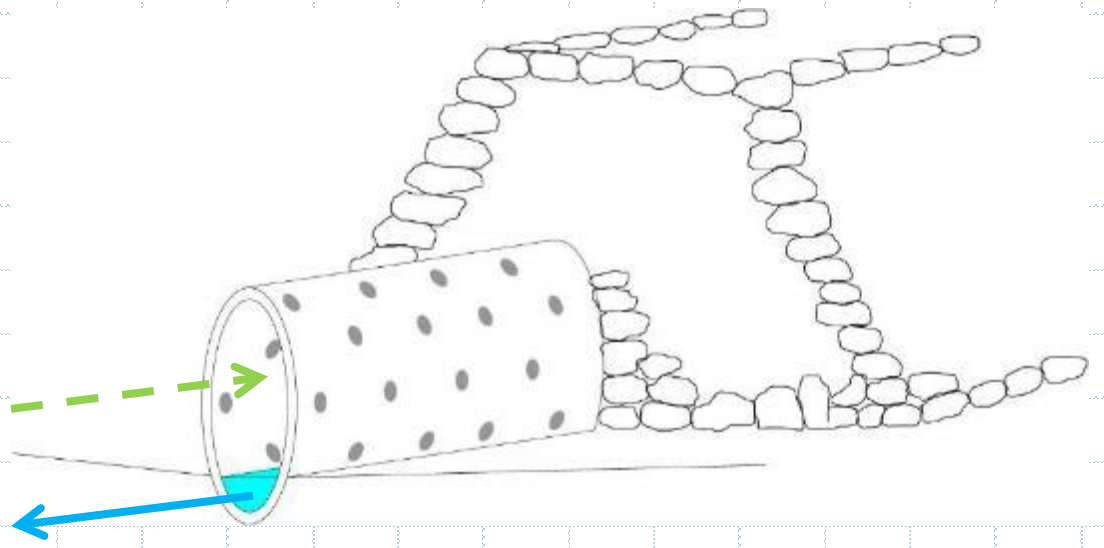
Leachate collection pipe

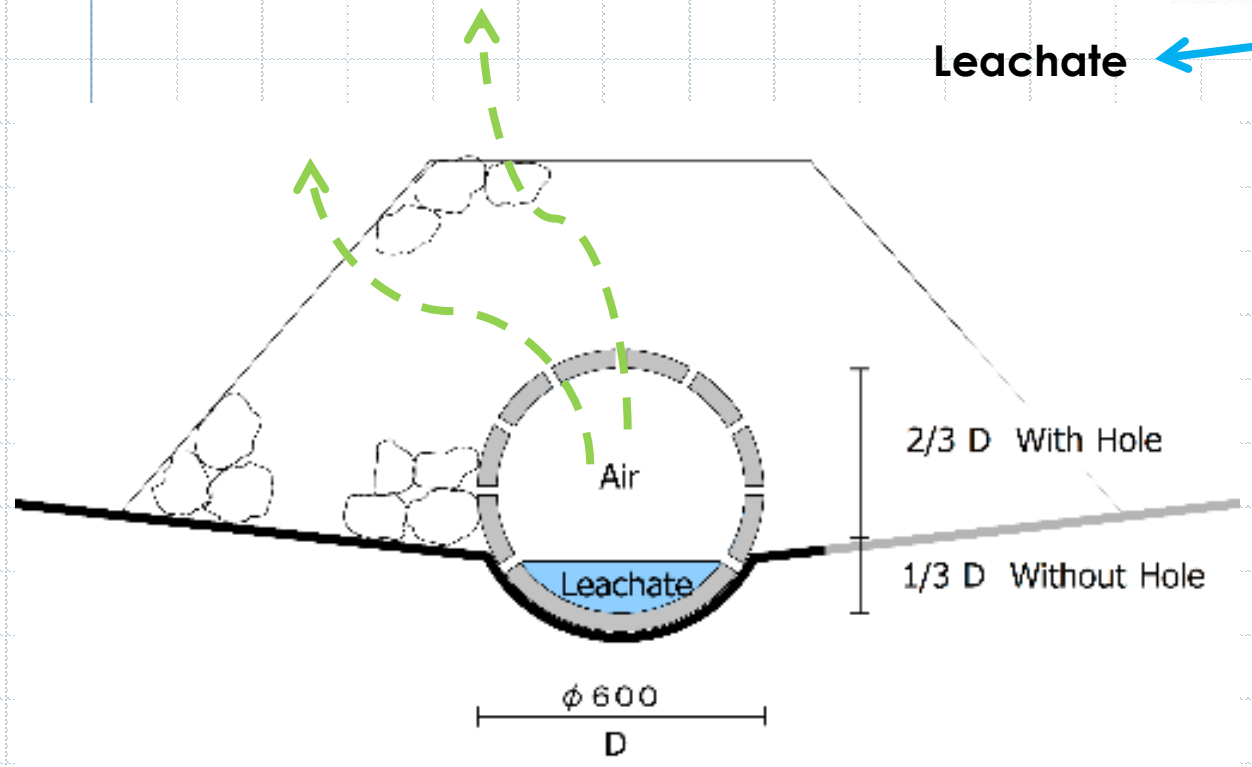
Gas venting pipe

Structure of leachate collection pipe

The diameter of the leachate collection pipe is about Φ600mm.

The leachate collection pipe has many holes on 2/3rd of upper side on diameter bases.



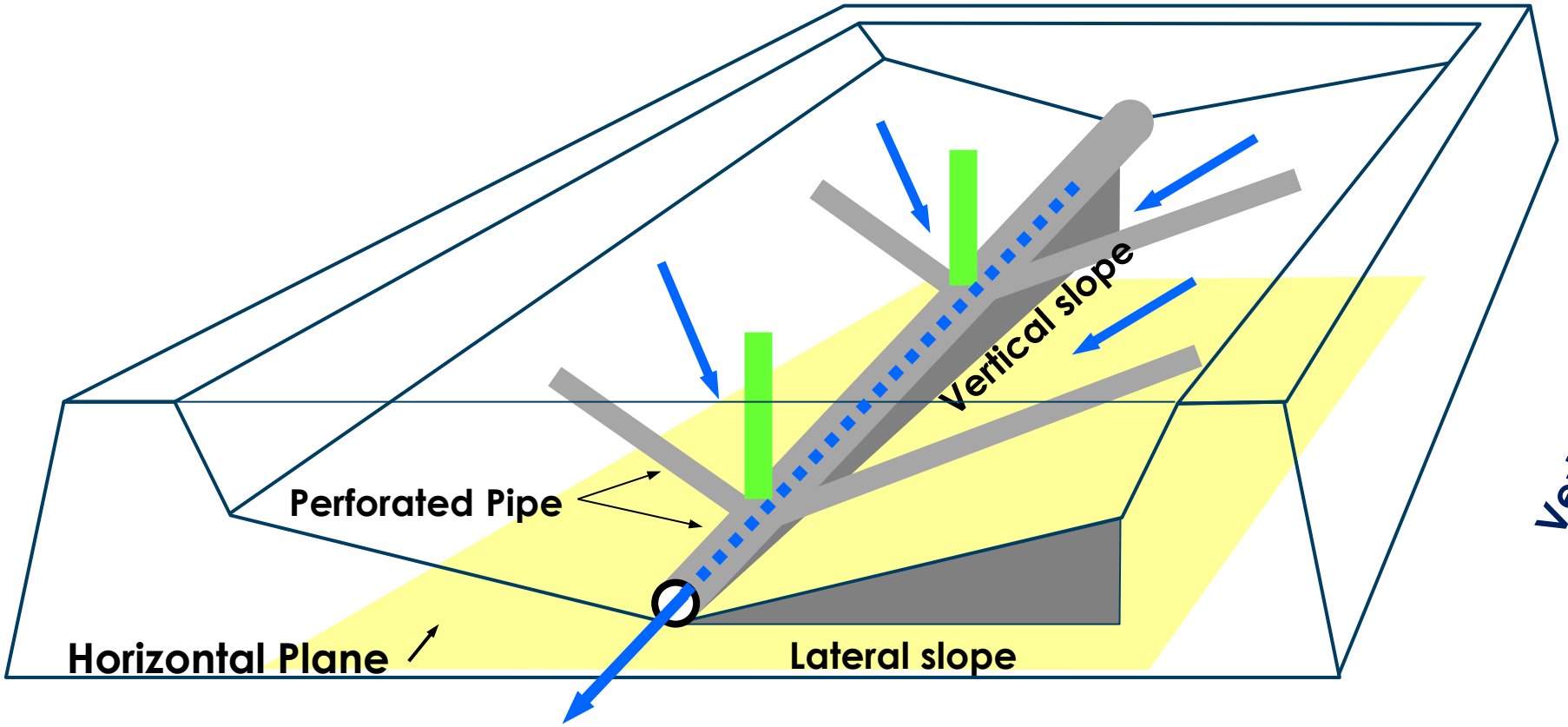


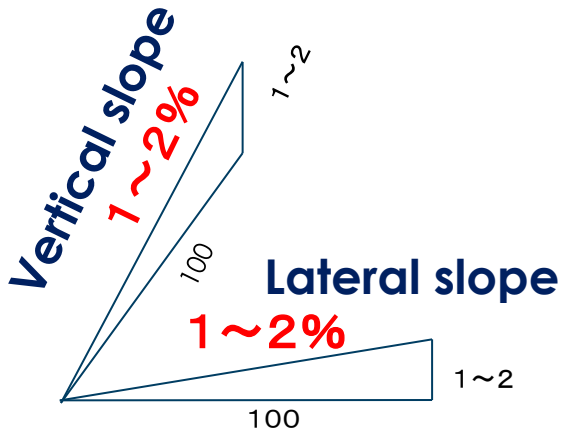
The leachate collection pipe has been surrounded by **crushed stones** of the size of **15cm or larger**, and which protect the collapse of pipe caused by weight and prevent the clogging of pipe.

Leachate flow on the bottom of the rubbish layer

Leachate flows toward less resistance for down the stream.

Perforated pipe can discharge leachate immediately.



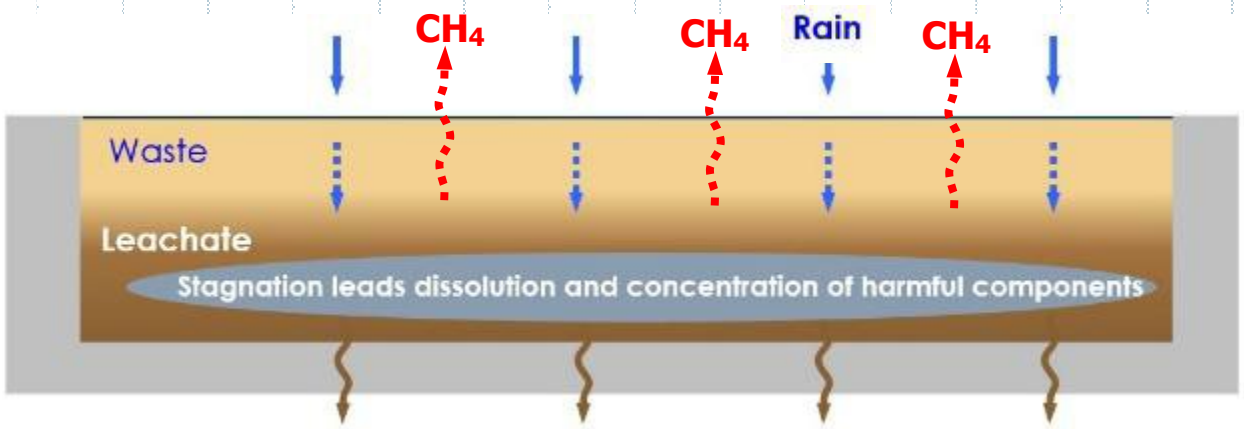


In a case where a landfill site has clay layers with **low water permeability** and the leachate can be removed perfectly without being retained in the landfill, expensive impermeable liner sheets are not necessarily required.

Conventional landfill and Fukuoka Method

Anaerobic Landfill Type (Conventional type)

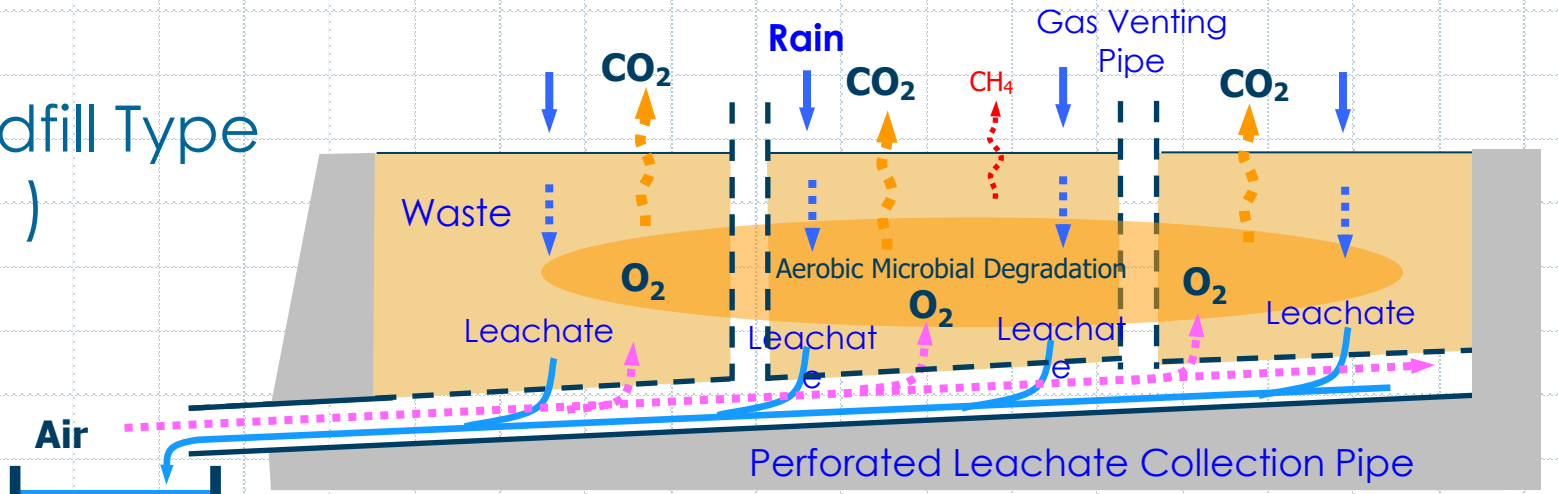
High concentration



1. Harmful ingredients become concentrated over time due to stagnated water.
2. Contaminate underground water

Semi-Aerobic Landfill Type (Fukuoka Method)

Low concentration



Leachate collection pond

1. **Aerobic bacteria decompose** organic matter.
2. **Quick removal of leachate** from waste makes it clean.

Fukuoka Method (semi-aerobic landfill type) mechanism

End of the pipe always opens to the air

■The inflow of air helps the internal condition be kept aerobic and accelerate the decomposition of waste materials.

Advantages of Fukuoka Method

1. structure is very simple and low cost
2. decomposition is fast and sanitary
3. leachate treatment become easier
4. Reduce the impact on **Global Warming**
5. The existing dumpsite can also be rehabilitated into sanitary landfill

Advantages of Fukuoka Method

1. structure is very simple and low cost

available for local materials such as Bamboo, Waste Drums, Waste Tires, etc.

Waste oil drum for Gas Venting pipe

China

Malaysia

Mexico

Advantages of Fukuoka Method

2. decomposition is fast and sanitary

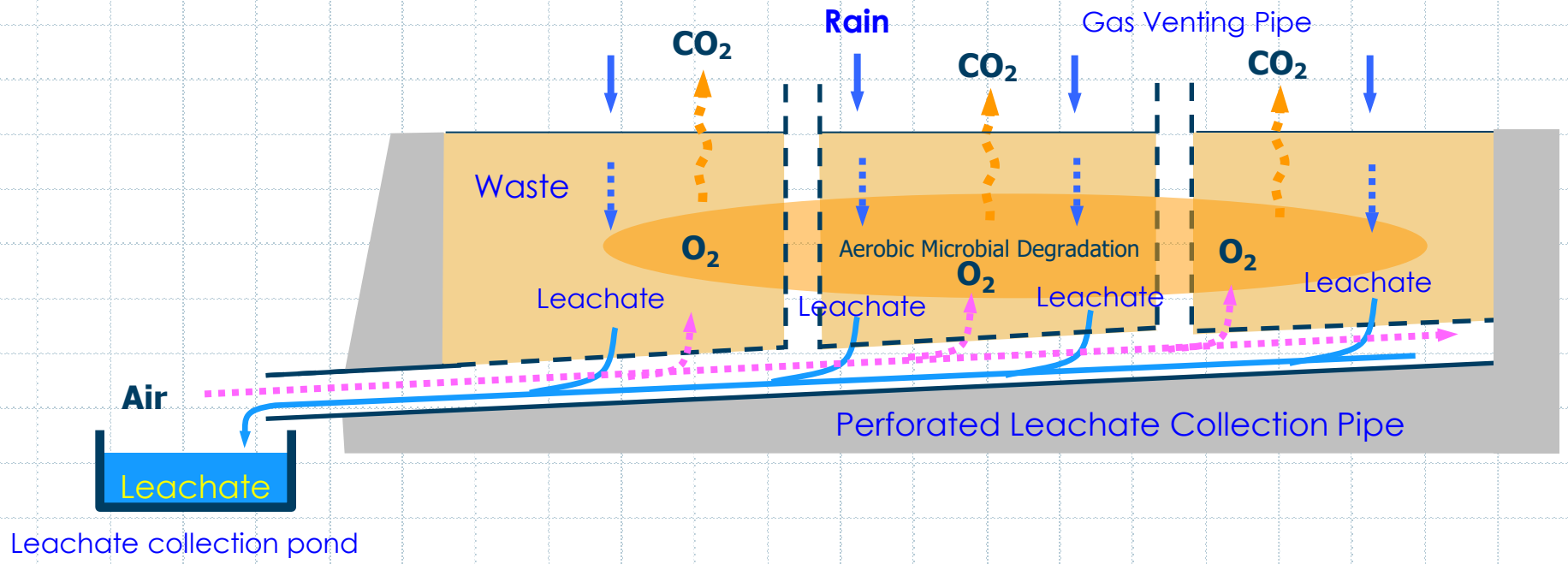
less odor

smooth for after land use

Advantages of Fukuoka Method

3. leachate treatment become easier

As the inflow of the air promotes aerobic microbial degradation, and quick removal of leachate makes it clean and also makes treatment easier.



