Soil's Environmental Purifying Function
- Polluted Water Treatment by Multi-Soil-Layering System -

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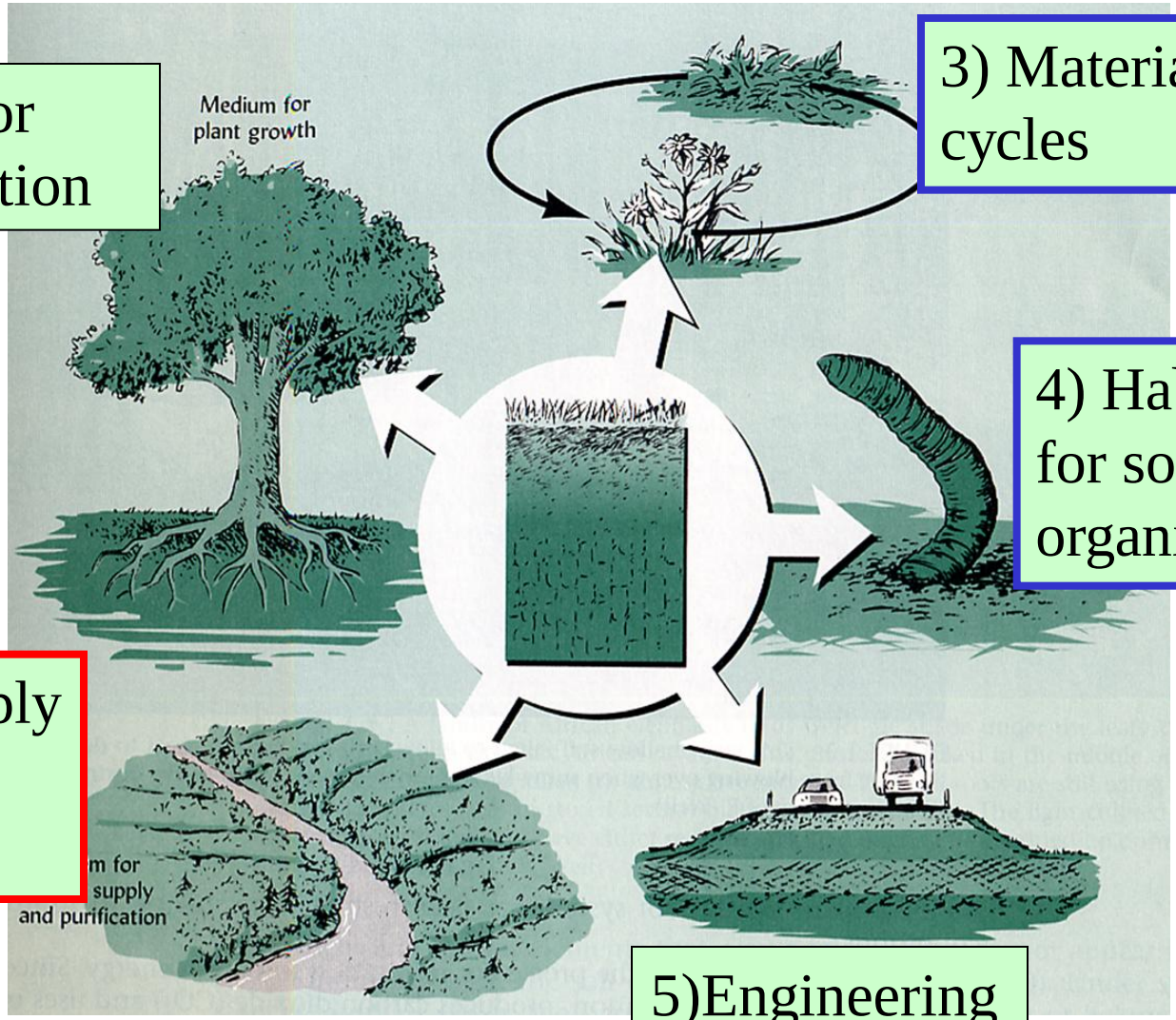
Function of soils

1)Medium for plant production



3) Material cycles

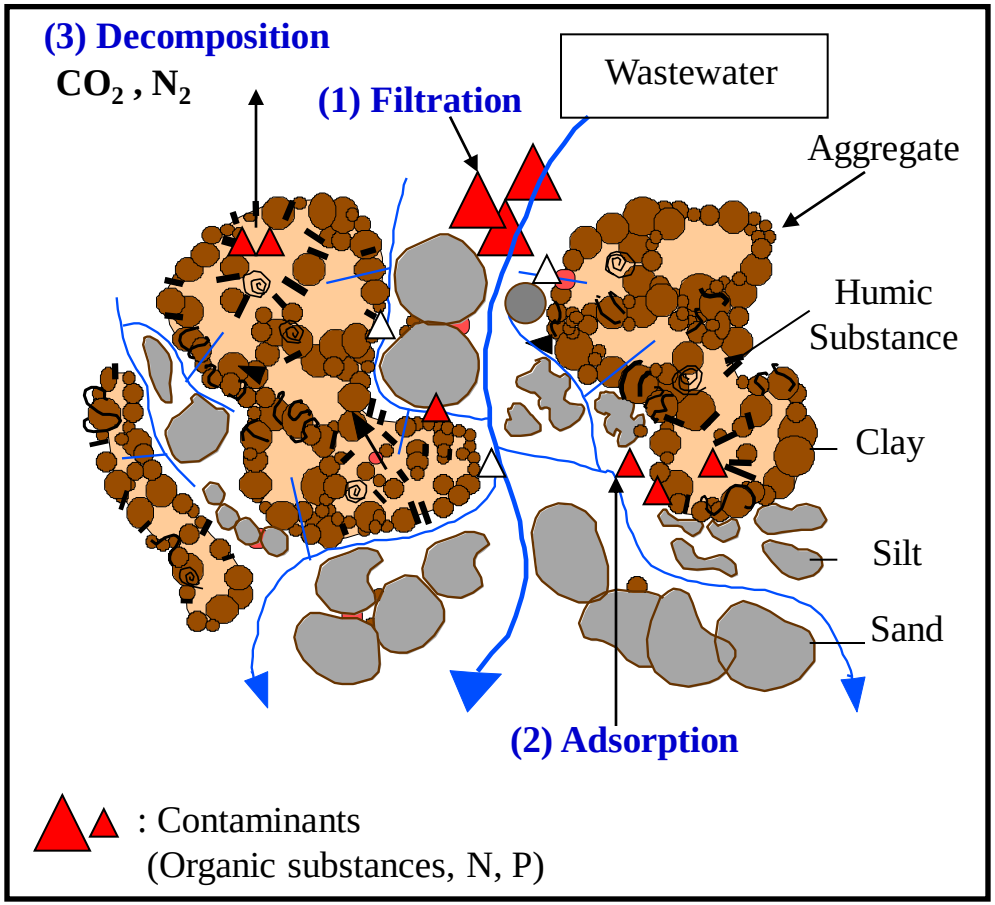
4) Habitat for soil organisms

2) Water supply and **purification**

5)Engineering medium

(Brady 2001)

Soil's Purifying Function of Wastewater



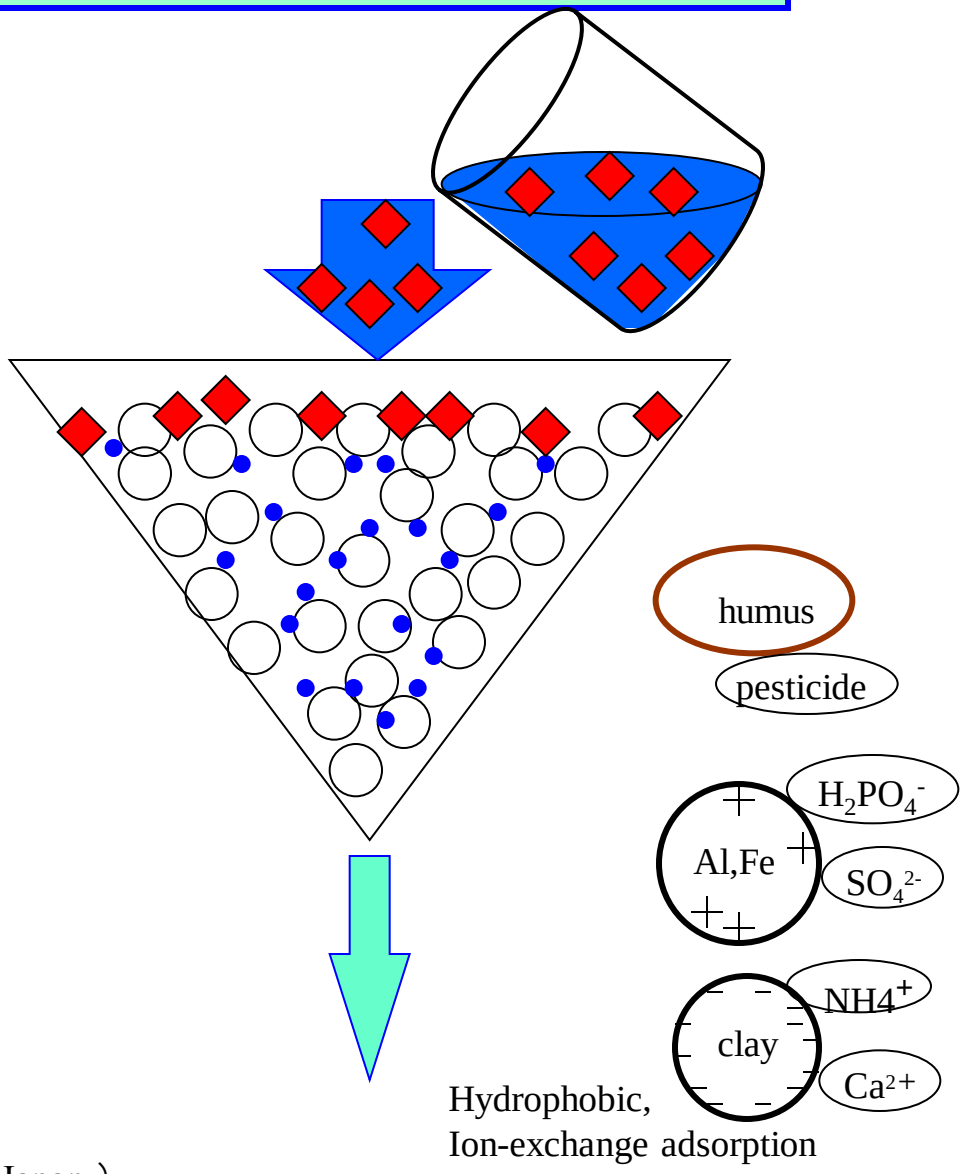
Composition of Soil
- minerals (clay, silt, sand, gravel)
- organic matters
  (humus, organic residues)
- organisms

High specific surface area
High variation of :
- size of particles
- physical and chemical properties
  (hydrophilic/phobic, ion exchange capacity,aerobic/anaerobic, etc)
- species of microorganisms

(1) Filtration
(2) Adsorption (NH_4, P, O.M.)
(3) Decomposition

Filtration and adsorption of materials in soils

Color removal by soil filter



（Picture cited from “Tsuchi no Ehon”, Nobunkyo, Japan ）

Table: The number, size, and biomass of organisms in surface soil

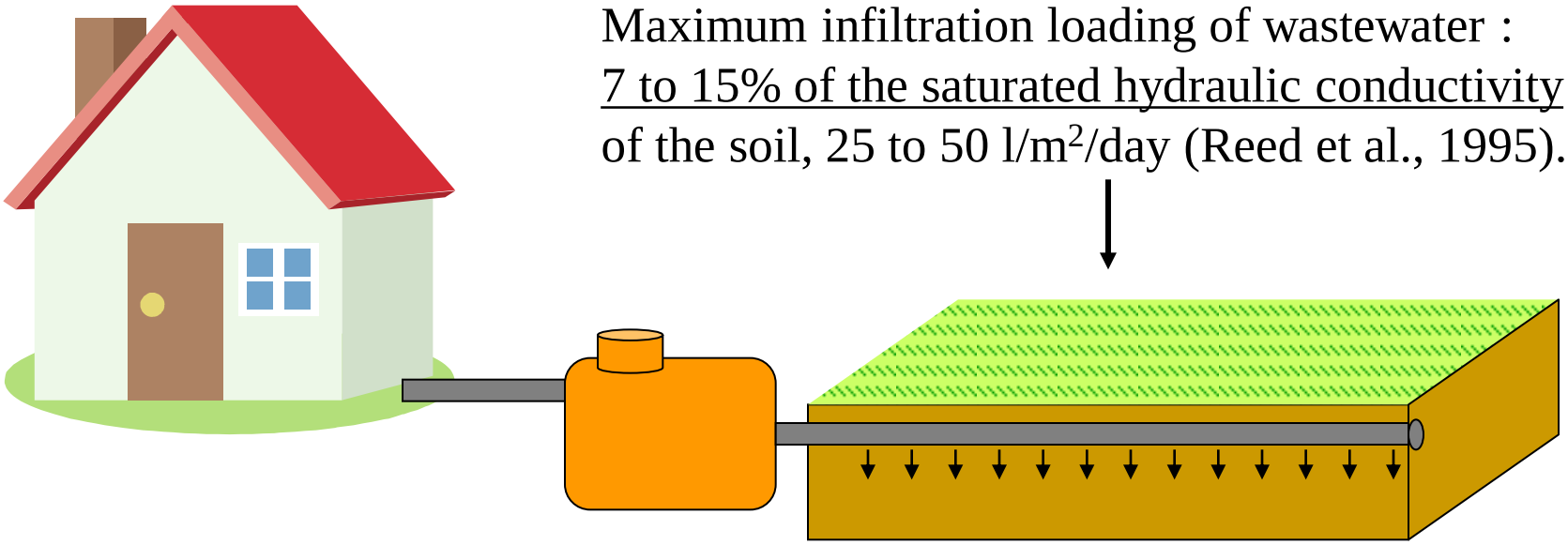
Type of organisms	Number (individuals/m^2)	Size (μm)	Biomass (g/m^2)
Bacteria	10^{13}~10^{14}	0.5~1	45~450
Actynomysethes	10^{12}~10^{13}	1~2	45~450
Fungi	10^{10}~10^{11}	0.3~10	112~1120
Protozoa	10^{9}~10^{10}	10~80	2~17
Nematoda	10^{6}~10^{7}	500~2000	1~11
Others	10^{3}~10^{5}	500~2000	2~17
Earthworm	30~300	2~>5000	11~110

Micro ~ Fine pore

It was estimated that microorganisms with more than 100 million in population and several thousands of species live in 1-g of soil (Trosvik 1990).

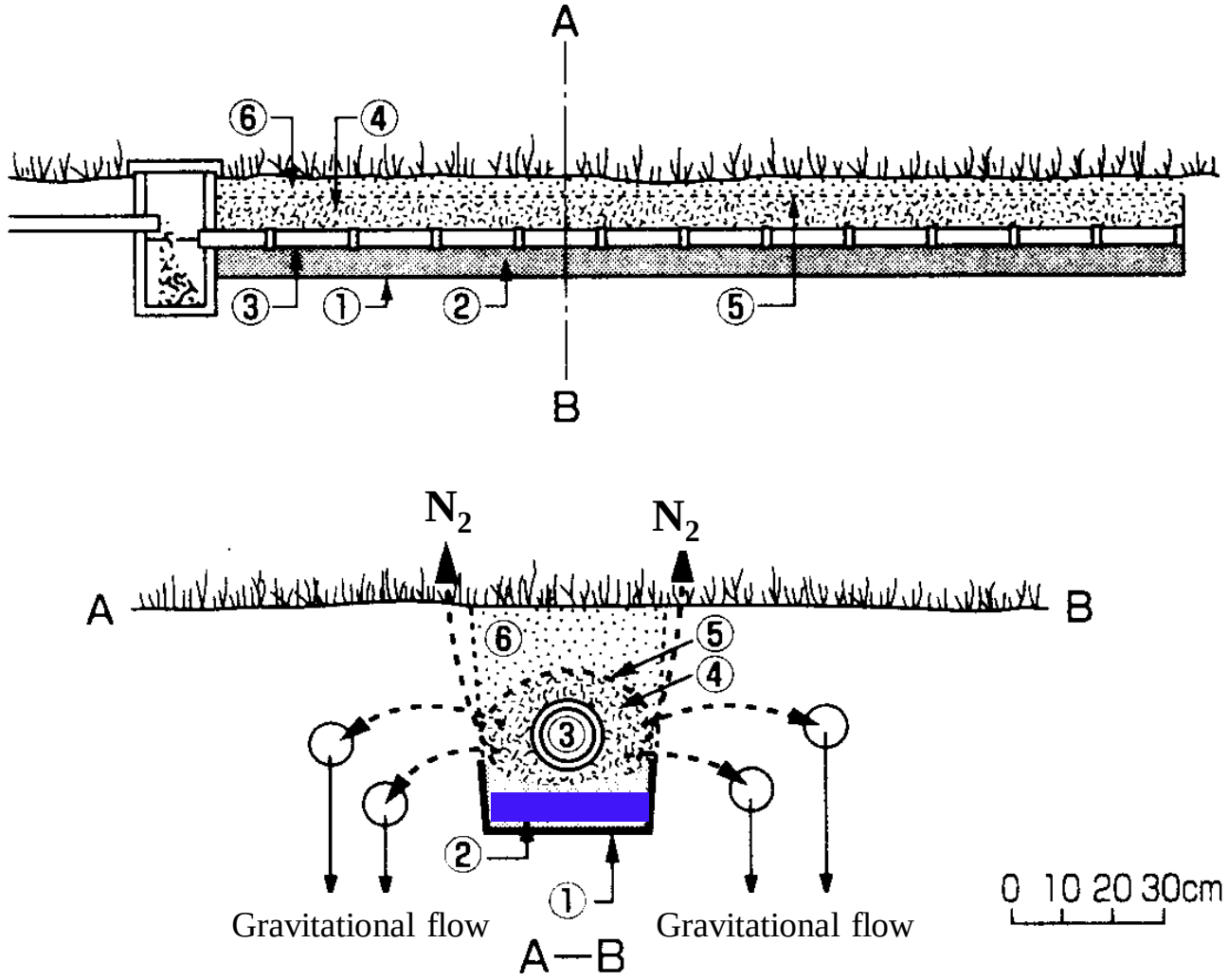
Use the soils for wastewater treatment

In the guideline of the application of soil trench system:
Maximum infiltration loading of wastewater :
7 to 15% of the saturated hydraulic conductivity of the soil, 25 to 50 l/m^2/day (Reed et al., 1995).