Advantages of Fukuoka Method

4. Reduce the impact on Global Warming

1) Fukuoka Method can transform the condition of waste from anaerobic to aerobic, that can reduce the emission of Methane gas(CH_4)

2) CH_4 has 25 times higher effect on global warming than that of CO_2

3) Emission of green-house gas from Semi-Aerobic type landfill is 54% smaller than Anaerobic type.

* according to the survey by Fukuoka unv.

Aerobic and Anaerobic Differences in Decomposition of organic matter

25 times greater effect on global warming than CO_2

In anaerobic condition

$$C_xH_yO_z \xrightarrow[\text{anaerobic bacteria}]{} CH_4 + CO_2 + H_2O$$

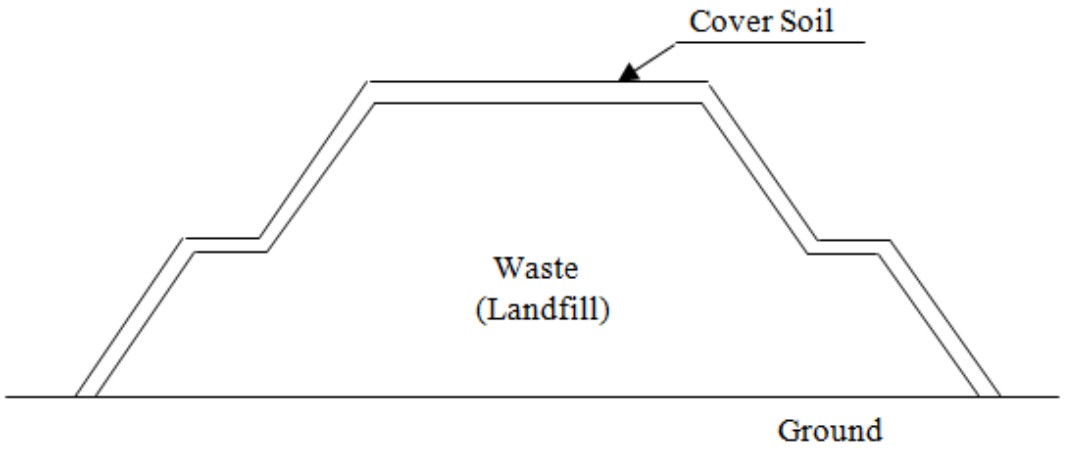
Organic matter

In aerobic condition

$$C_xH_yO_z + O_2 + \xrightarrow[\text{aerobic bacteria}]{} CO_2 + H_2O$$

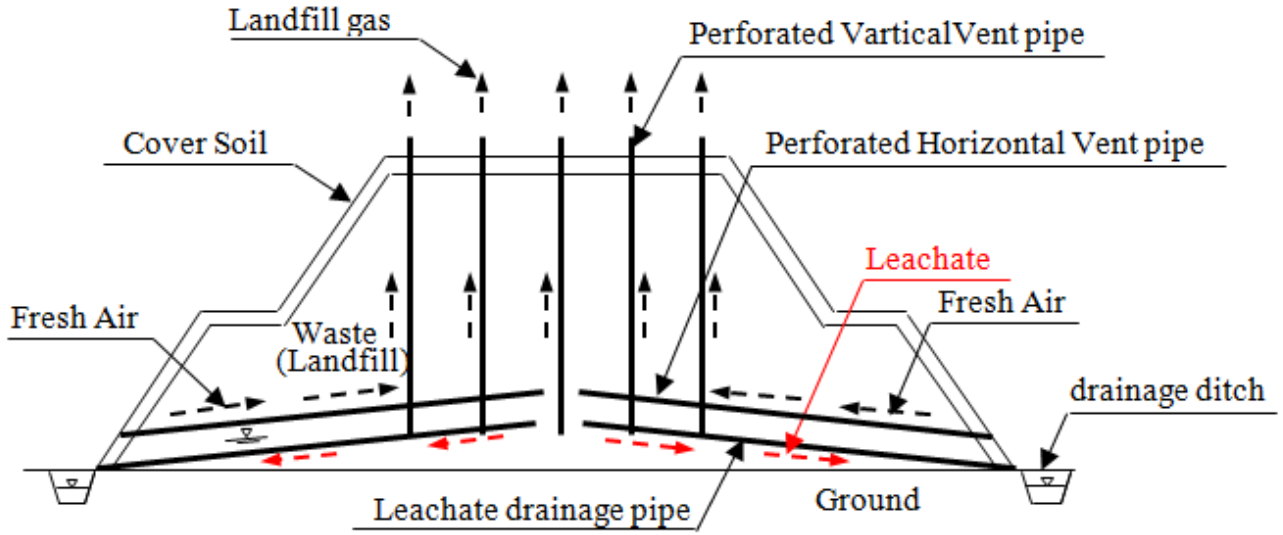
Organic matter

Approved as a new CDM methodology by UNFCCC

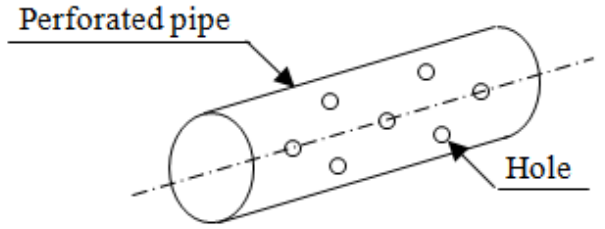


CASE-1 Anaerobic condition
(Applicable waste disposal site)

Case study in Malaysia



CASE-2 Semi-aerobic condition
(Improved waste disposal site)



(Example of Perforated pipe)

Title：AM0093（NM0333） July,2011

Avoidance of landfill gas emission by passive aeration of landfills

Advantages of Fukuoka Method

5. The existing dumpsite can also be rehabilitated into sanitary landfill

Samoa

Mexico

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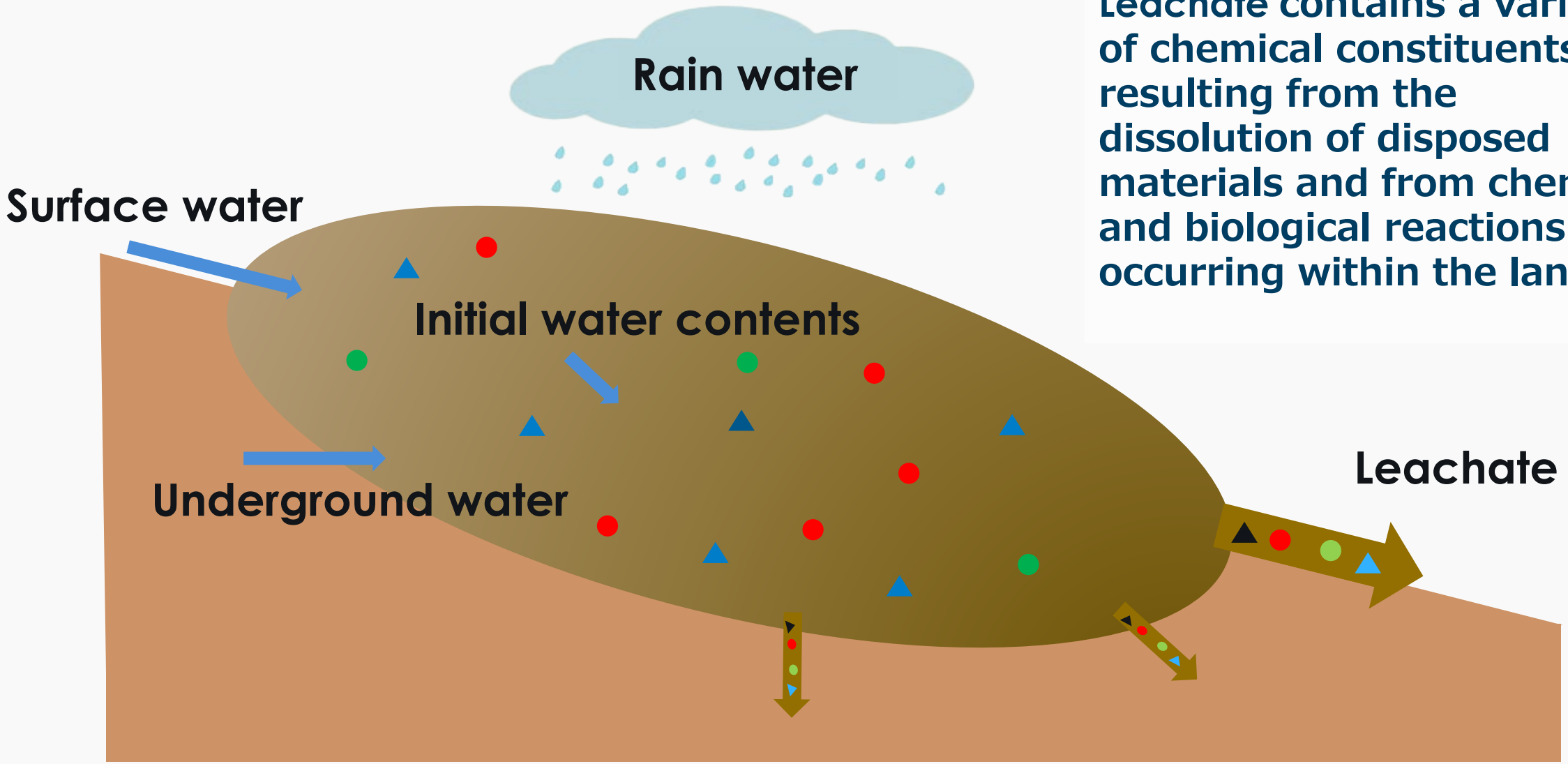
What is leachate?



Leachate contains a variety of chemical constituents resulting from the dissolution of disposed materials and from chemical and biological reactions occurring within the landfill.

Causes of Water Pollution

Three Major Pollutants : C · N · P

Mainly from food waste → Deterioration of living environment → ***Biological treatment***

Hazardous Chemicals: Dioxins, PCBs, Pesticides, etc.

Mainly industrial by-products → Health hazards → ***Adsorption and removal***

Heavy Metals: Cd , CN, Pb, Hg , As, etc.

Mainly industrial by-products → Health hazards → ***Adsorption and removal***

Pathogenic Bacteria: O157, Cryptosporidium, other pathogenic bacteria

Health hazards → ***Disinfection***

Contributing factors to the pollution load

Three major water pollutants

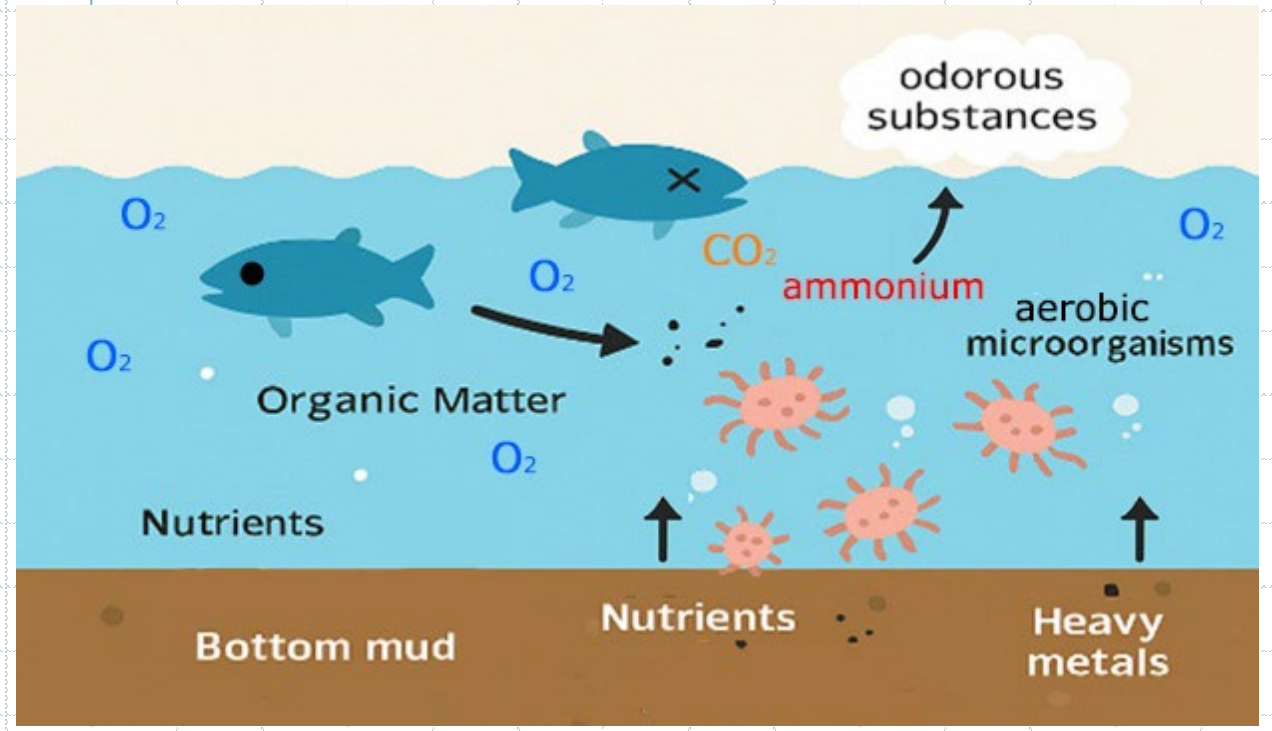
C · N · P

106 : 16 : 1 Phytoplankton C:N:P ratio

Three major nutrients

N · P · K

The process of Organic pollution



When organic matter is present in water, it is decomposed and absorbed by aerobic microorganisms, consuming dissolved oxygen in the process.

If the concentration of organic pollutants is high, more oxygen is required for decomposition, leading to a reduction in dissolved oxygen levels and causing the death of aquatic organisms such as fish and shellfish."

In addition, when the amount of dissolved oxygen decreases in the lower layers of rivers, lakes and other bodies of water, odorous substances such as hydrogen sulfide and ammonia are generated, and nutrients and some heavy metals accumulated in the bottom mud become more likely to dissolve, causing secondary pollution.

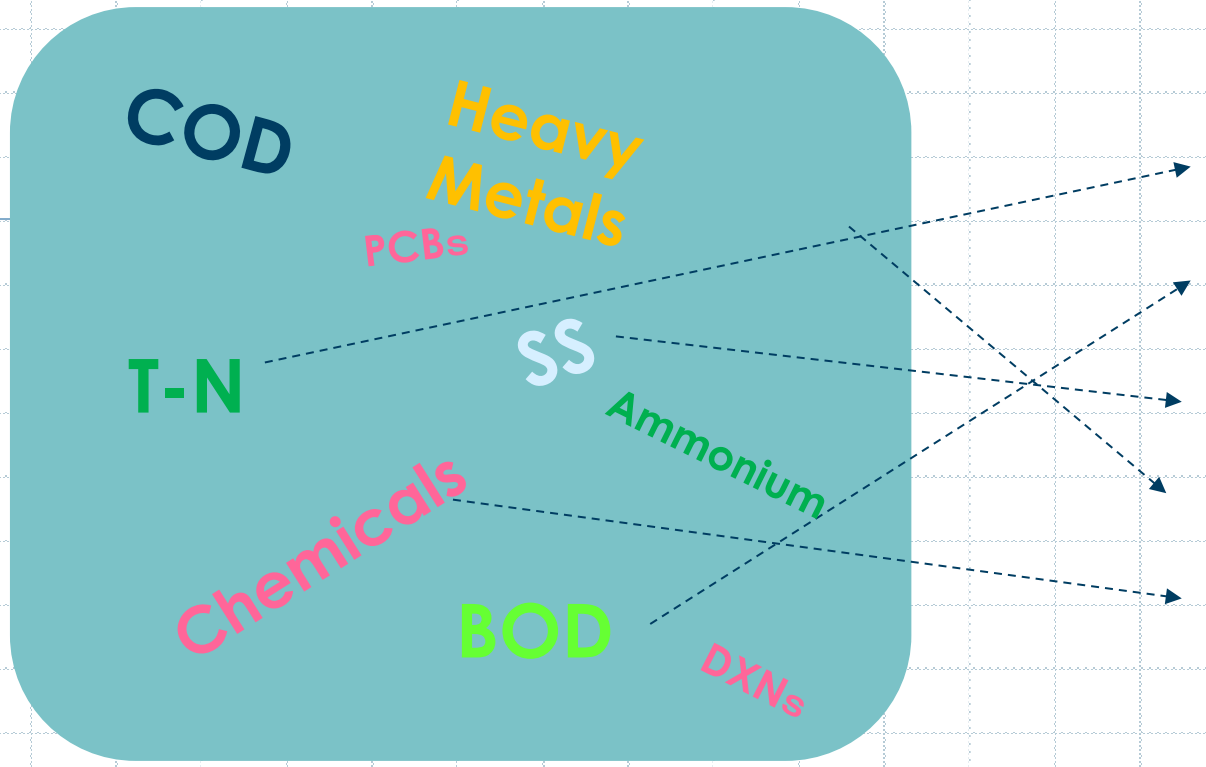
Classification of Wastewater Treatment

	Biological Treatment	**Chemical** Treatment	**Physicochemical** Treatment
Feature	A method that utilizes the activity of microorganisms to decompose and remove organic matter and nutrients.	A method that utilizes chemical reactions to remove pollutants.	A method that combines physical operations and chemical actions to remove pollutants.
Representative Examples	• **Activated Sludge Process** (aerobic microorganisms decompose organic matter) • **Trickling Filter** (formation of a microbial film on a fixed bed) • **Anaerobic Digestion** (decomposition of organic matter without oxygen, producing biogas) • **Biofilm Process, Nitrification–Denitrification Method** (nitrogen	• **Neutralization Treatment** (pH adjustment of acidic and alkaline wastewater) • **Oxidation Treatment** (removal of organic matter and odors using ozone, hypochlorite, etc.) • **Reduction Treatment** (detoxification of hazardous substances such as hexavalent	• **Coagulation–Sedimentation Method** (aggregating fine particles with chemicals and settling them) • **Adsorption Method** (adsorbing organic matter and odors using activated carbon, etc.) • **Ion Exchange Method** (removal of hardness components and heavy • **Membrane Separation Method** (separating fine particles and salts using RO membranes, UF membranes,
Objects	Organic wastewater, domestic wastewater, and food industry	Acidic and alkaline wastewater, heavy metal-containing wastewater, and hazardous chemical substances.	Suspended solids, refractory organic matter, heavy metals, and salts
Advantages	• High treatment efficiency • Environmentally friendly	• Immediate effect • Effective against specific pollutants	• Advanced treatment is possible • Effective for securing reclaimed water
Disadvantages	• Requires microbial management • Vulnerable to load fluctuations	• High chemical costs • Requires treatment of by-products	• High equipment costs • Requires maintenance of chemicals and membranes

Summary of Leachate Treatment Method

◎ : Most suitable
○ : Suitable
△ : So so
× : Not applicable

	BOD	COD	SS	T-N	Color	Heavy Metal
Rotary Bio-disk Contactor Process	◎	○	△	△	△	△
Contact Aeration Process	◎	○	△	△	△	△
Activated Sludge Process	◎	○	△	△	△	△
Biological Trickling Process	◎	○	◎	△	△	△
Biological Nitrogen Freeing Process	◎	○	△	◎	△	△
Coagulation Sedimentation	○	◎	◎	△	◎	○
Sand Filtration	△	△	◎	×	△	×
Activated Carbon	◎	◎	○	△	◎	○
Ozone Oxidation	×	○	×	×	◎	×
Chelates	×	×	×	×	×	◎



Biological treatment
- Recirculation
- ECO-FAN
- Tornado, ···

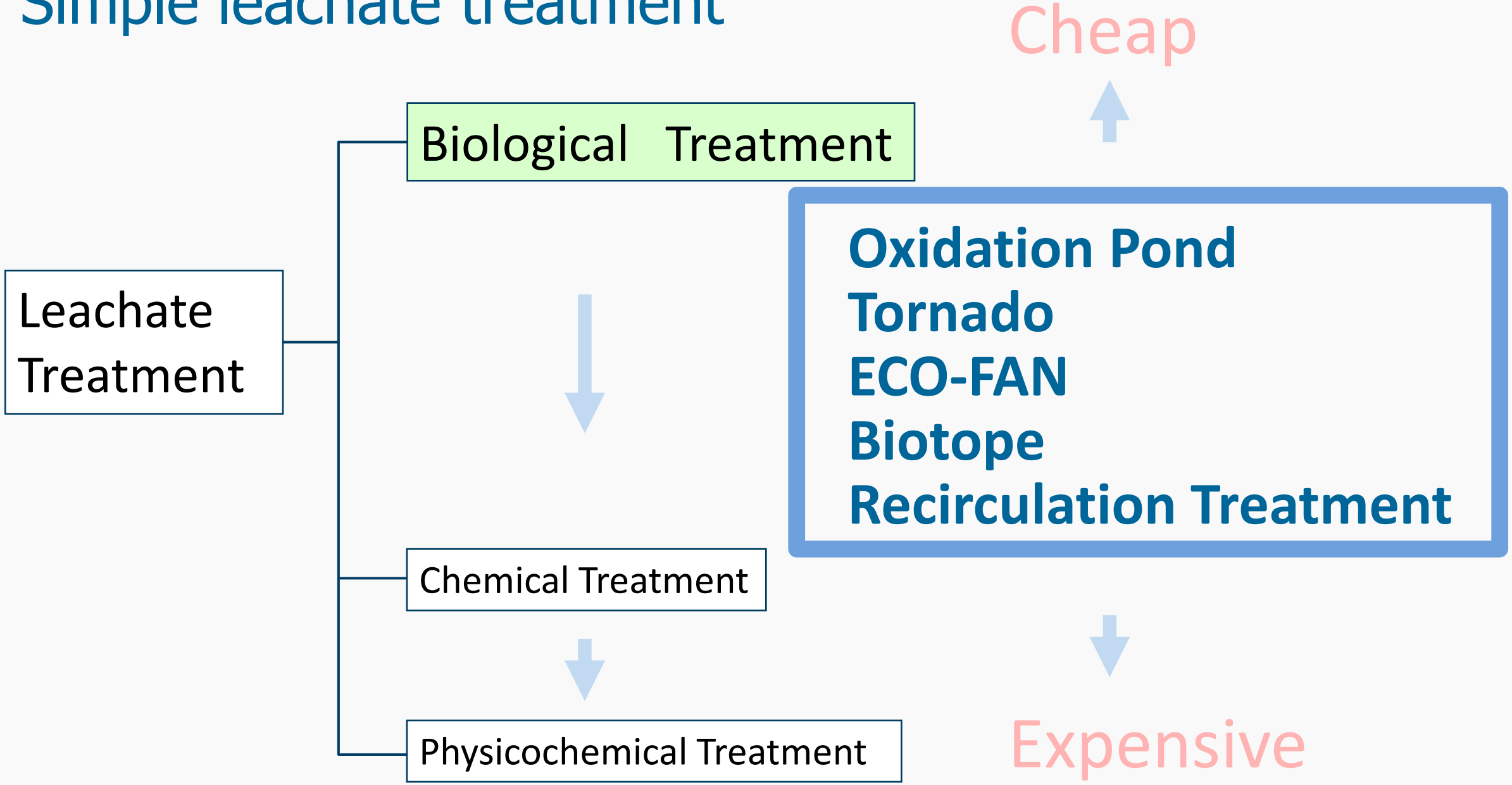
Physical treatment
- Sand filtration
- Sedimentation/Coagulation, ···

Physicochemical treatment
- Activated carbon adsorption
- Ion exchange
- Chelates, ···

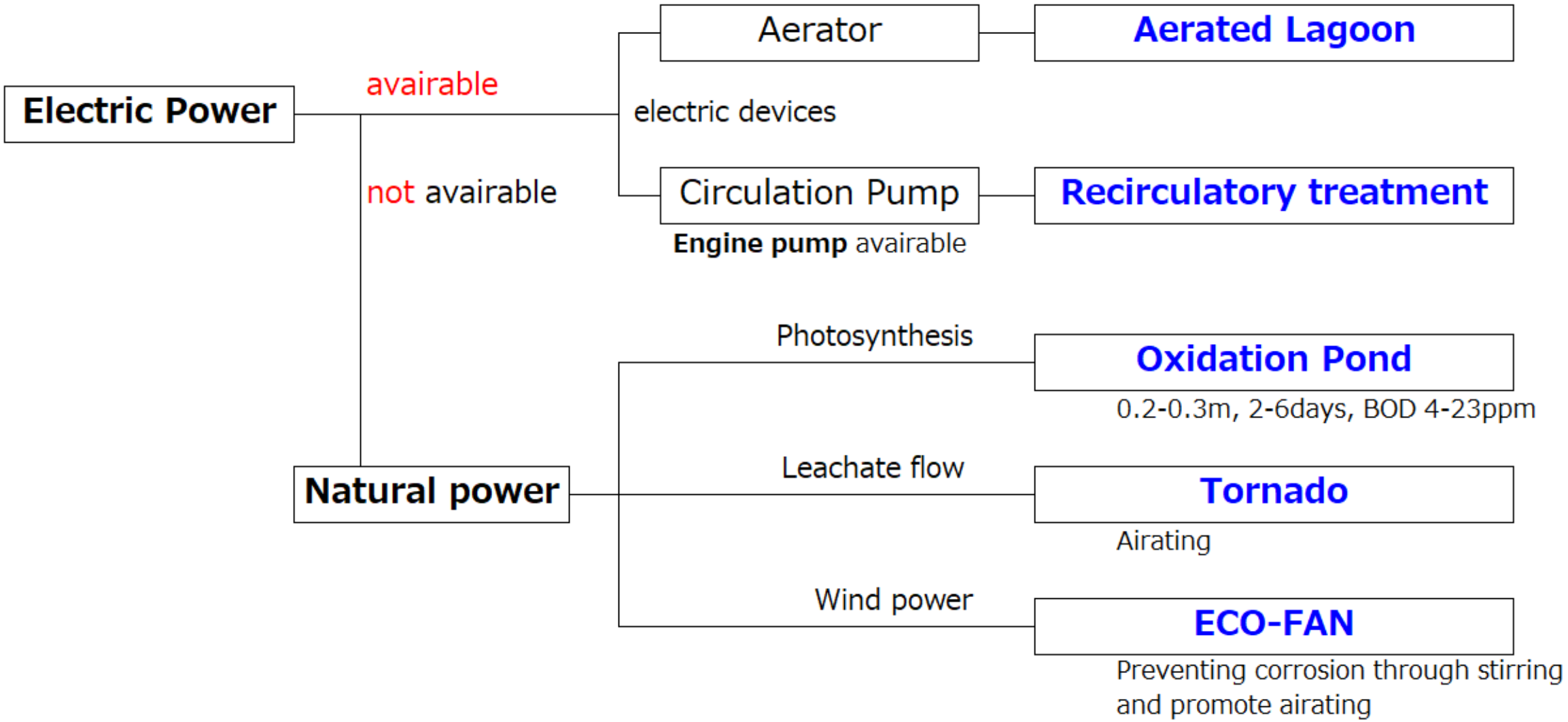
Since various components are dissolved in leachate, an appropriate **combination** of multiple treatment methods is effective for treatment.

Find treatment methods that is suitable for your landfill site.

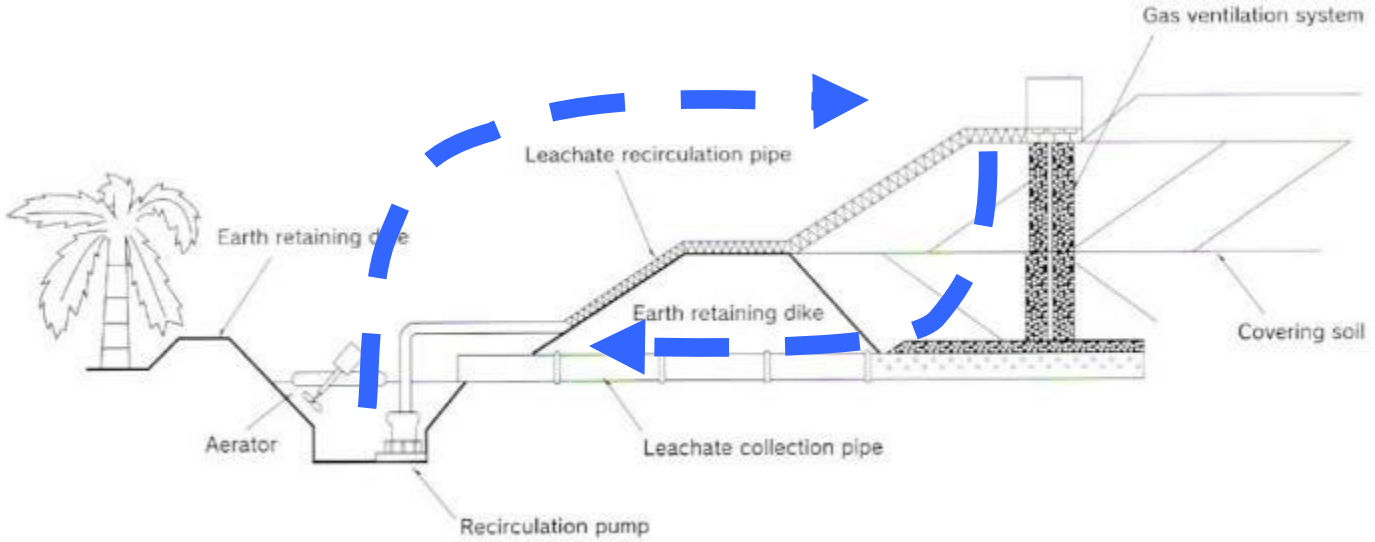
Simple leachate treatment



Biological treatment applications

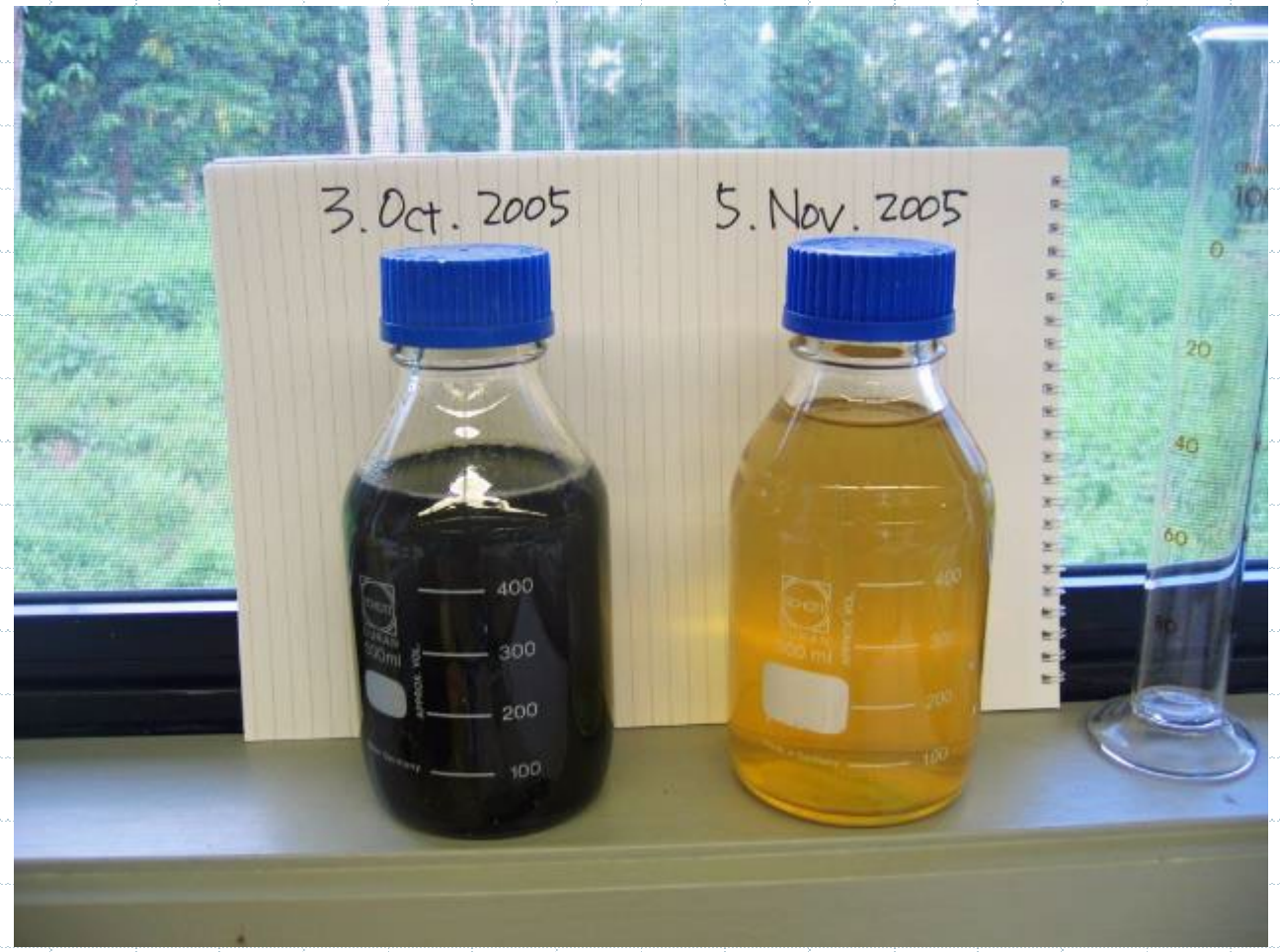


Recirculatory Semi-aerobic Landfill



- The **recirculatory** semi-aerobic landfill returns leachate to the landfill to accelerate the purification of leachate.
- By recirculating the leachate, nitrification and denitrification are encouraged and organic and nitrogen components are removed thus reducing the pollutant load in the leachate.