In the U.S.A., about 30% of households, where they treat wastewater individually at their home, use this type of system.

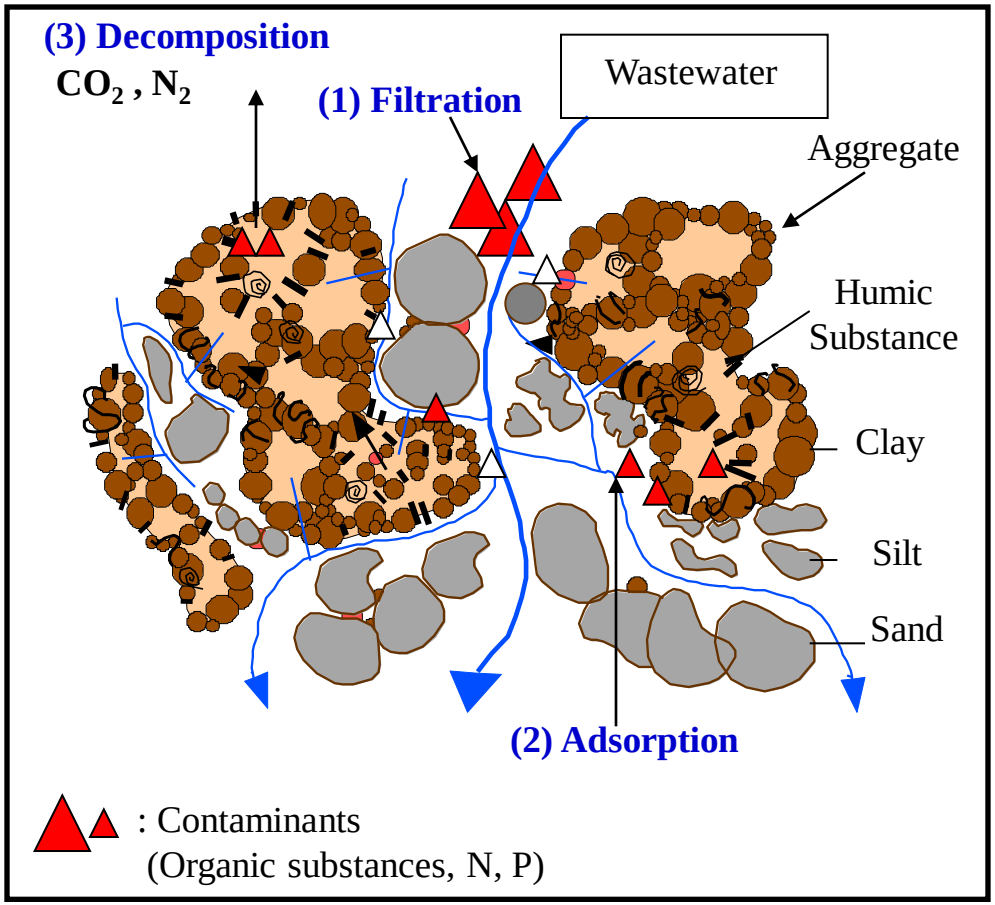
Figure: Septic tank - Soil trench system for domestic wastewater treatment.



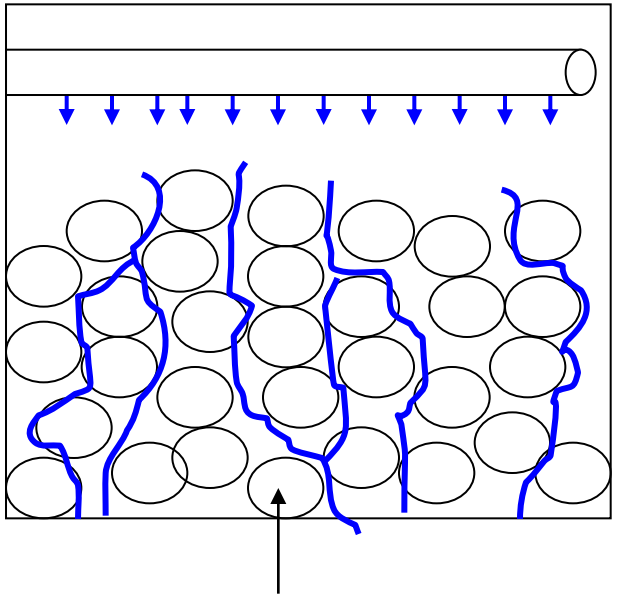
①Plastic tray ②Sand ③Inlet pipe ④Gravel ⑤ Plastic net ⑥ Covering Sand

Figure: Structure of a type of soil trench system

Soil's Purifying Function of Wastewater



Trickling filter method



Medium to develop bio-film and to adsorb contaminants

Principle of purifying mechanisms of soil is the same with that of the trickling filter method.

Table: Comparison between Trench-type Wastewater treatment method using Soil and Trickling Filter Method

	Purifying Method using Soil	Trickling Filter Method
Specific Surface Area	10^5 - 10^8 m^2/m^3 **large contact area**	10^2 m^2/m^3
Pore	40 - 90% (Aerobic-Anaerobic)	40 - 90% (Aerobic)
Active Al, Fe,	1 - 10% **P adsorption**	0%
Loading Rate	10 - 100 $l/m^3 \cdot d$ **slow speed**	1 - 3 × 10^3 $l/m^3 \cdot d$
Loading Rate per Specific Surface Area	10^{-3} - 10^{-5} $l/m^2 \cdot d$ **efficient contact**	10 - 100 $l/m^2 \cdot d$

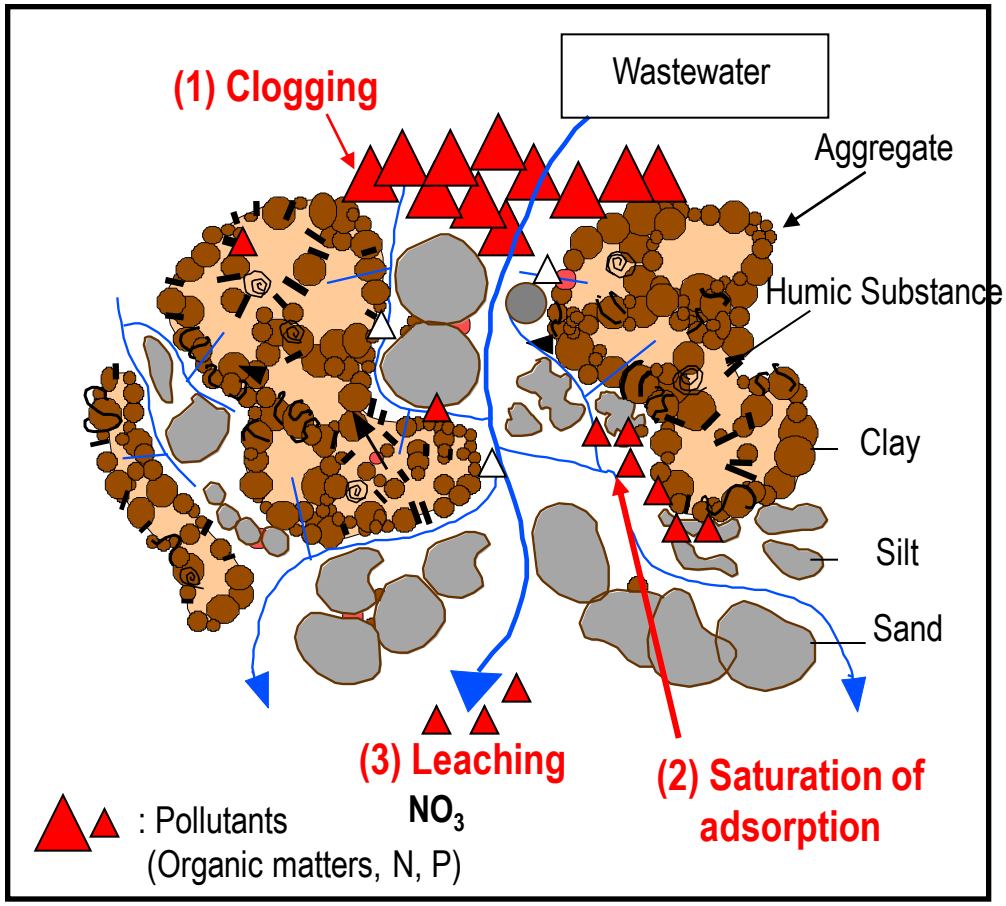
(Wakatsuki, 1997)