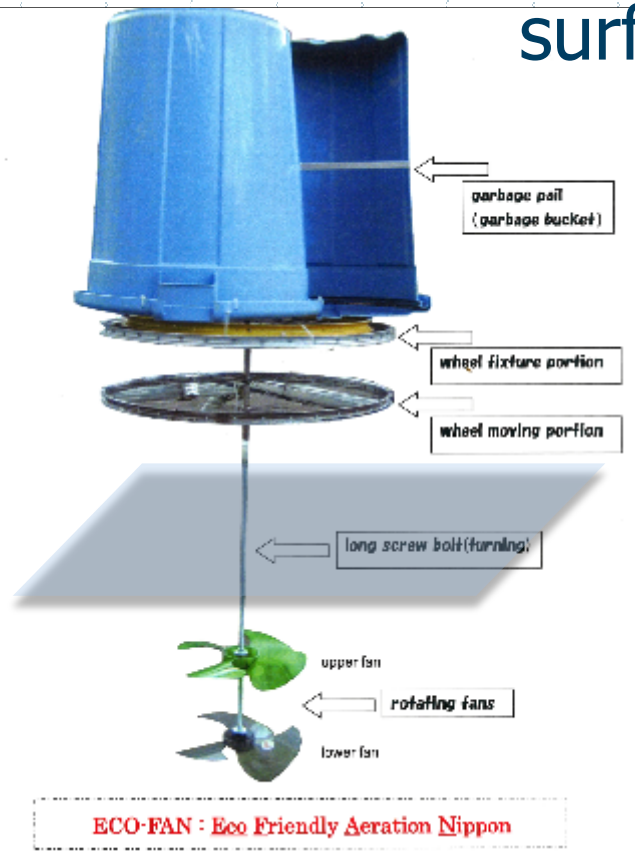
Effect of recirculatory treatment



Improvement of the Leachate after 1 month operation of re-circulatory treatment.

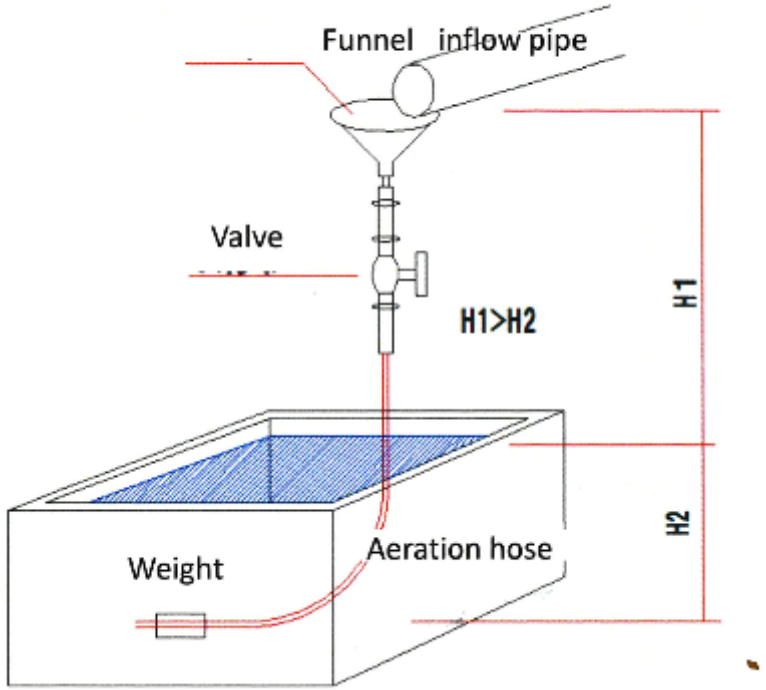
ECO-FAN

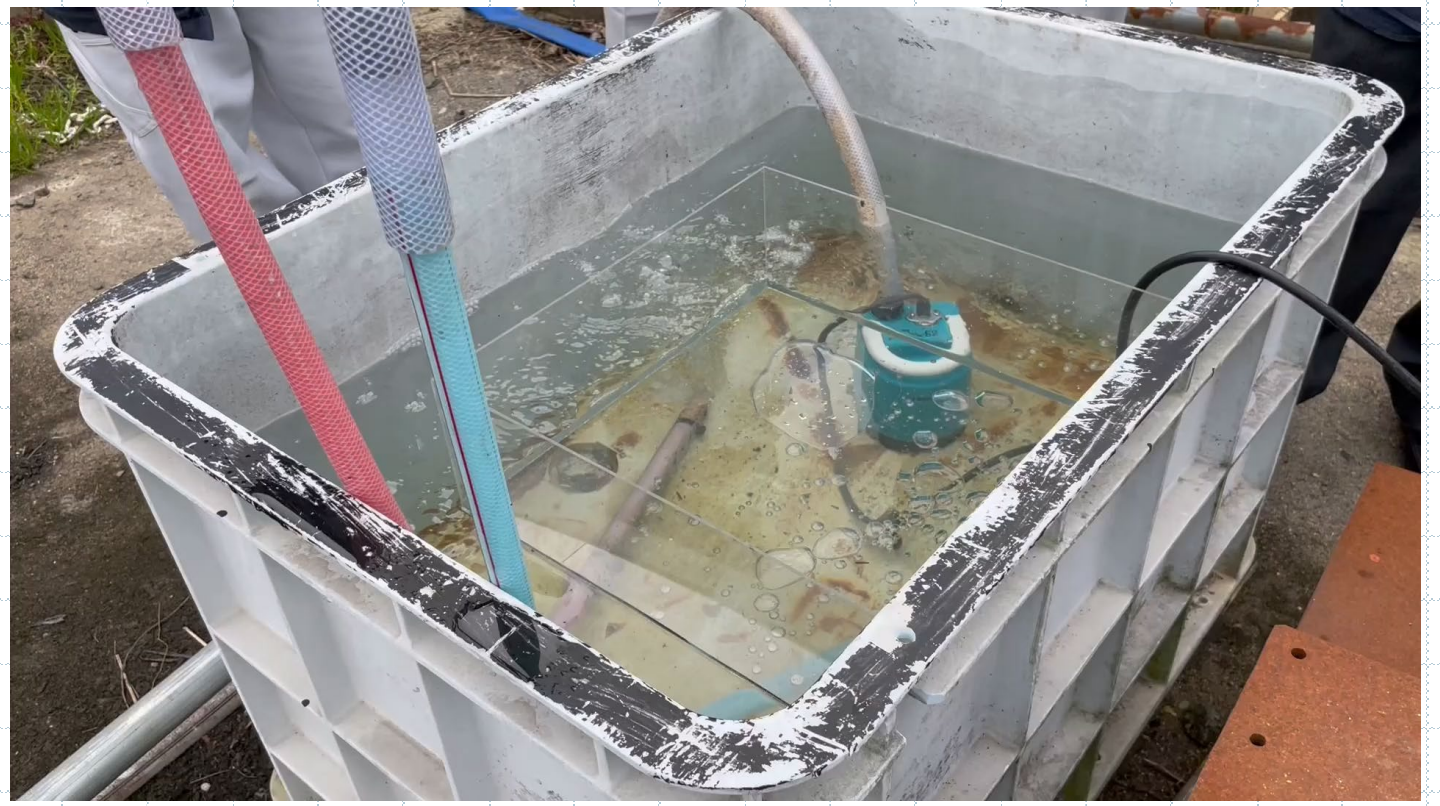
An ECO-FAN is a windmill made from items such as plastic water containers, bicycle rims, and fan blades. Its underwater blades can agitate the water within a diameter of 4 meters, enhancing the surface aeration effect.



Tornado

The Tornado is an aeration system that utilizes a water drop, creating a vortex with a watering can to draw air into the flowing water and thereby aerate it.





Categories of Bio-remediation

Bio-remediation	**Biological treatment** Bacterial decomposition of organic matter		Decomposition (catabolism) of organic substances
			Uptake, degradation, and volatilization of nitrogen compounds nitrification and denitrification
	Phyto-remediation Uptake and degradation by plants		Uptake, degradation, immobilization, and volatilization of contaminants (including heavy metals, organic compounds, and radionuclides)
			Uptake (assimilation) of eutrophic substances (nitrogen and phosphorus)

Representative bacteria for each treatment target

1. **Organic matter** degradation (BOD removal)

Aerobic

- **Pseudomonas** : Degradation of diverse organic matter
- **Bacillus** : Highly durable, capable of degrading proteins and starch
- **Zoogloea** : Contributing to floc formation
- **Ciliates** (Paramecium, Vorticella, etc.)

→ CO_2 + H_2O

Anaerobic Division of roles in the fermentation process

- Clostridium : Decompose organic matter into acids → Acid
- Methanosaeta : Methane production from acetate
- **Methanobacterium** : Methane production from hydrogen and carbon dioxide

→ Methane

Able to thrive in high-strength wastewater and recover biogas

2. **Nitrogen** removal

Aerobic (Nitrifying bacteria)

- **Nitrosomonas** → Nitrous acid
- **Nitrobacter** → Nitric acid

Facultative anaerobic (Denitrifying bacteria)

- **Pseudomonas denitrificans** → Nitrogen gas

Under aerobic conditions, they perform normal respiration, and when oxygen decreases, they switch to nitrate respiration with flexibility.

3. **Phosphorus** removal

Aerobic

- **Accumulibacter** : Representative phosphorus-accumulating bacteria → Polyphosphate

Directly linked to eutrophication prevention

Phosphorus removal occurs in the aerobic phase, but pretreatment under anaerobic conditions is essential.

4. Oxidation and reduction of **Sulfur compounds**

Aerobic Sulfur-oxidizing bacteria

- **Acidithiobacillus** → SO_4^{2-}

Anaerobic Sulfate-reducing bacteria

- **Desulfovibrio** → H_2S

The sulfide (H_2S) produced by sulfate-reducing bacteria is oxidized back to sulfate (SO_4^{2-}) by sulfur-oxidizing bacteria.
This cycle is called the **sulfur cycle**, and it plays an important role in nature and wastewater treatment.

5. **Heavy metal** removal

Removal of up to 99.96% of hexavalent chromium
- Microbacterium paraoxydans strain VSVM IIT (BHU)

Degradation and adsorption of aromatic compounds and heavy metals
- Pseudomonas putida

In an anaerobic environment, lead, cadmium, and mercury are precipitated as sulfides.
- Desulfovibrio (Sulfur-reducing bacteria)

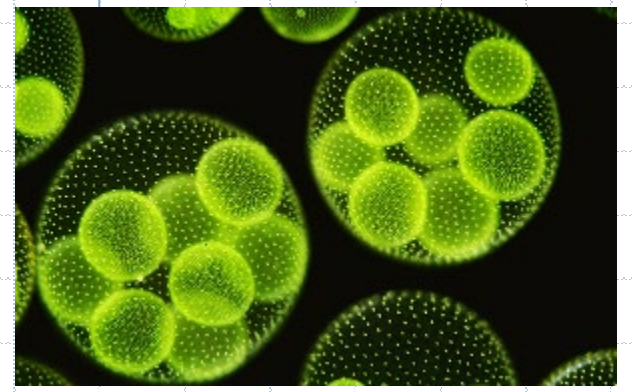
Involved in the redox reactions of iron, manganese, and chromium
- Shewanella oneidensis

These diverse groups of bacteria work together to support the efficiency and stability of wastewater treatment.

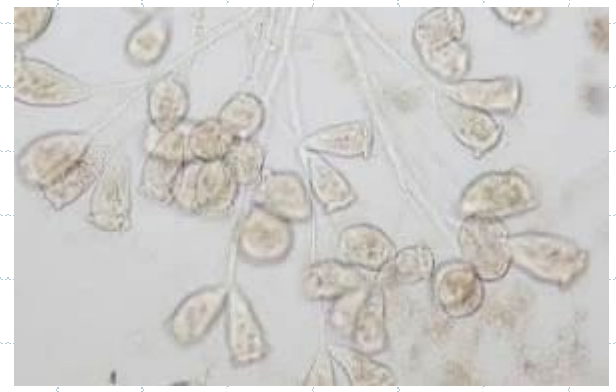
Biological Treatment

In the natural system, bacteria and microbe decompose organic matters into clean carbon-dioxide and water.

And multiplies themselves.

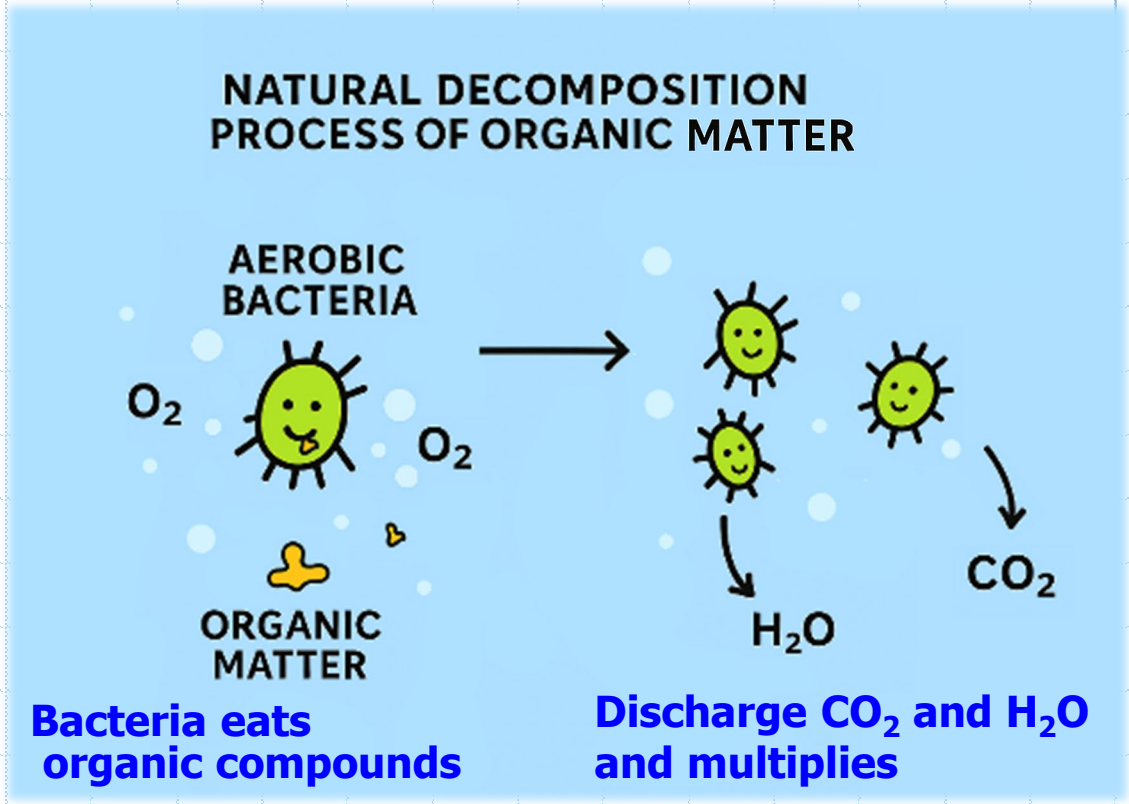


Volvox



vorticella

Natural Cleansing Mechanism



In aerobic condition

$$C_xH_yO_z + O_2 \xrightarrow{\text{aerobic bacteria}} CO_2 + H_2O$$

Organic matter

Biological Treatment

Nitrification-Denitrification

Nitrification process in **aerobic** condition

Oxdation

Nitrosomonas

$NH_4^+ + O_2 \rightarrow NO_2^- + H^+ + H_2O$

Nitrobacter

$NO_2^- \rightarrow NO_3^-$

$NH_4^+ + 3/2\ O_2 \rightarrow NO_2^- + 2H^+ + H_2O$

$NH_4^+ + 2\ O_2 \rightarrow NO_3^- + 2H^+ + H_2O$

Denitrification process in **anaerobic** condition

Reduction

NO_2^-

NO_3^-

$+ H \rightarrow N_2\uparrow + OH^- + H_2O$

Hydrogen donor

N2 Gas

Pseudomonas

$2NO_2^- + 3H_2 \rightarrow N_2\uparrow + 2OH^- + 2H_2O$

$2NO_3^- + 5H_2 \rightarrow N_2\uparrow + 2OH^- + 4H_2O$

Oxygen demand / DO : Dissolved Oxygen

- In order for **aerobic Microorganisms** to be active,

DO > **2mg/L**

- For **fish and shellfish**,

> 3mg/L

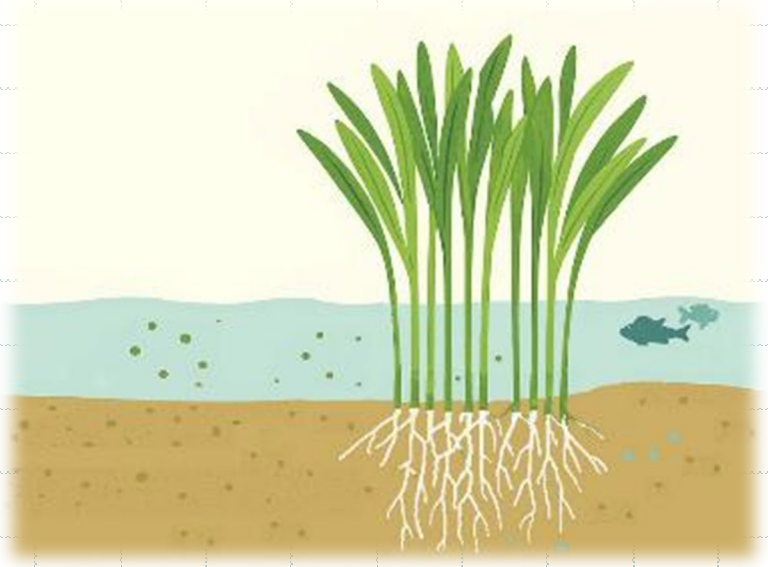
- To maintain **sound eco system**

> 5mg/L

Natural aeration

Ragged river bed makes turbulence of the flow and it helps dissolution of oxygen.

Phytoremediation Effects



1. Suspended Solids Removal:

   Plant stems and roots slow water flow, helping particles settle.

2. Microbial Organic Matter Decomposition:

   Microbes and algae on plant surfaces break down organic matter, supported by small animals in the ecosystem.

3. Nutrient Uptake:

   Plants and attached algae absorb excess nutrients like nitrogen and phosphorus from the water.