Higher contact efficiency of wastewater and media in the systems

↓

High purifying ability of wastewater

Limitation of Water Purifying Function of Soil



Limitation and causes

(1) Low permeability of soil
= require large land area

(2) Clogging
- small pore size
- high organisms activity

(3) Saturation of adsorption
- active Al/Fe for P
-humic substances for hydro-phobic materials

(4)Nitrate leaching
- preferential flow
- shortage of C source for denitrification
- lack of anaerobic condition

Table: Saturated hydraulic conductivity of soils and zeolite

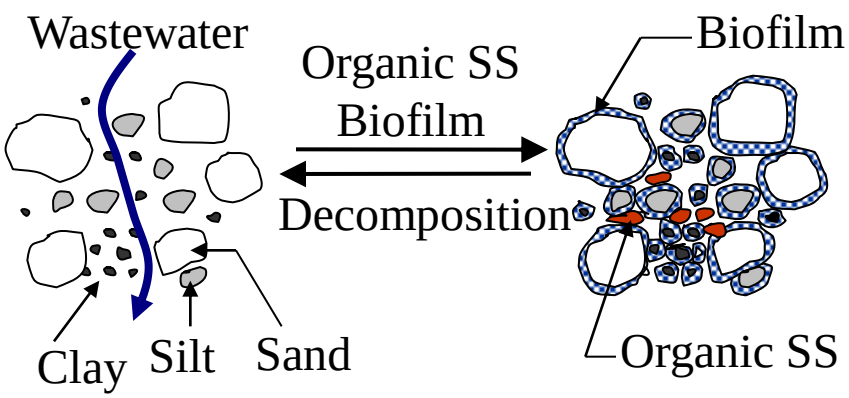
	Sandy soil		Volcanic ash soil			Zeolite		
						(1-3mm)	(3-5mm)	(4-6mm)
Bulk density (g/cc)	1.3	1.5	0.8	0.9	1.0	1.0	1.0	1.0
Saturated Hydraulic Conductivity (cm/sec)	9.8 x 10^{-3}	9.6 x 10^{-4}	3.2 x 10^{-3}	1.1 x 10^{-3}	1.8 x 10^{-4}	0.1	0.8	1.6

Coarse particles

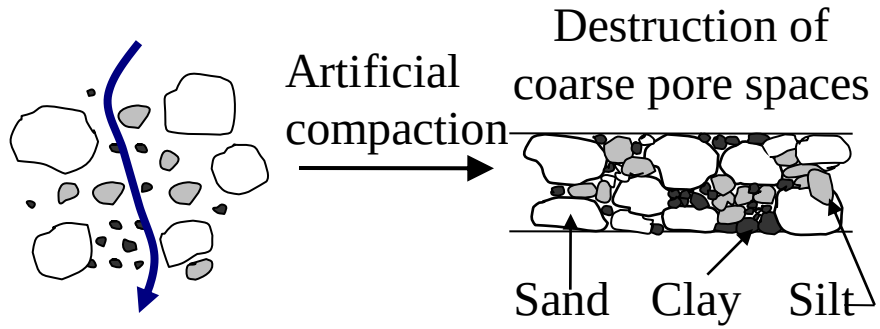
Very high specific surface area

Very low permeability comparing to coarse materials

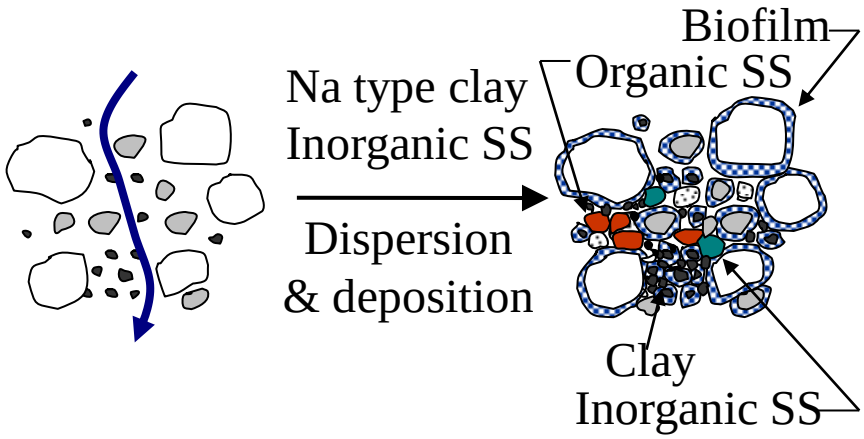
Mechanisms of clogging of soil



a) Clogging by biofilm and organic SS (can be recovered)



c) Destruction of coarse pore space by artificial compaction



b) Clogging by clay dispersion and deposition including biofilm, inorganic and organic SS

Clogging a) can be recovered by keeping the soil aerobic with no wastewater loading for a few months.

Clogging b) and c) must be prevented as these can never recovered naturally.

How to avoid b) and c)?

Varieties in type of soils.

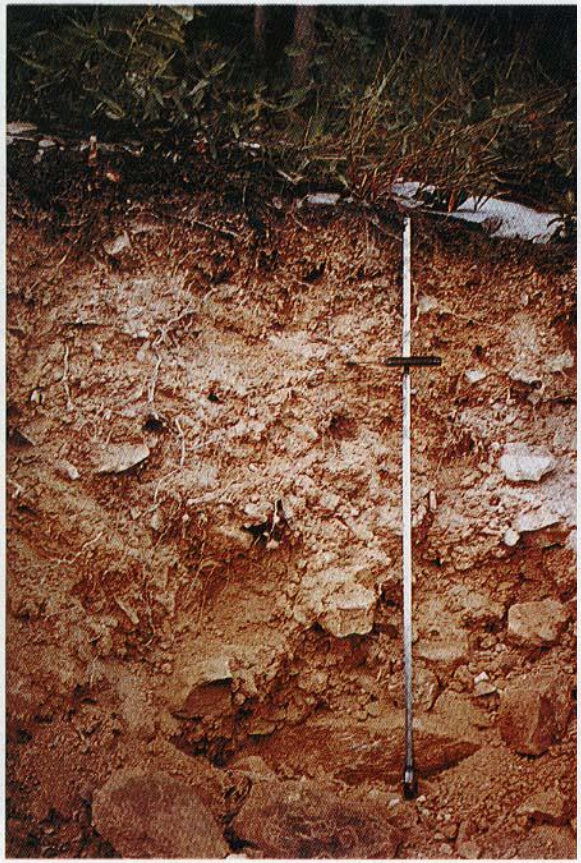


PLATE 7 Inceptisols—a Typic Dystrudept from West Virginia. Knife is in cambic horizon.

course organic poor soil

PLATE 8 Mollisols—a Typic Hapludoll from central Iowa. Mollic epipedon to 1.8 ft. Scale in feet.

organic rich soil

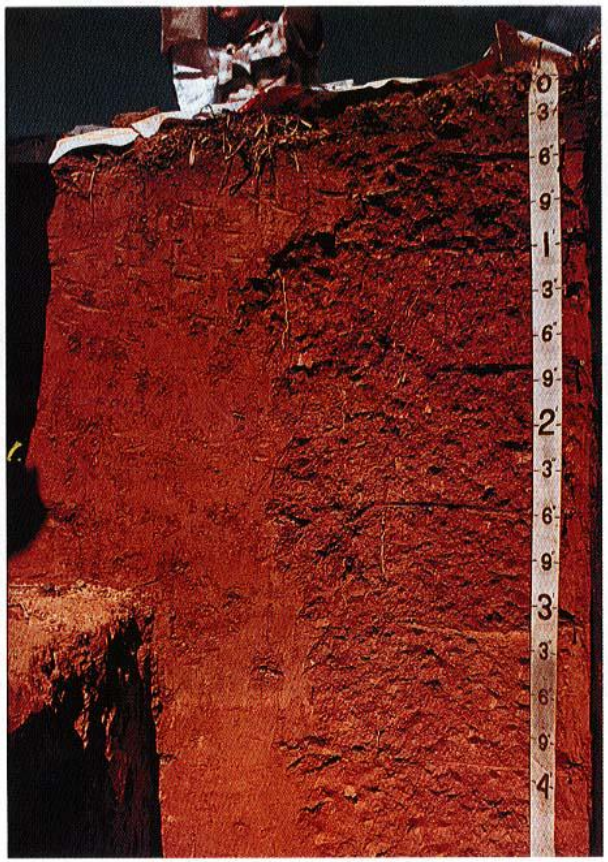


PLATE 9 Oxisols—a Udeptic Hapludox from central Puerto Rico. Scale in feet and inches.

highly weathered iron rich soil

(pictures cited from Brady 2001)

Table: General Physical and Chemical Properties of Sandy Soil, Volcanic ash Soil and Red Clayey Soil

	Sandy soil	Volcanic ash soil	Red clayey soil
pH (H_2O)	5.9	4.9	4.8
pH (KCl)	3.7	4.3	3.7
Particle size Composition (%)			
Coarse Sand (2 to 0.2 mm)	70.5	14.1	1.3
Fine Sand (to 0.02 mm)	20.2	49.5	8.2
Silt (to 0.002 mm)	1.6	19.6	32.3
Clay (0.002 mm or less)	7.7	16.8	58.2
Total Organic Carbon (%)	0.04	8.21	0.22
Total Nitrogen (%)	0.004	0.355	0.034
C/N Ratio	10	23	6
Effective Cation Exchange Capacity (cmol(+)/kg soil)	10.3	7.63	39.36
Active Fe (%)	0.28	0.6	4.51
Active Al (%)	0.09	5.63	2.53
Phosphoric Acid Adsorption Coefficient (mg P_2O_5/100 g soil)	342	2410	1560

Water permeability

N removal (NH_4 adsorption Denitrificaltion)

P removal capacity

Treatment of wastewater (polluted water) using Soil

Land treatment, Sand filter, Soil trench

Water treatment

Purification functions
-Filtration
-Adsorption
-Decomposition

(depending on soil types)

Low permeability
> need large area
> Risk of clogging

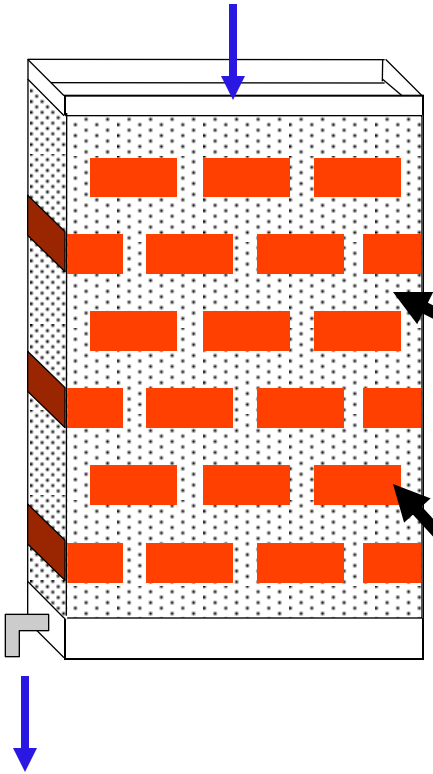
Increase the permeability

Soil-ecological engineering

Multi-Soil-Layering method

Control and enhancement of the purification functions

Multi-Soil-Layering（MSL） method



A Multi-Soil-Layering (MSL) system consists of water permeable layers and soil mixture layers which are arranged in brick pattern.

Water permeable layer：(Ks > 0.1 cm/sec)
- uniform size（Φ1-5mm）of particles
（ zeolite, pumice, gravel, charcoal, etc.）

Soil mixture layer : high purification function
- Natural soil
- Metal iron (P absorbent, reducer)
- Organic matter (H donor for denitrification)
- Charcoal (absorbent of various pollutants) or/and other functional materials

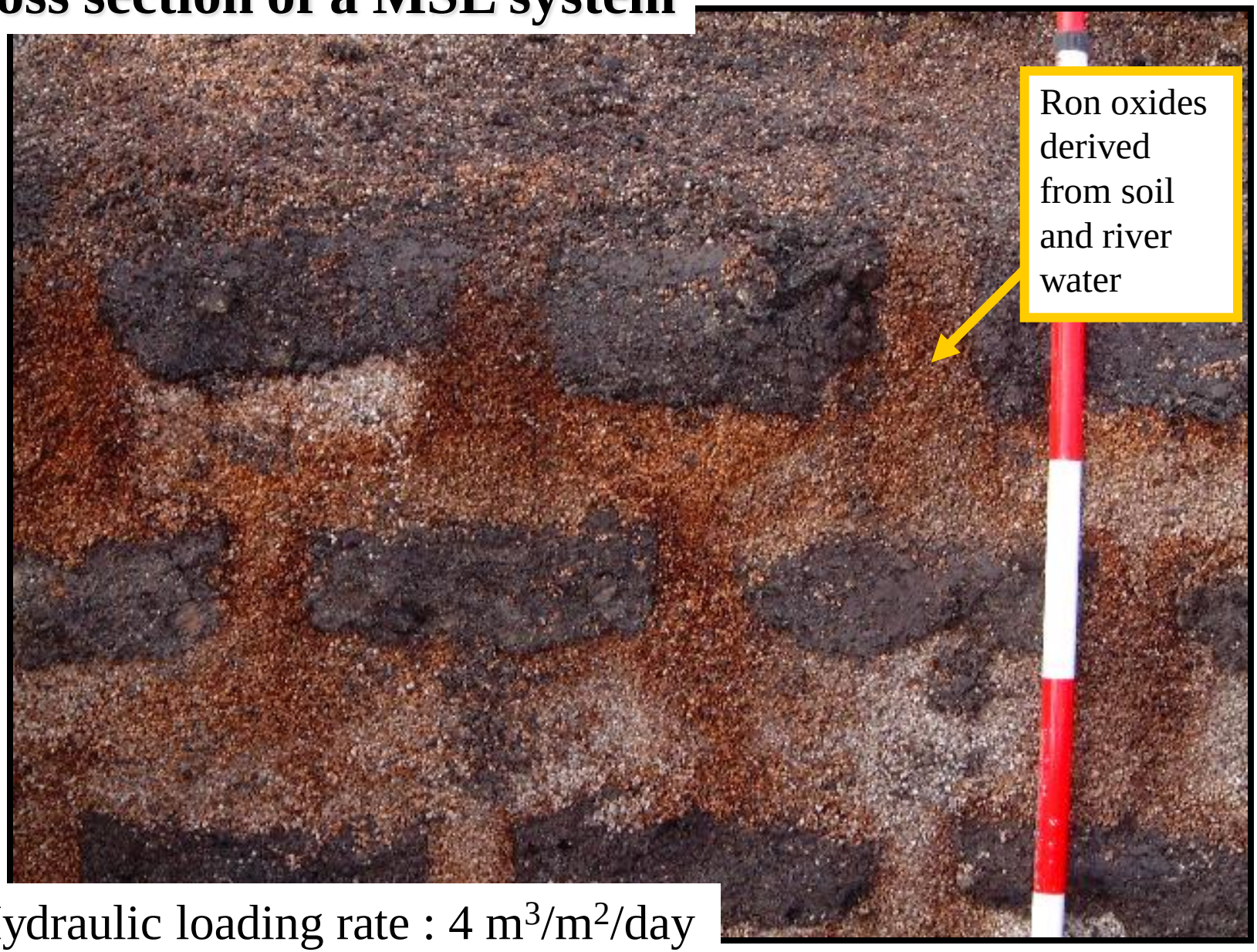
Aeration: control availability of O_2

Cross section of a MSL system used for a field experiment of river water treatment in Kyusyu, Japan.

Permeable layer
(pumice)

Soil mixture layer
(local soil, charcoal)