Aquatic Vegetation

Reed and Cyprus

← Cyprus ↓ Lotus ↑ Irises ↓ Water Lily

4 Steps of Water Quality Improvement

Step **1:Introduction of Fukuoka Method** **(Semi-Aerobic Landfill)**

Early decomposition of waste and improvement of raw water quality

Step **2: Recirculation Treatment**

Reduction of organic pollution and nitrification–denitrification effects

Step **3: Combination of Multiple Water Treatment Methods**

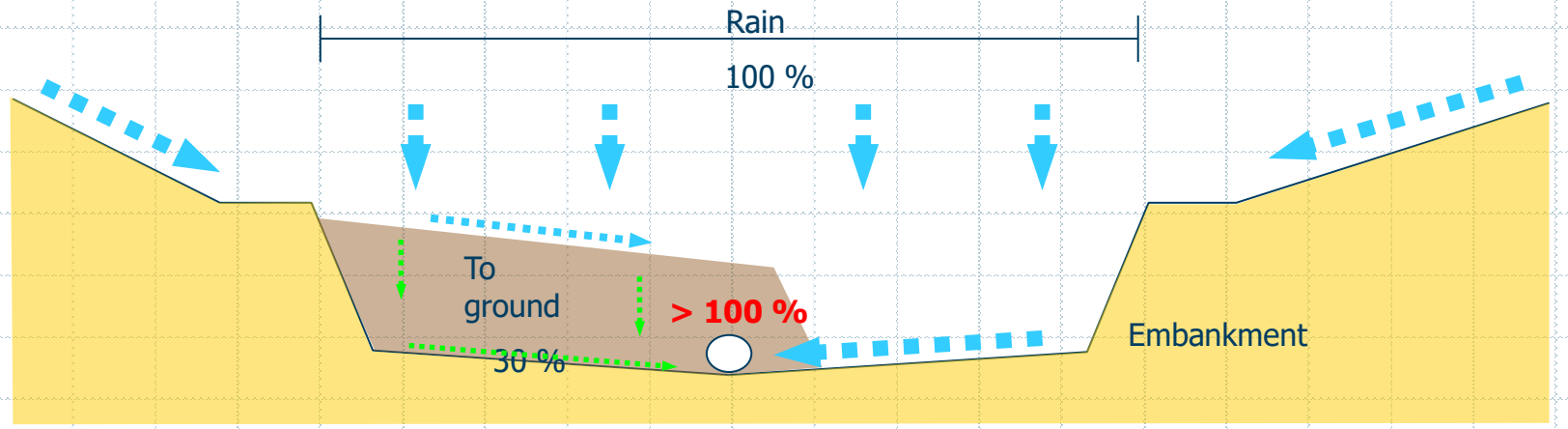
Improvement of leachate treatment efficiency

Step **4: Implementation of Rainwater Exclusion**

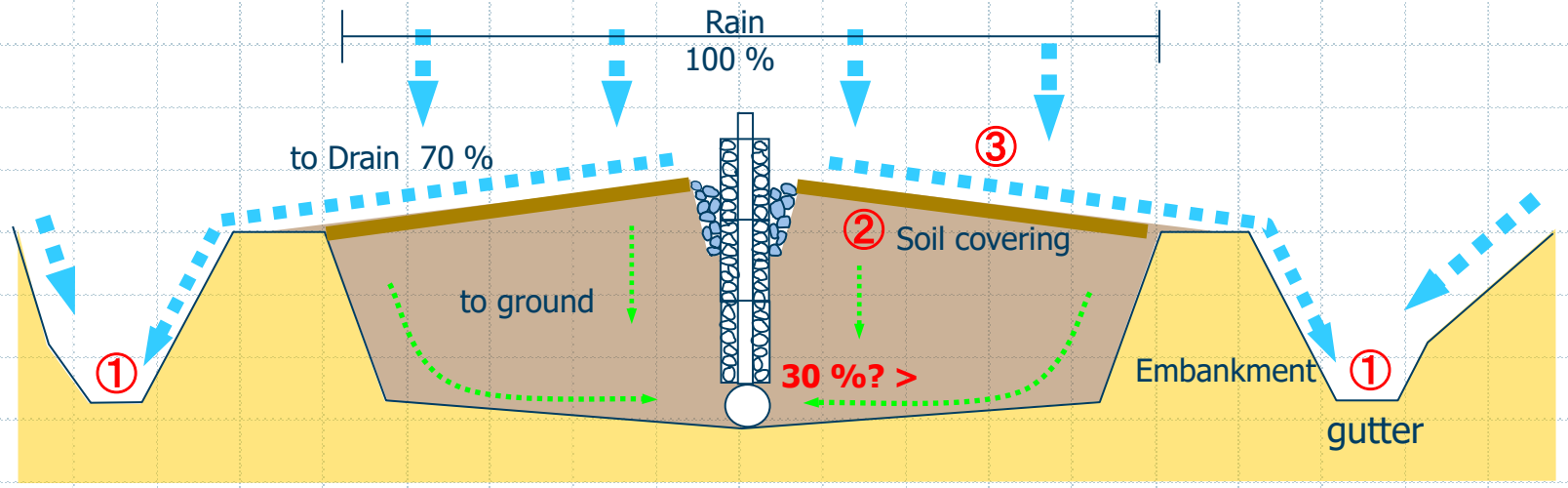
Improving the efficiency of leachate treatment by reducing the volume of water requiring treatment

Step **4:**
Rainwater Elimination （Preventive measures）

→ Reduces the volume of water to be treated



no measure



measured

① Gutter

② Soil covering

③ Slope 2~3%

Leachate

Processing Load = (Quality × Volume)

Recommended Items of simple leachate monitoring in level 2 landfill

items	definition	index	period
pH	pH is a scale for classifying liquids into acidity, neutrality, and alkalinity.	An important indicator when observing the decomposition and reaction of substances dissolved in water	weekly
BOD	Biological Oxygen Demand, which shows amount of oxygen (mg/l) required by organisms to decompose organic matter in water.	Typical pollution index of organic matter in water [living environment items]	
COD	Chemical oxygen demand, which shows amount of oxygen (mg/l) required to oxidize oxidizable substances in water	One of the representative indicators of water quality, and is sometimes used as an alternative indicator to BOD because it is easier to measure than BOD.	weekly
Cl-	Amount of chloride ions present in water	The concentration of chloride ions is an indicator of domestic wastewater pollution such as night soil.	monthly
TOC	Total Organic Carbon, which shows the total amount of organic matter in water by the amount of carbon contained in the organic matter.	Representing total organic matter in water	
T-N	All of the various forms of nitrogen compounds in water	Expresses the degree of eutrophication of water	weekly

Contents

1. Samoa in the Pacific
2. What is the Fukuoka Method
3. Leachate treatment
4. Fukuoka Method for Leachate Treatment in Samoa

Tafaigata Landfill Site

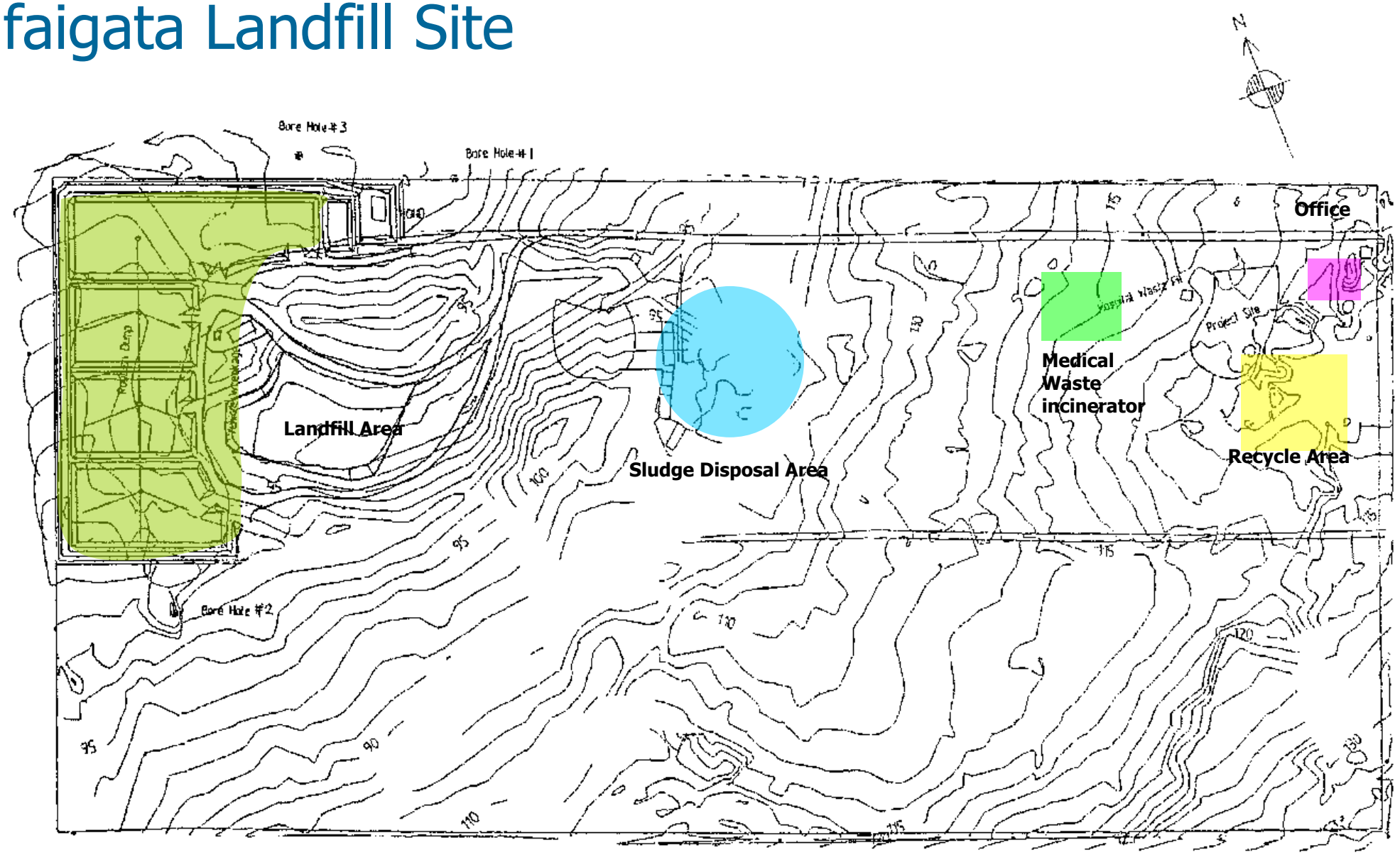
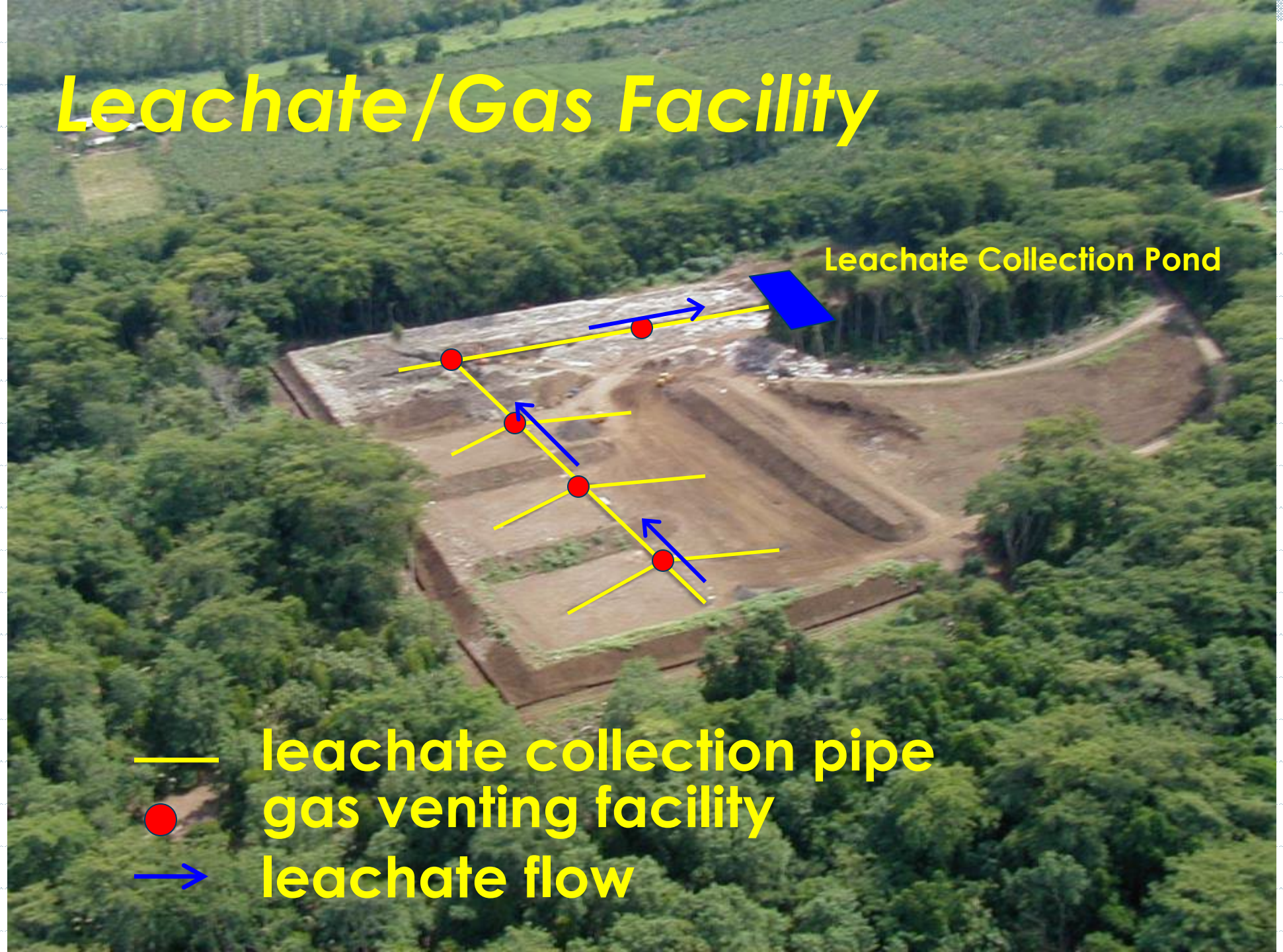