Cross section of a MSL system



Hydraulic loading rate : 4 $m^3/m^2/day$

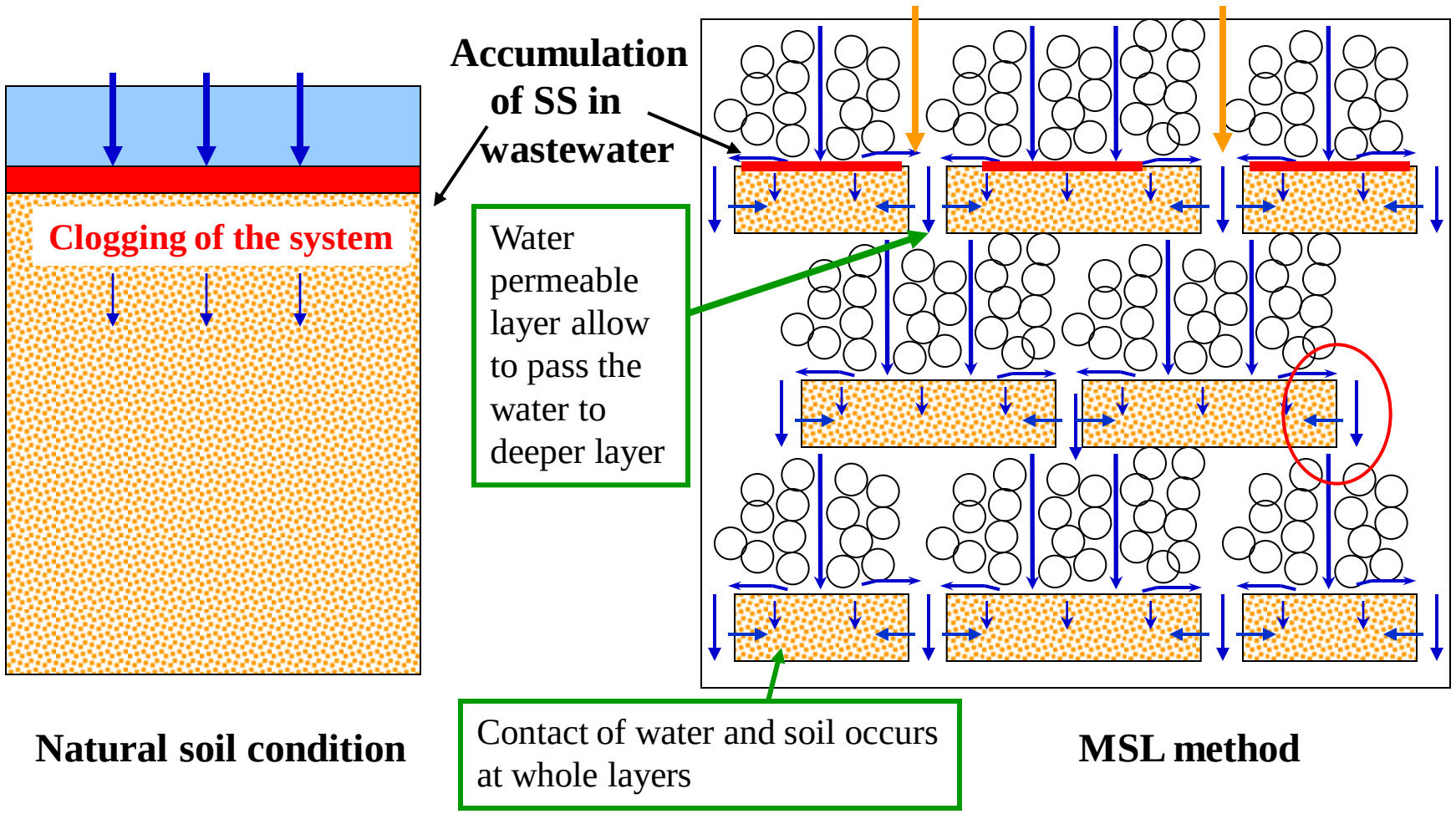
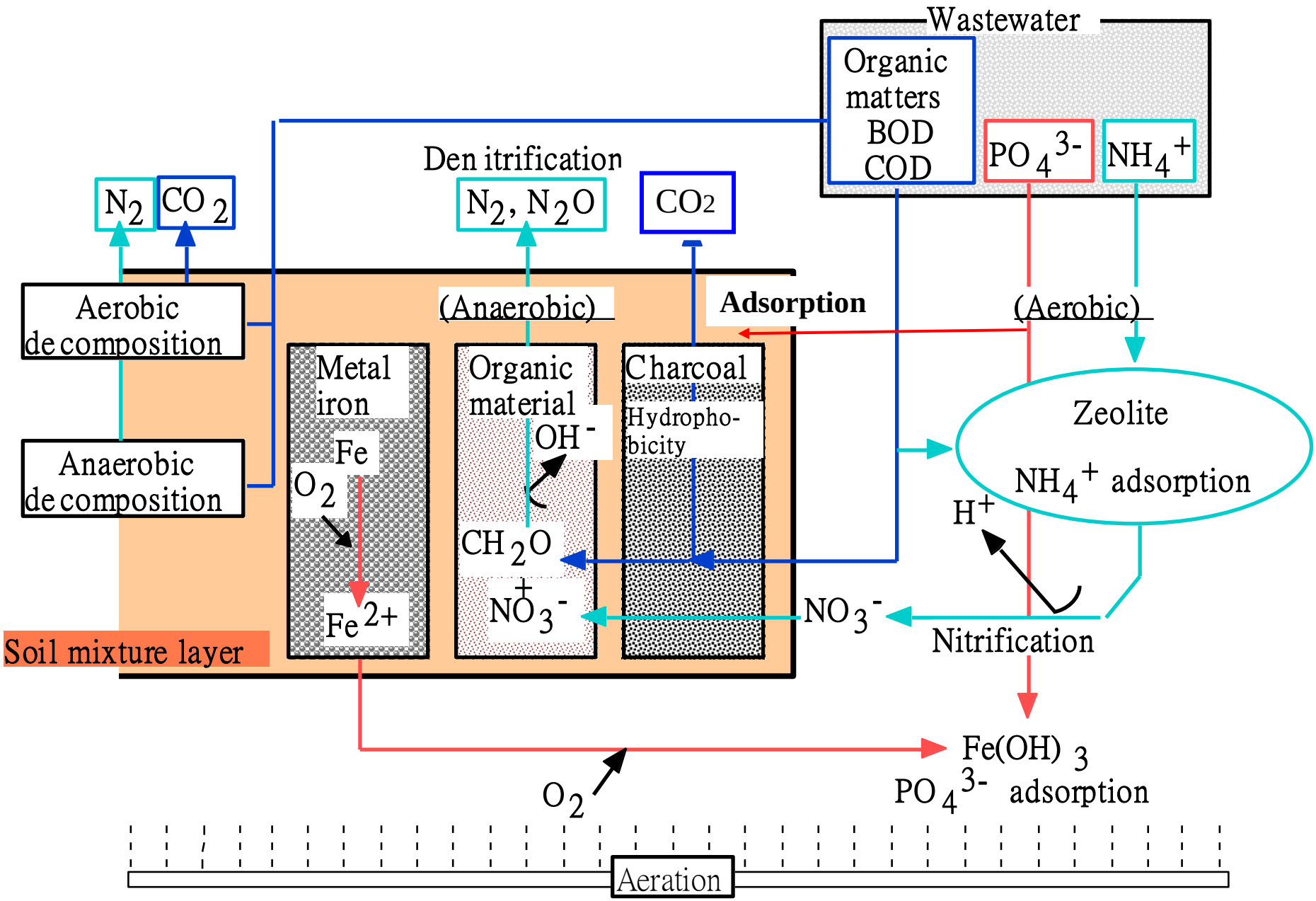
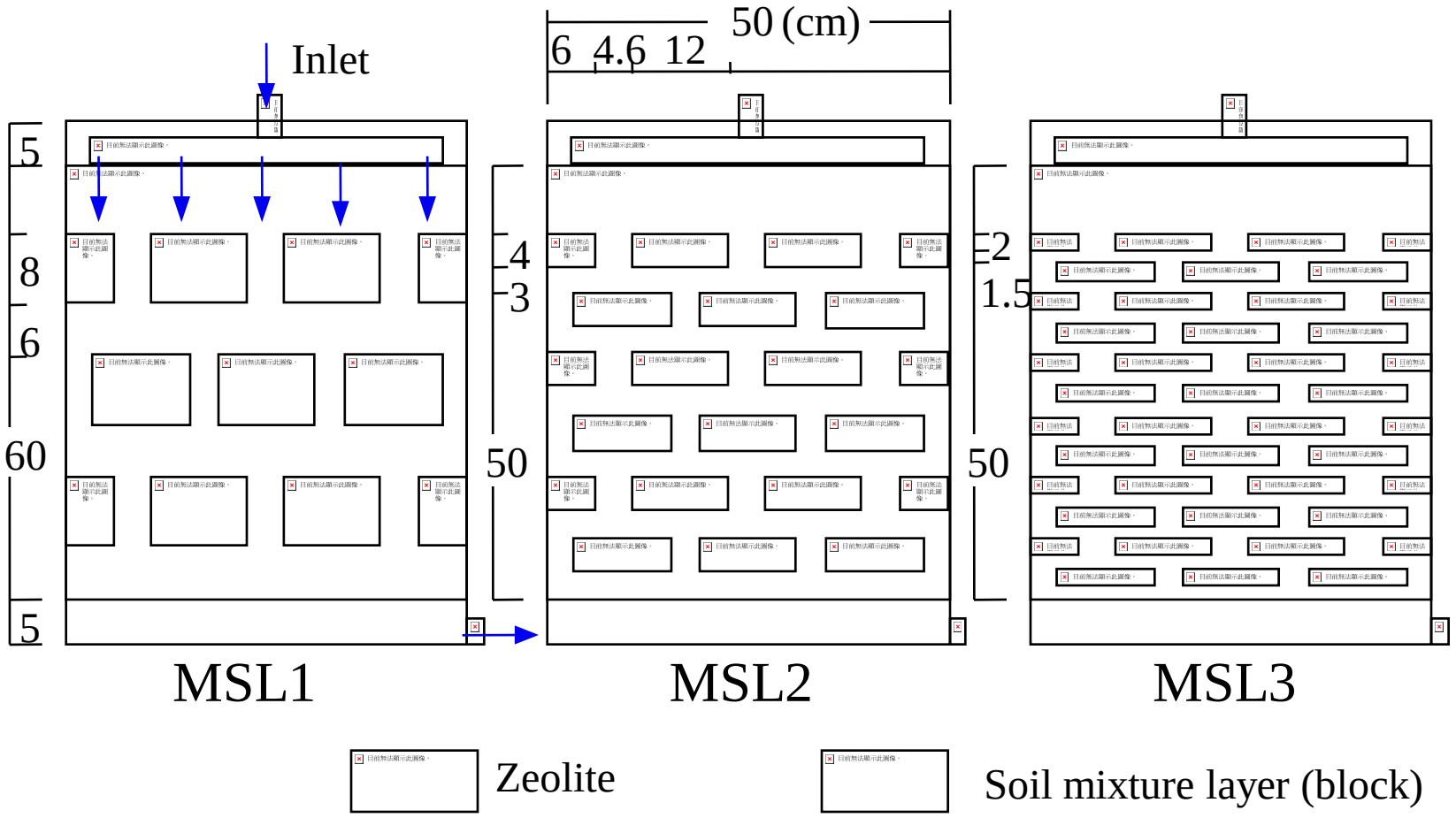


Figure: Control mechanisms of prevention of clogging by MSL method



Possible mechanisms of wastewater treatment in MSL

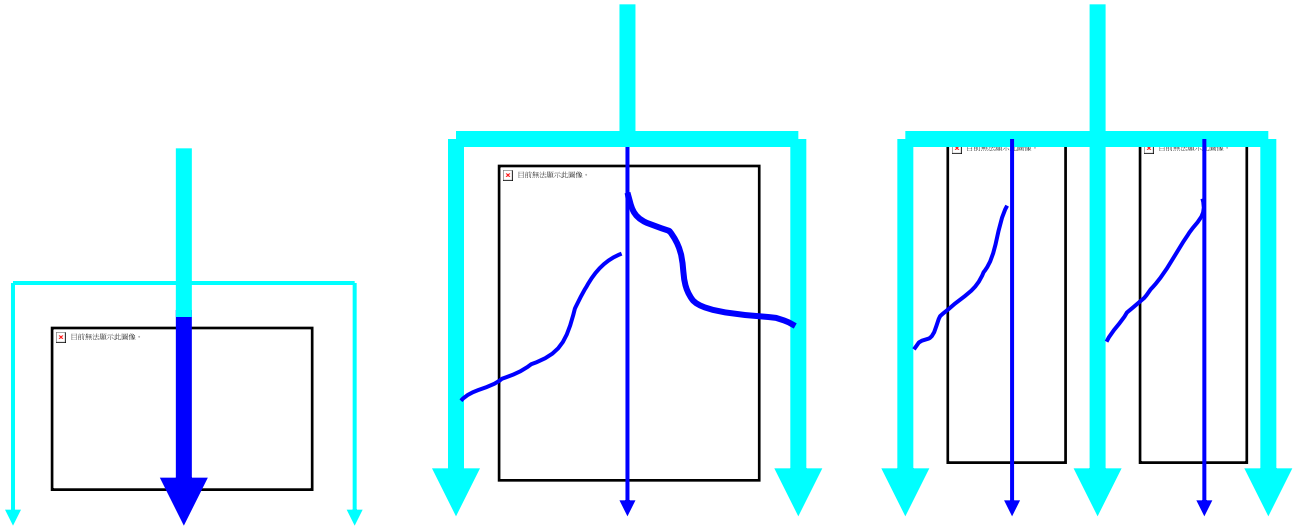
Variation of MSL structure



Thickness

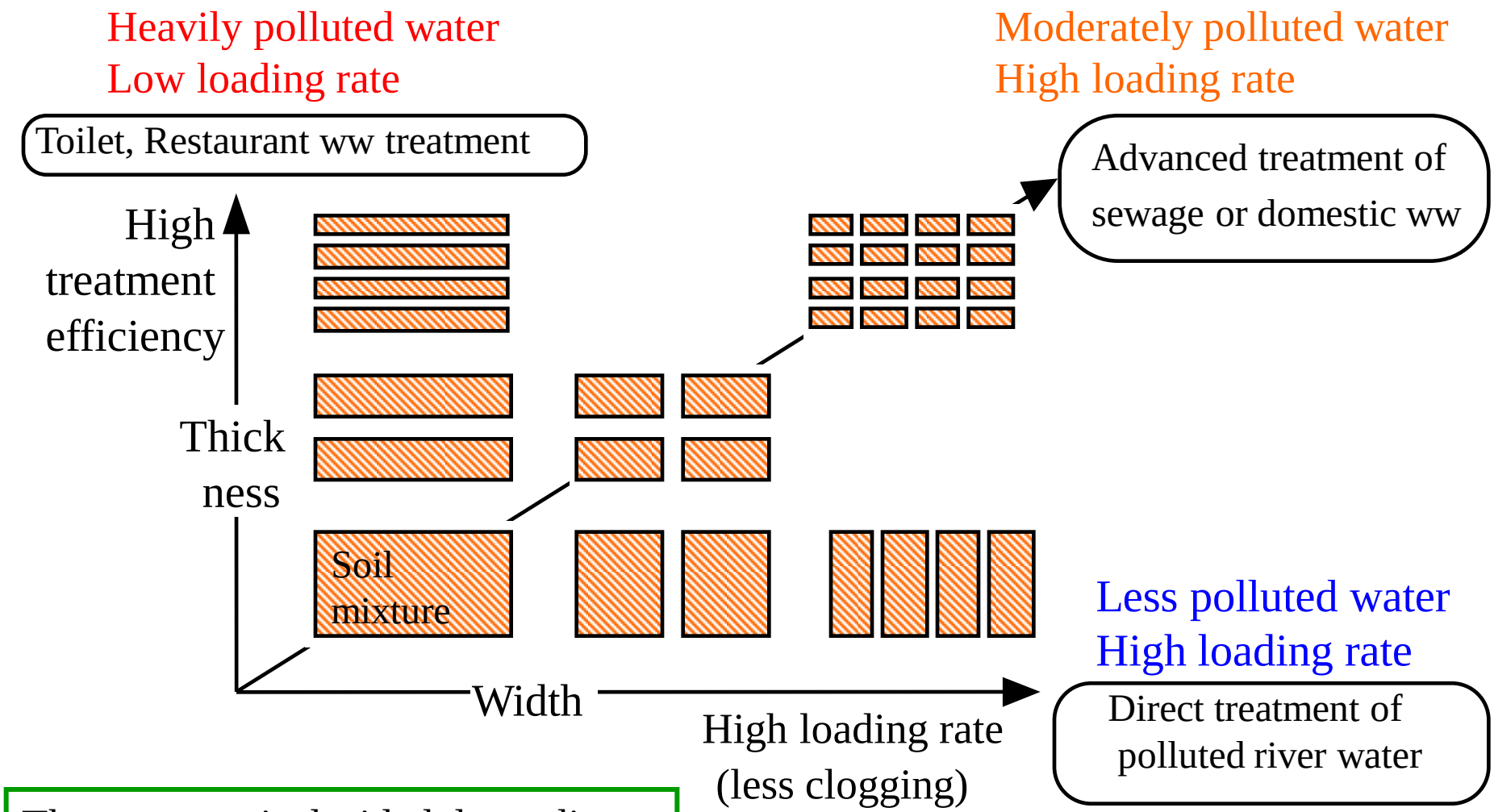
Width

Water distribution and contact at soil unit



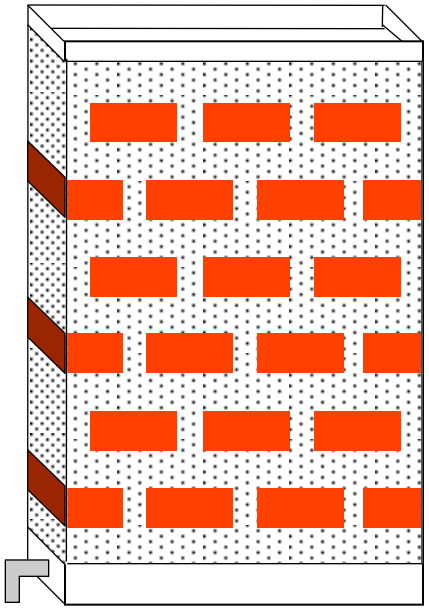
Water distribution	inside	outside	outside
Contact efficiency	high	low	moderate
Advantage	High treatment efficiency (per unit soil)	Simple structure (easy construction)	Smooth water flow High loading rate (less clogging)

Variation of MSL structures and type of water treatment



The structure is decided depending on the treatment condition.

Application of MSL System for wastewater treatment



Domestic wastewater from individual houses or a community development (secondary-advanced treatment)

Sewage (advanced treatment)

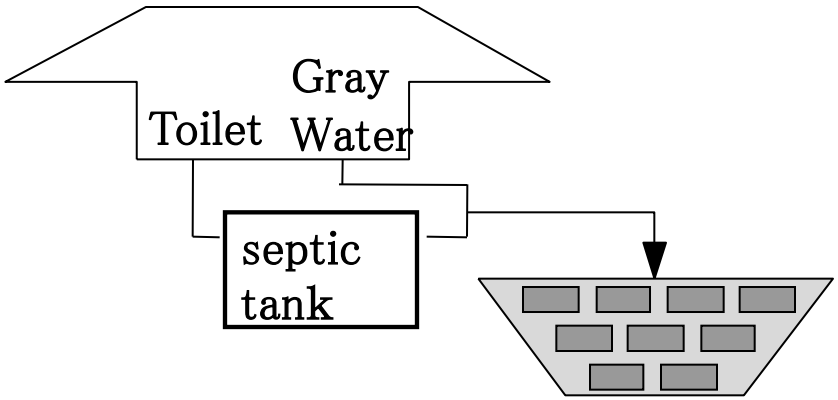
Toilet wastewater (advanced treatment)