Fig.1 General Layout of Tafaigata Area

Nov 2002

Leachate/Gas Facility



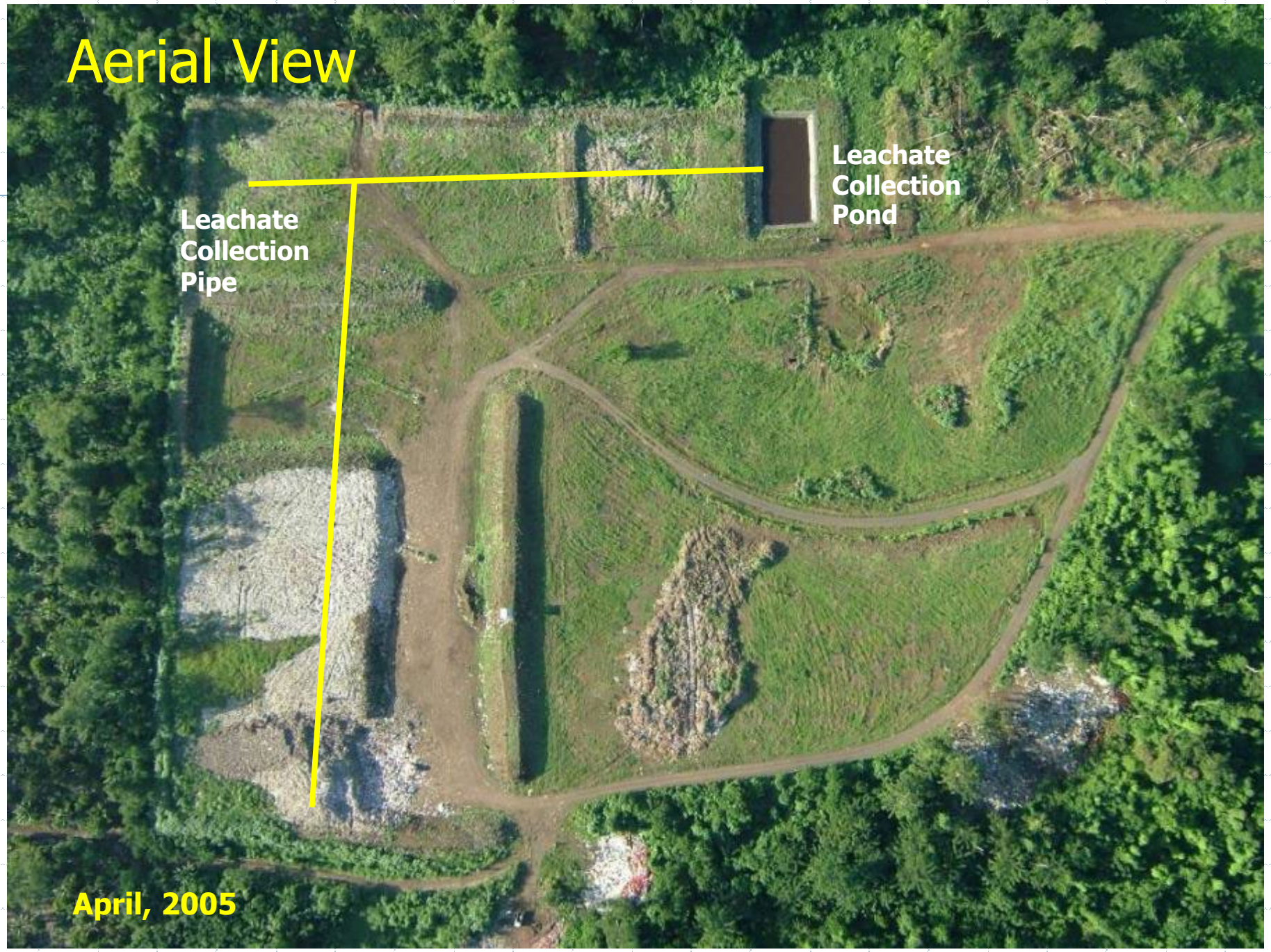
Embankment using existing waste

Perforated Leachate Collection Pipe on the slightly inclined base

Perforated Gas Venting Pipe

Leachate Collection Pond

Aerial View

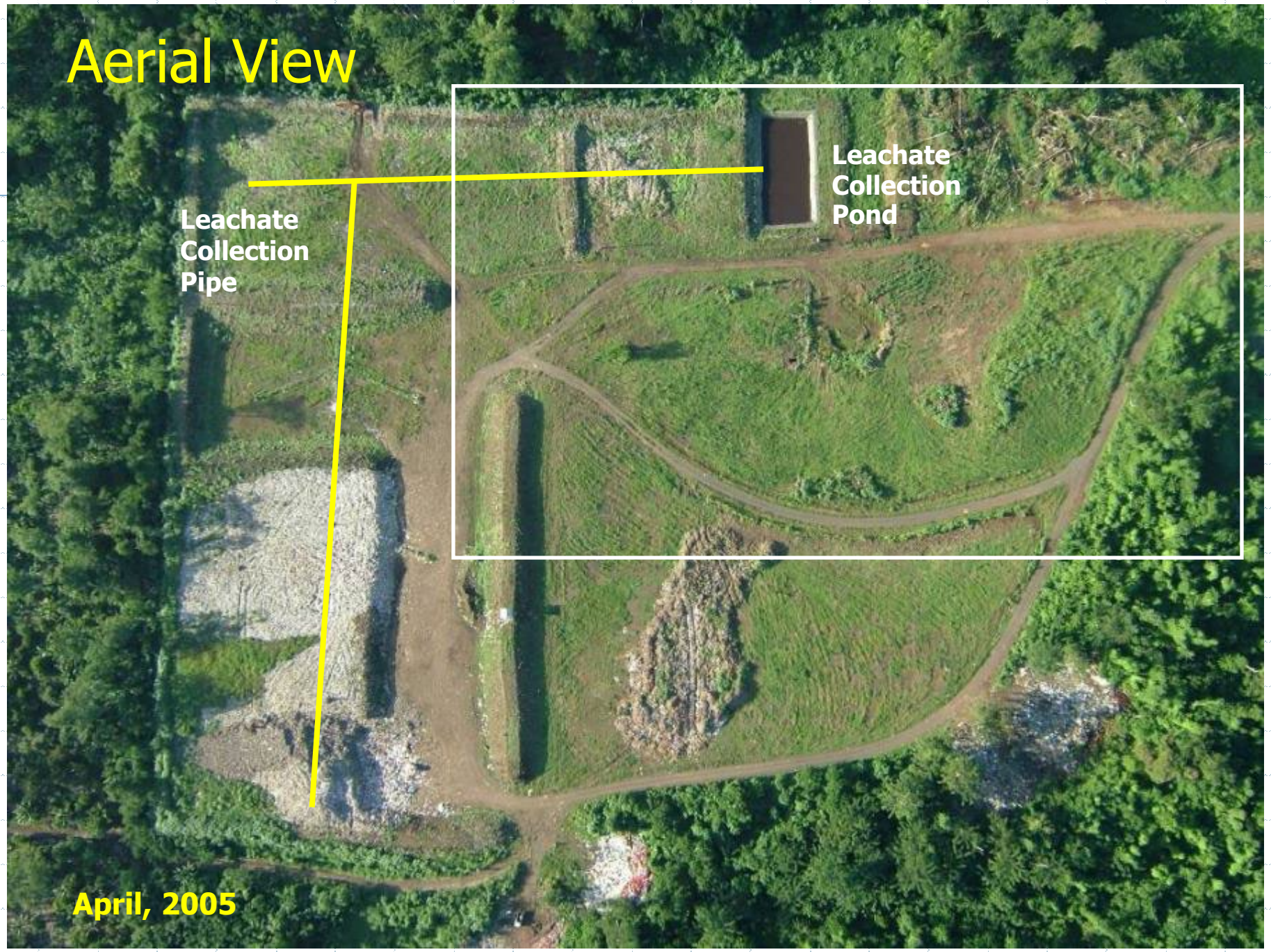

Leachate Collection Pipe
Leachate Collection Pond
April, 2005

Concept for Leachate treatment facilities at Tafaigata landfill

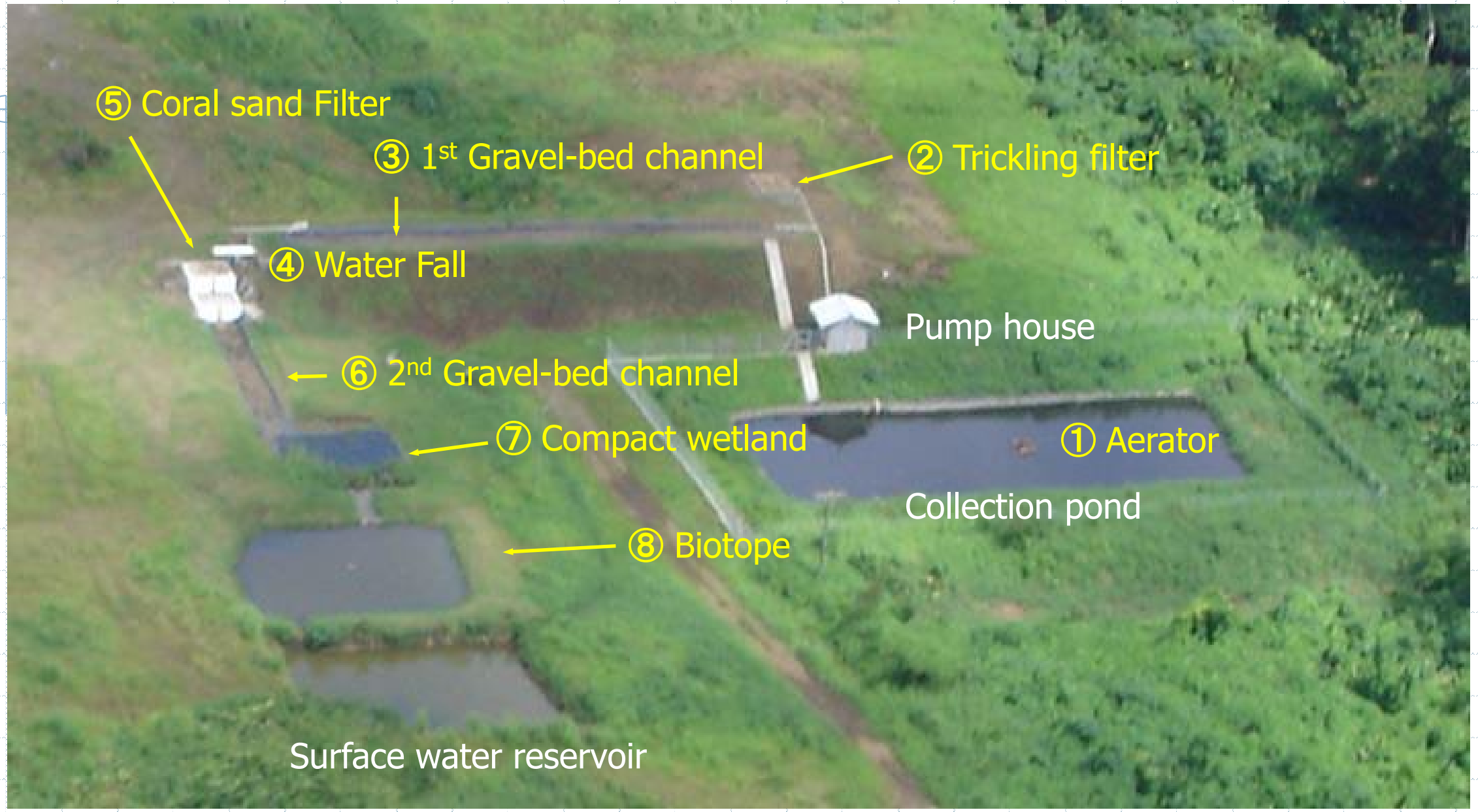
This simplified treatment facility was designed with a focus on removing organic pollution from a sanitary standpoint and ensuring **sustainability** through local staff.

1. Reduction of **construction costs**
   - Construction using civil engineering technique
2. Reduction of **maintenance costs**
   - Minimize of energy consuming machine
   - Water flow by using gravity
   - Natural cleansing effect
3. **Low technique**
   - Manual control by operator
   - User-friendly operation accessible to anyone
4. Adoption of **local materials** and **natural cleansing effect**
   - Lava stone、Coconut husk、Coral、Aquatic vegetations

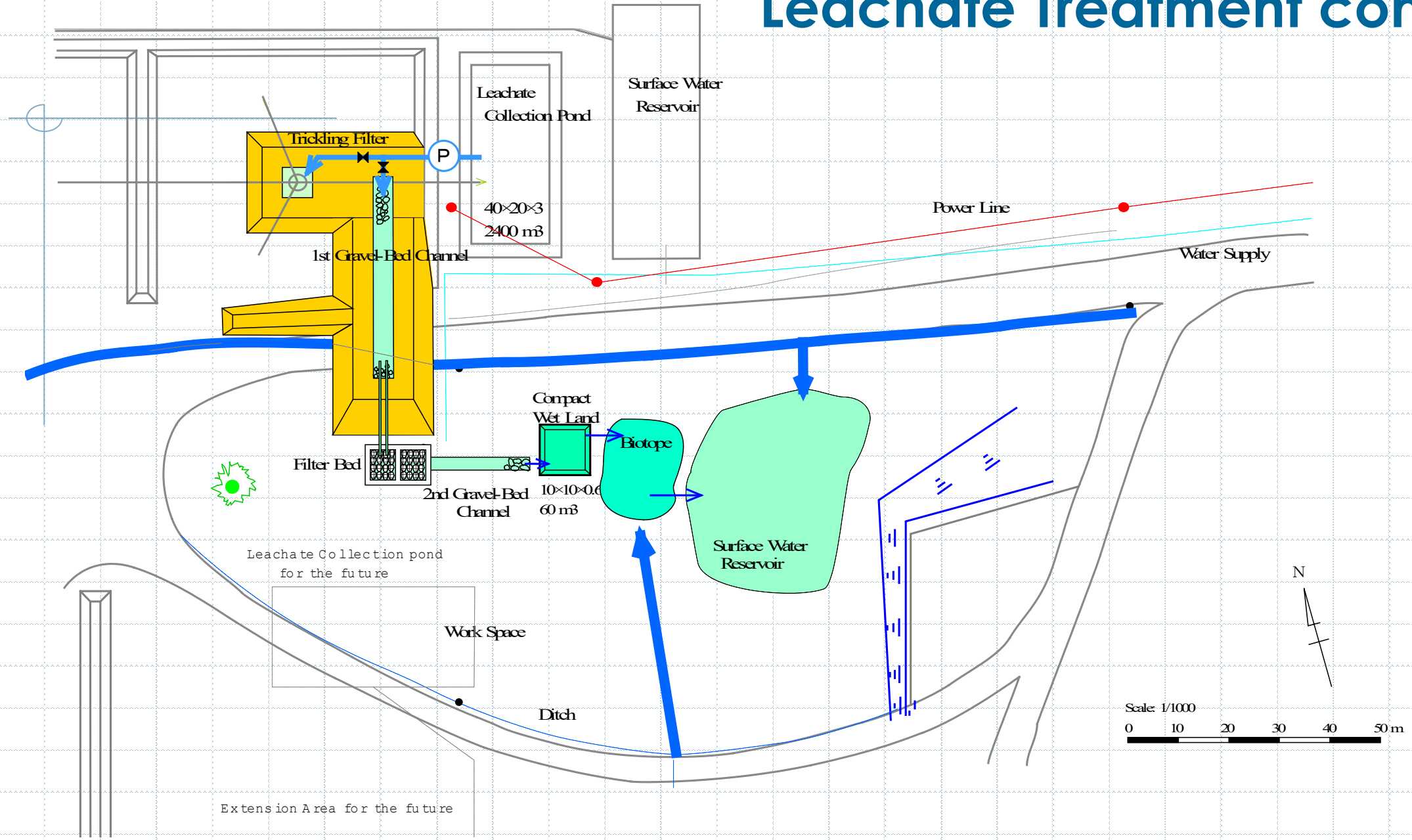
Aerial View


Leachate Collection Pipe
Leachate Collection Pond
April, 2005

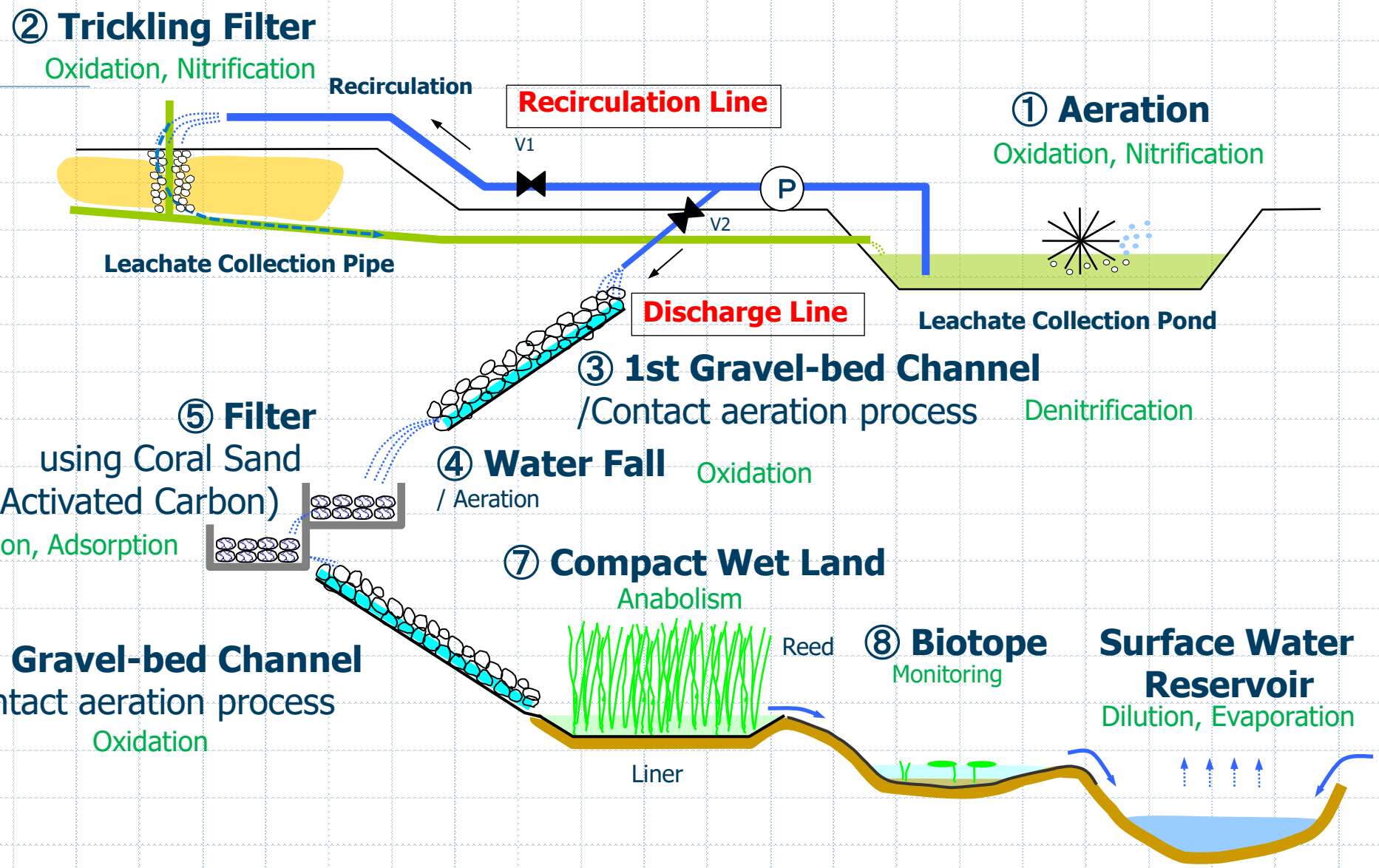
Leachate Treatment Complex



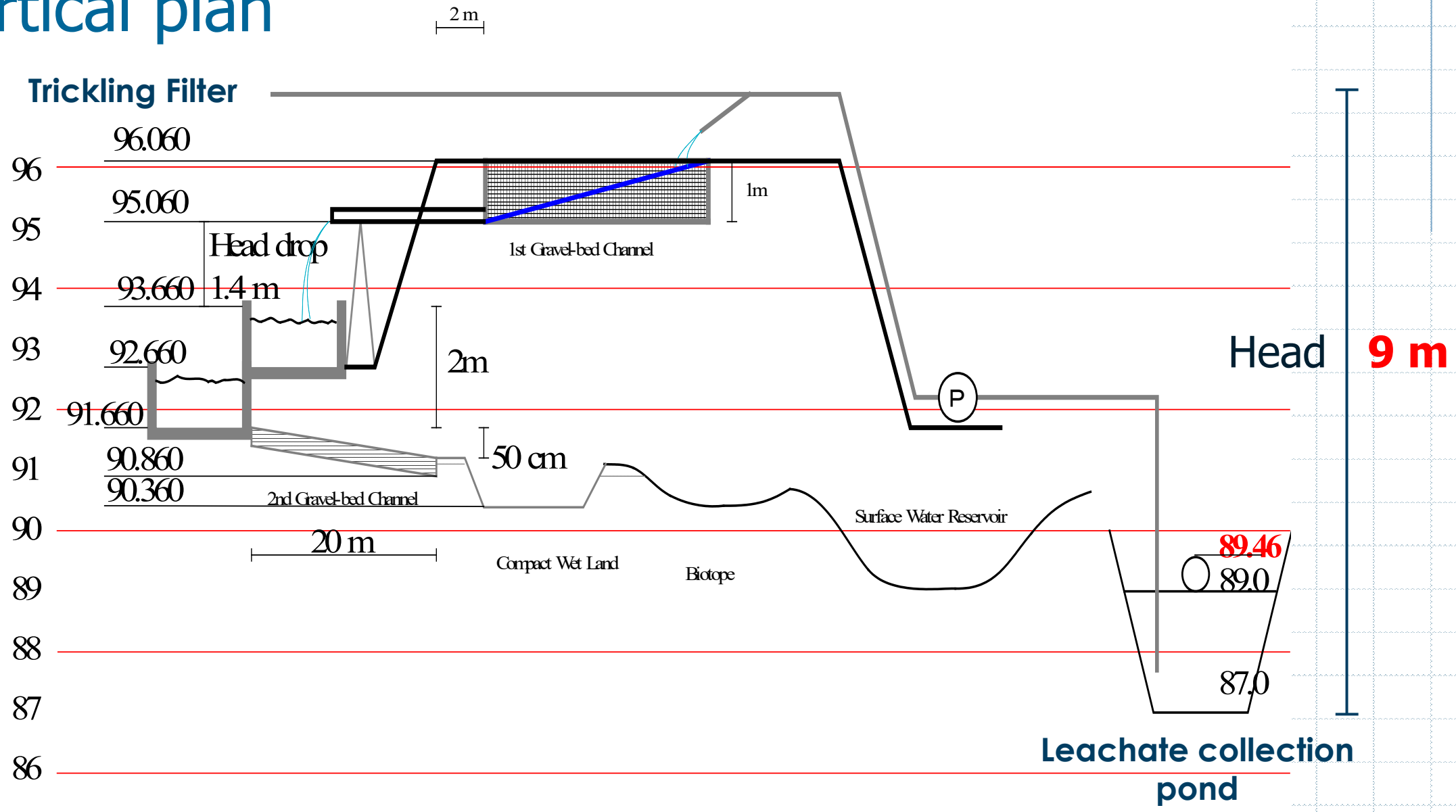
Leachate Treatment complex



Leachate Treatment Flow



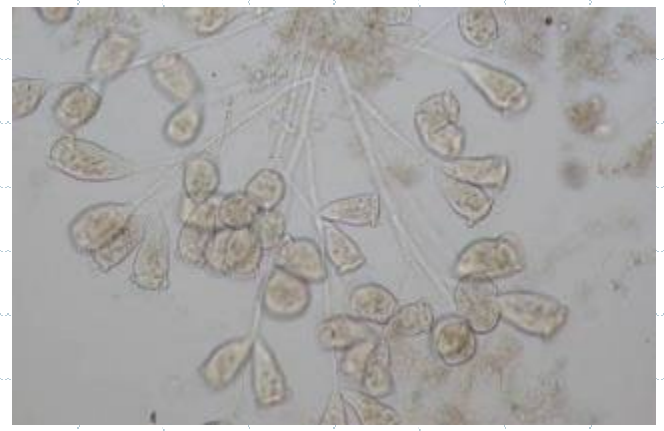
Vertical plan



Outline of facilities

- **Disposal capacity**：70m³/day
- **Control method**：Manual control by operator in checking with water level
- **Treating method**
  Circulation line： Aeration、Trickling filter
  Discharge line： Grabel-bed channel、Filter、Compact wetland
- **Energy**： Electric power、Pump（1．1kw×2sets）、
  Aerator（0．4kw） Total 1．5kw
- Cost for construction： **$80,000** leachate treatment only
- Duration of construction： June-December/2005

① Aeration



for
microbial degradation
with aerobic bacteria

Provide oxygen to the Micro Organism and promote microbial degradation

- Aerator for fish farming

  3φ, 2.2A/200V, 0.4 kw

  Cost: ＄1,500 （￥155,000）

【Side Effect】

- Sharp decrease of mosquito larvae by water flow.

② Circulation column with trickling filter

Aerobic condition
for **microbial degradation**
with aerobic bacteria

【Function】

・ A leachate treatment system through a trickling filter back down to the leachate collection pipe. Trickling filters are an aerobic treatment system that exploit micro-organisms growing on the rocks exposed to air, these aerobic bacteria metabolize organic matter from waste water.

【Features】

・ Main system in the facility.

Organic substances shall be treated.

・ Porous rocks (15cm) are stuffed in

the mass of L × W × H ： 3m × 3m × 3m

【Effect】

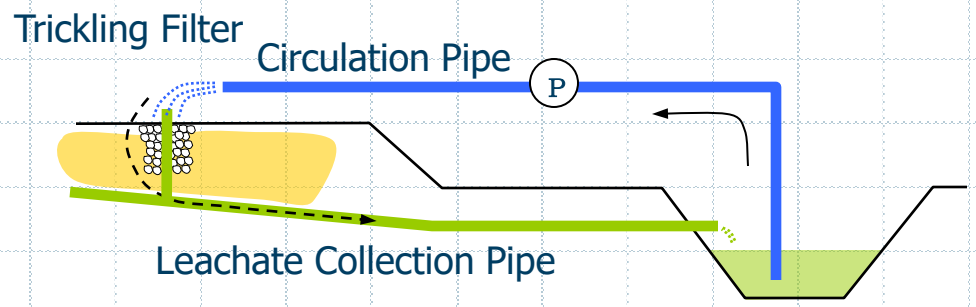
・ Most of organic and nitrogen components are removed.

Trickling Filter

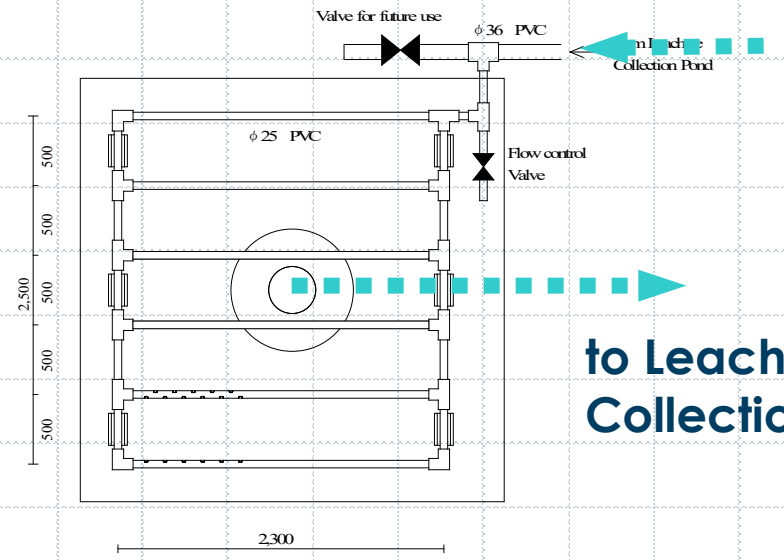
Circulation treatment using Trickling Filter

Trickling Filter

Circulation Treatment

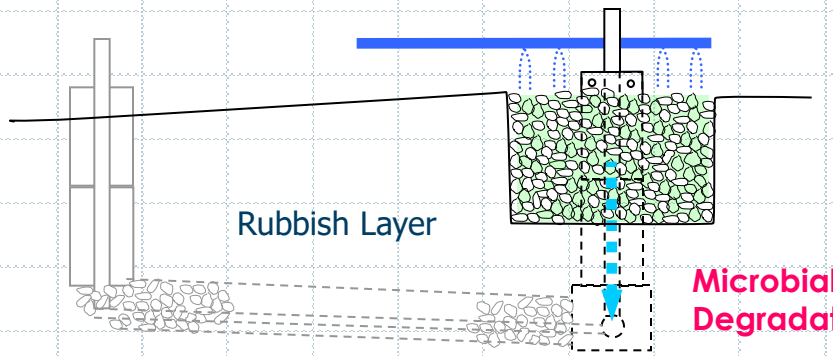


from Leachate Collection Pond



to Leachate Collection Pond

Top View



Cross Cutting

Circulation treatment using Trickling Filter

Trickling Filter

To prevent clogging in pipe, better adopting spoon head

Making of trickling filter

③ ⑥ Gravel-bed Channel

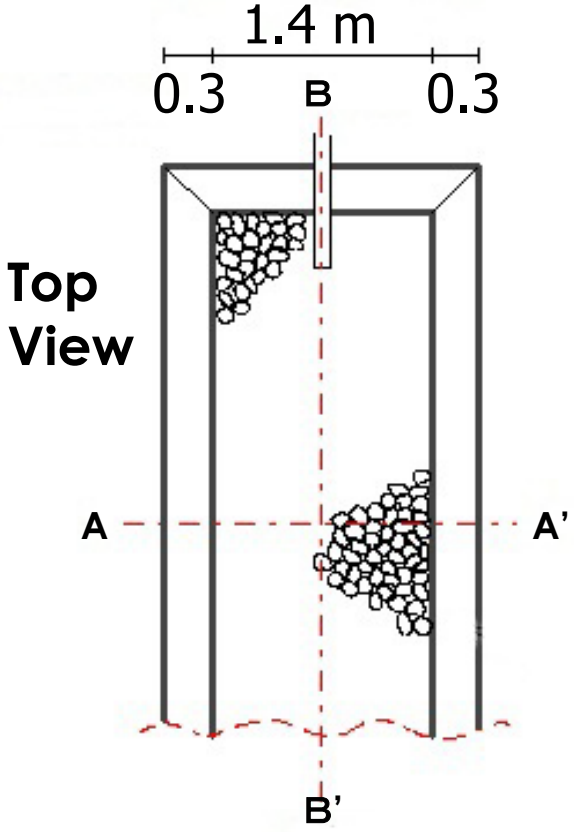
Micro Organism attached to rocks decompose organic substances

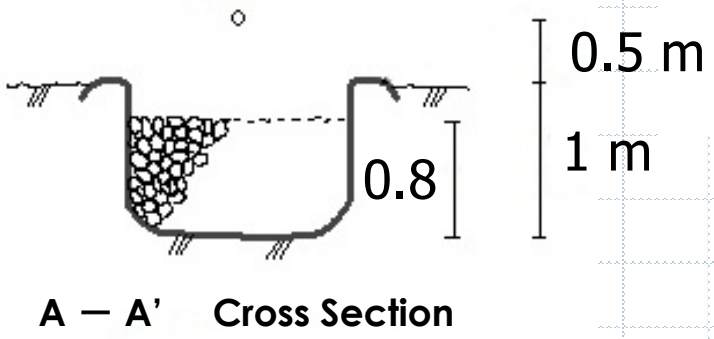
Lava rock is ideal for microbe to attach on the surface, since it has plenty of holes.

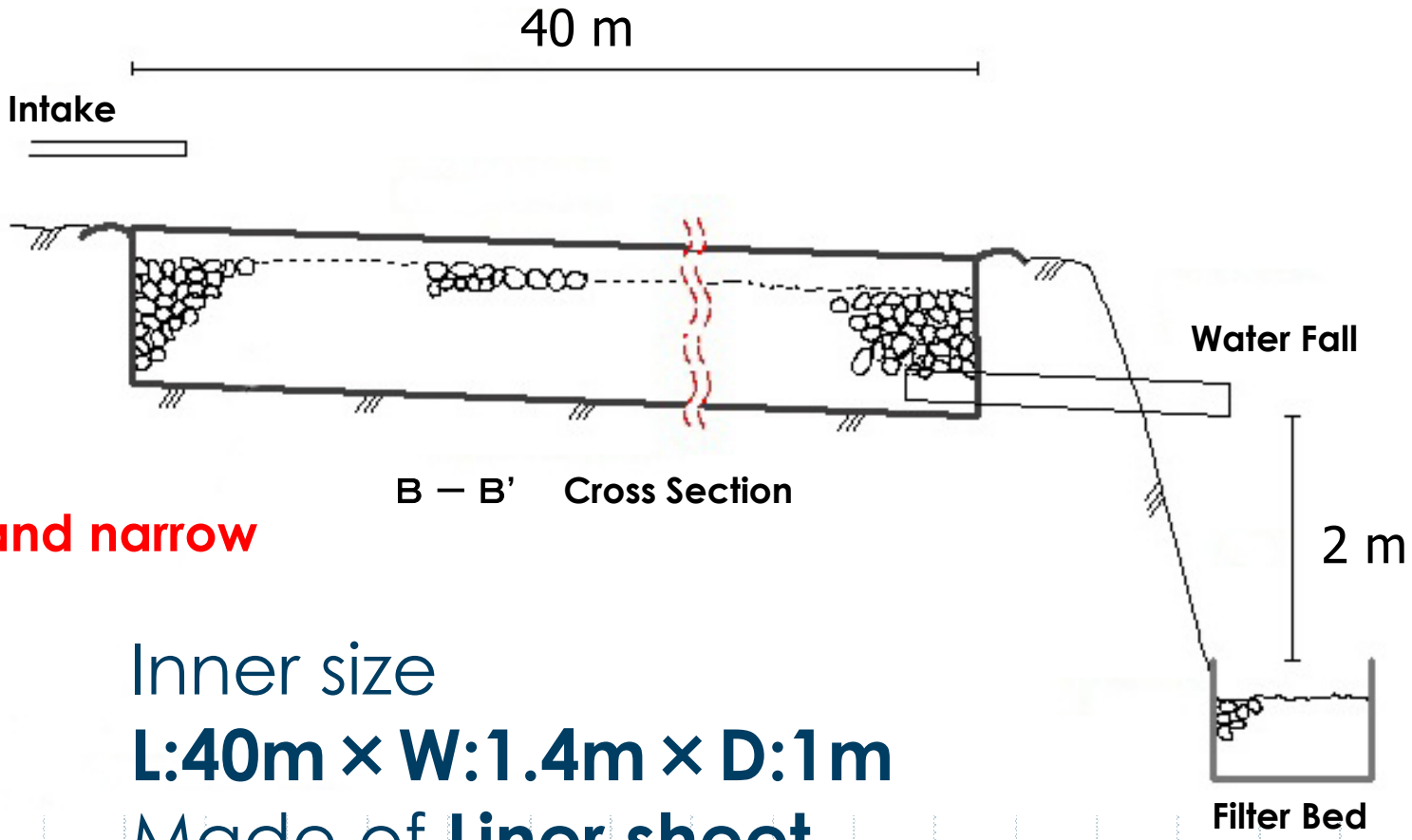
Lava rock is used for circulation column as well.

③ Gravel-bed channel-1

Anaerobic condition
for **denitrification**



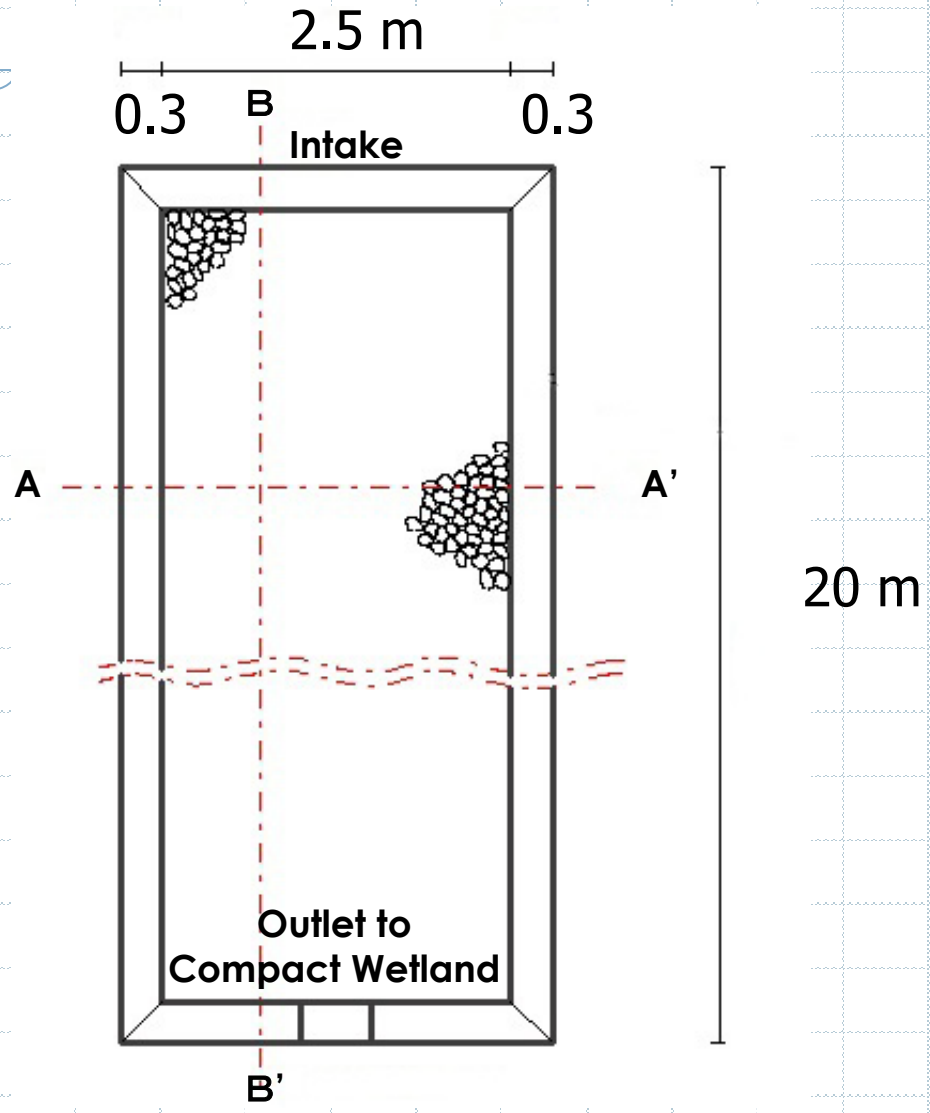




deep and narrow

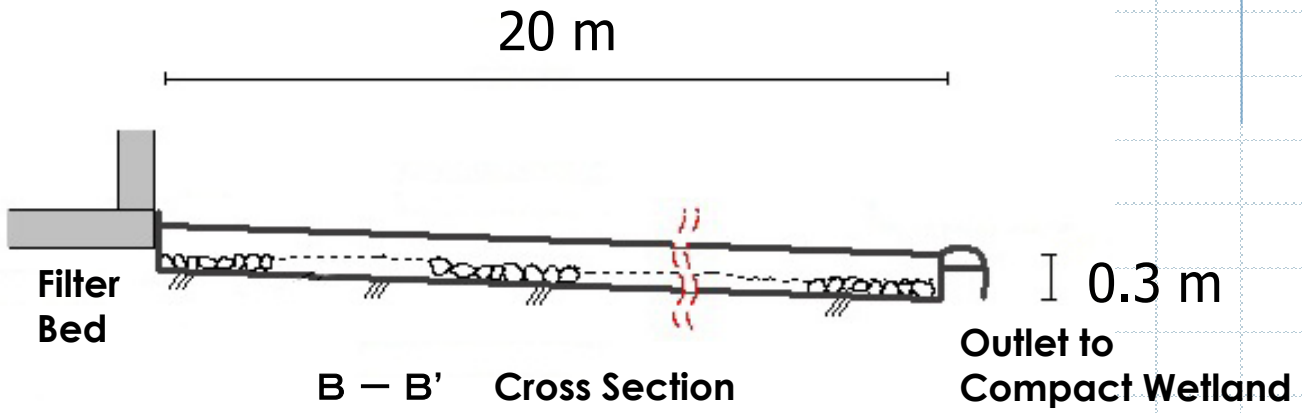
Inner size
L:40m × W:1.4m × D:1m
Made of **Liner sheet**

⑥ Gravel-bed channel-2

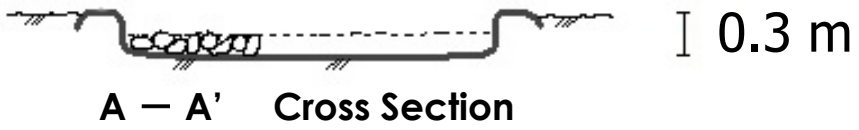


Top View

Aerobic condition
for **microbial degradation**



shallow and wide



Inner size
L:20m × W:2.5m × D:0.3m
Made of **Liner sheet**

④ Water Fall

Water fall is set at in-flow for aeration again.

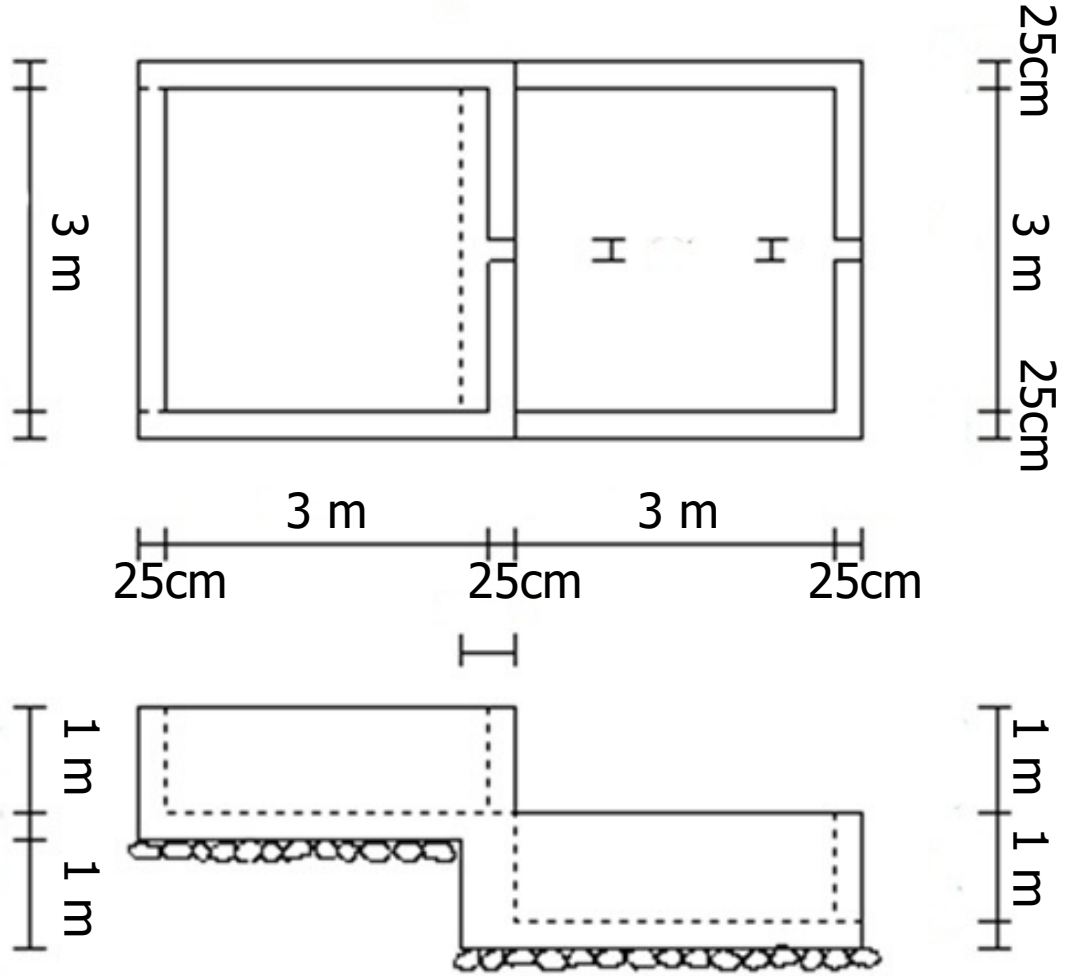
Height difference: **2 m**

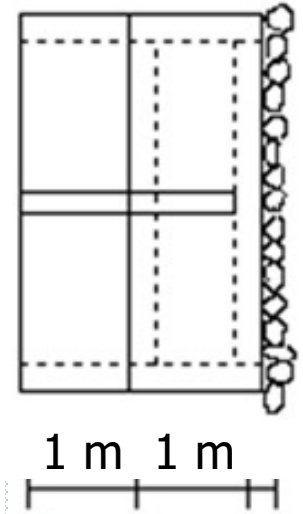
⑤ Filtration

Using local materials for filter i.e. Coral chip, Coconut husk activated carbon.

Filter bed

for **adsorption**
of chemicals and heavy metals

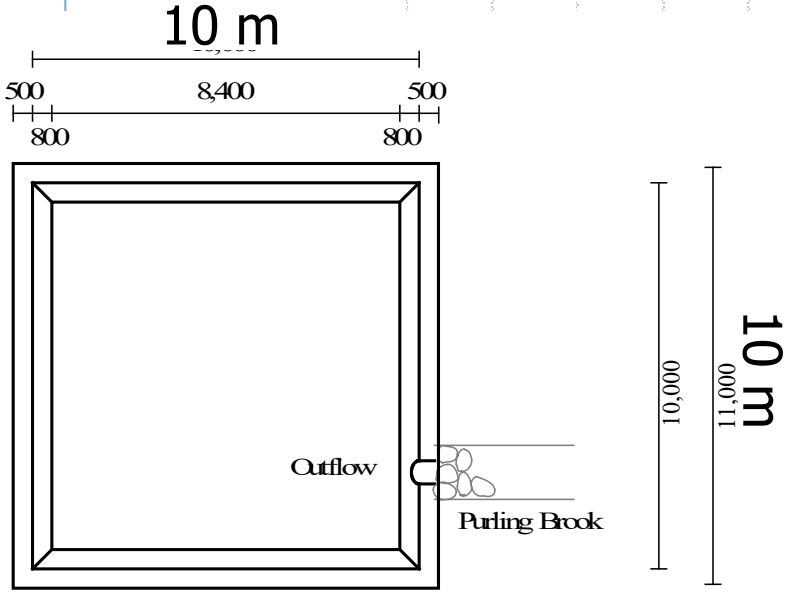


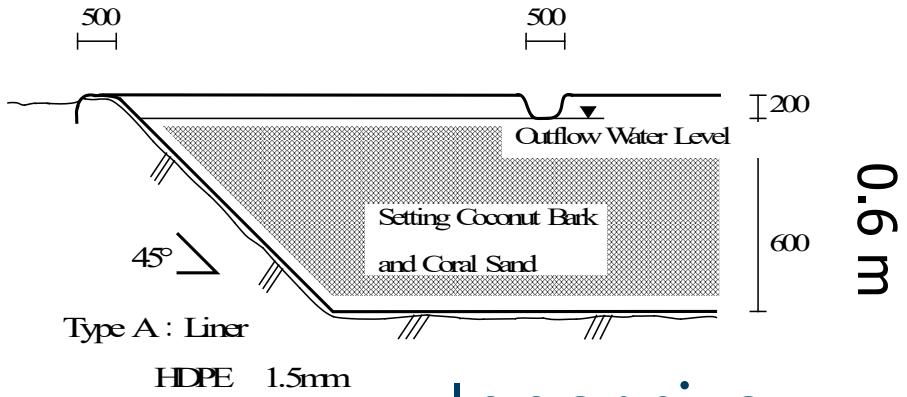


Inner size
L:3m × W:3m × D:1m
Made of **Reinforced Concrete** with **25cm thick**

⑦ Compact wetland

Using indigenous aquatic vegetation i.e. Reed, Sedge etc. for absorption of Nitrogen and Phosphorus.





for **removal** of **P**hosphorus and **N**itrogen

Inner size
L:10m × W:10m × D:0.6m
Made of **Liner sheet**

Top View

⑧ Biotope

for **monitoring**
of water quality

- **Biotope is eco system around the area**
- **By using Biotope as a simple measurement of treated water, if plants or fish die treatment is not enough**

- **As water quality variation is little in the leachate that daily observation of biotope works as an easy measurement.**

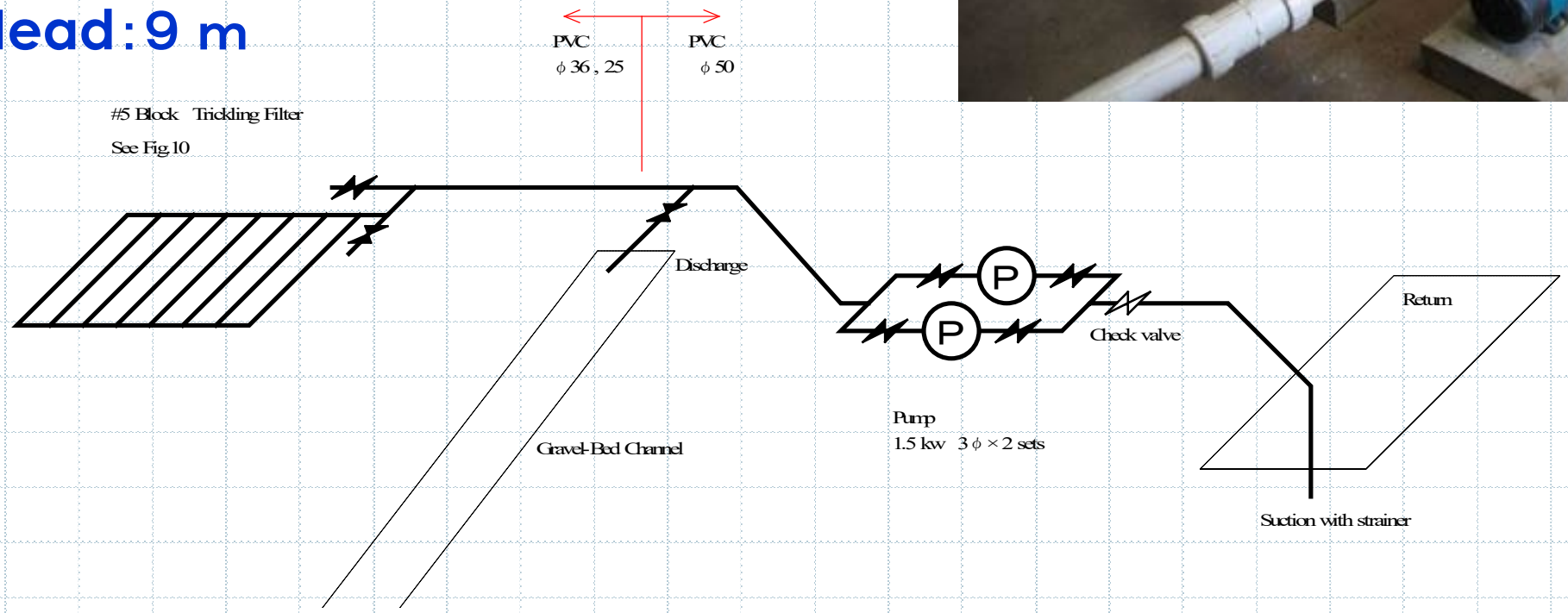
Pipe works

Pipe：PVC

Pump：1φ1.1kw×2、for sewage、

With Idle running protection

Head：9 m



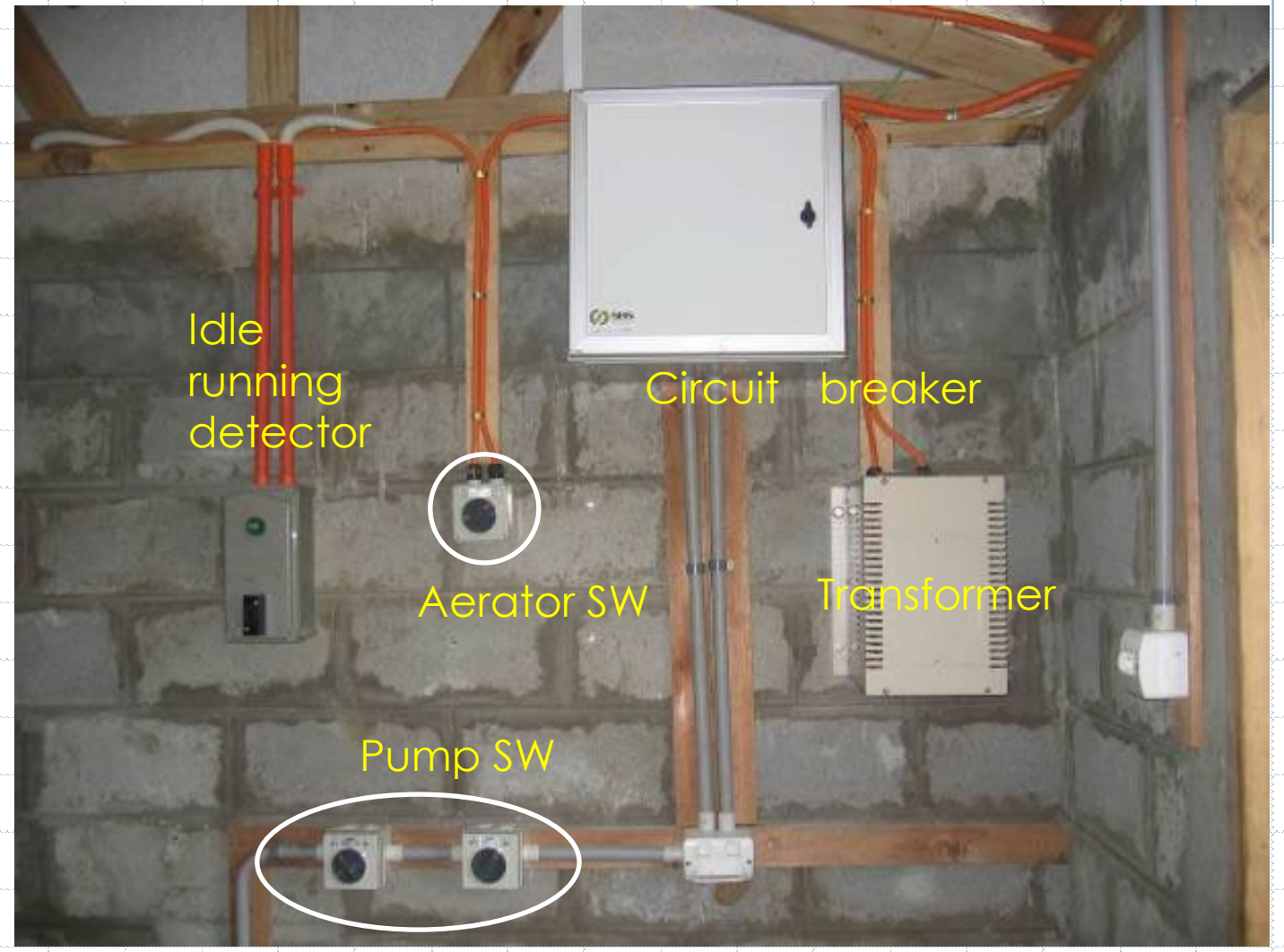
Pipe works

Manual Valve

Strainer

Electric works

- Manual operation with checking water level.



Tafaigata , Samoa

Fukuoka , Japan

Basic process is same !

Fa’afetai

Thank you

Merci

ご清聴ありがとうございます