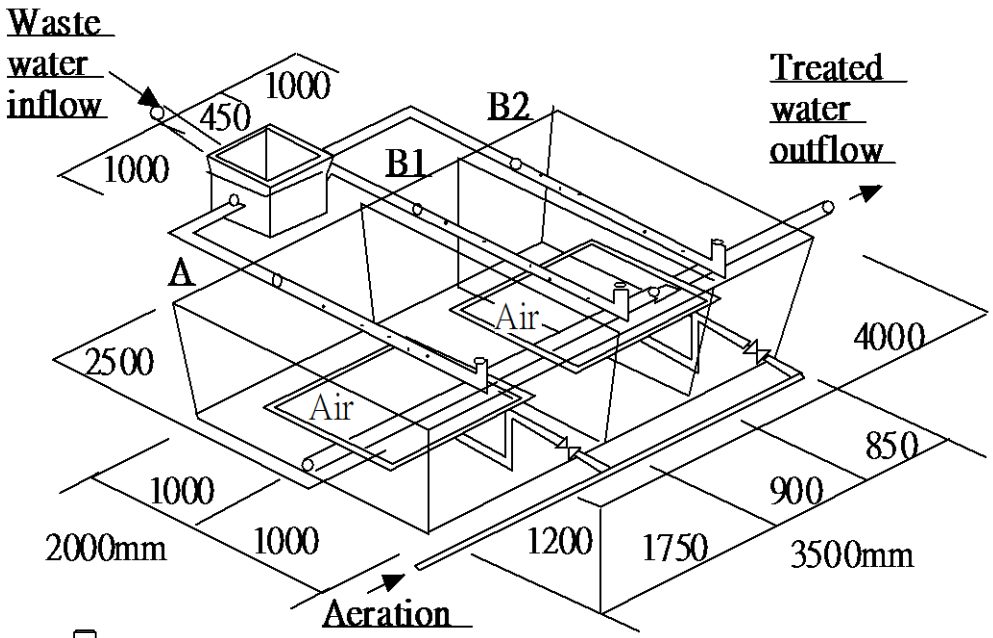
Wastewater from toilet, shower, kitchen of a camping facility (secondary-advanced treatment)

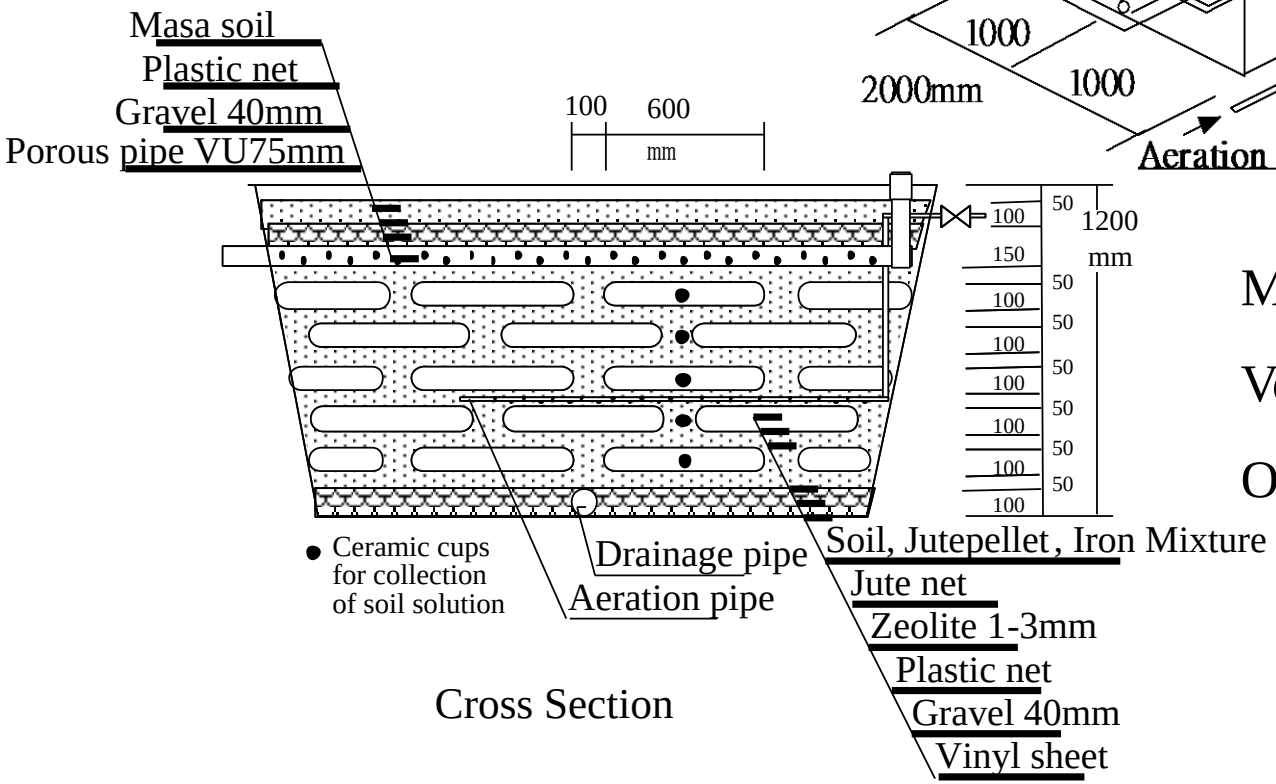
Polluted river water

Domestic wastewater treatment in Fukuoka

Domestic wastewater treatment in Shimane







Cross Section

Mean surface area: 3.9 m^2

Volume : 4.3 m^3

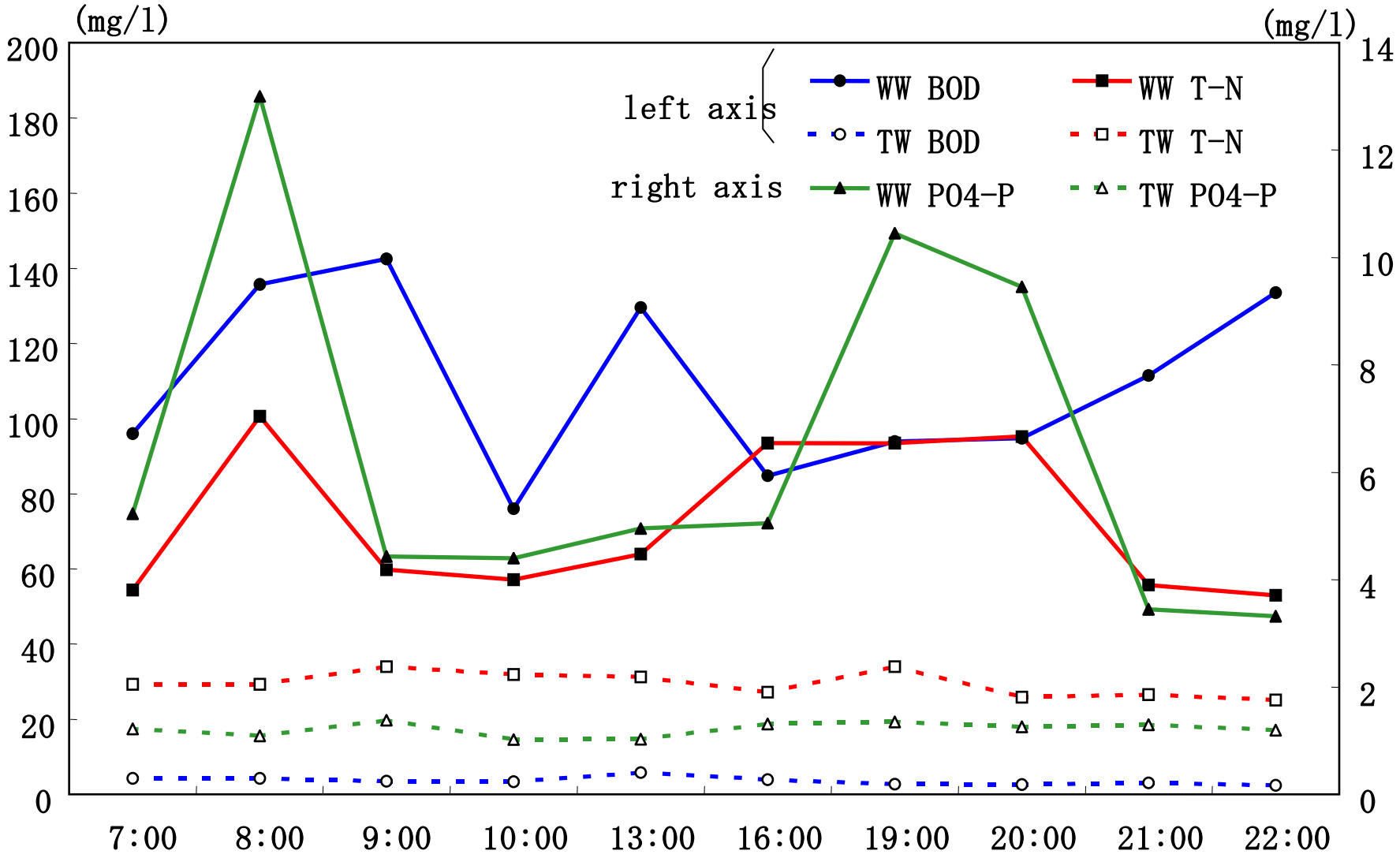
Operation: July 1990 - July 2003

Construction of a MSL system for domestic Wastewater treatment in a household in Shimane.

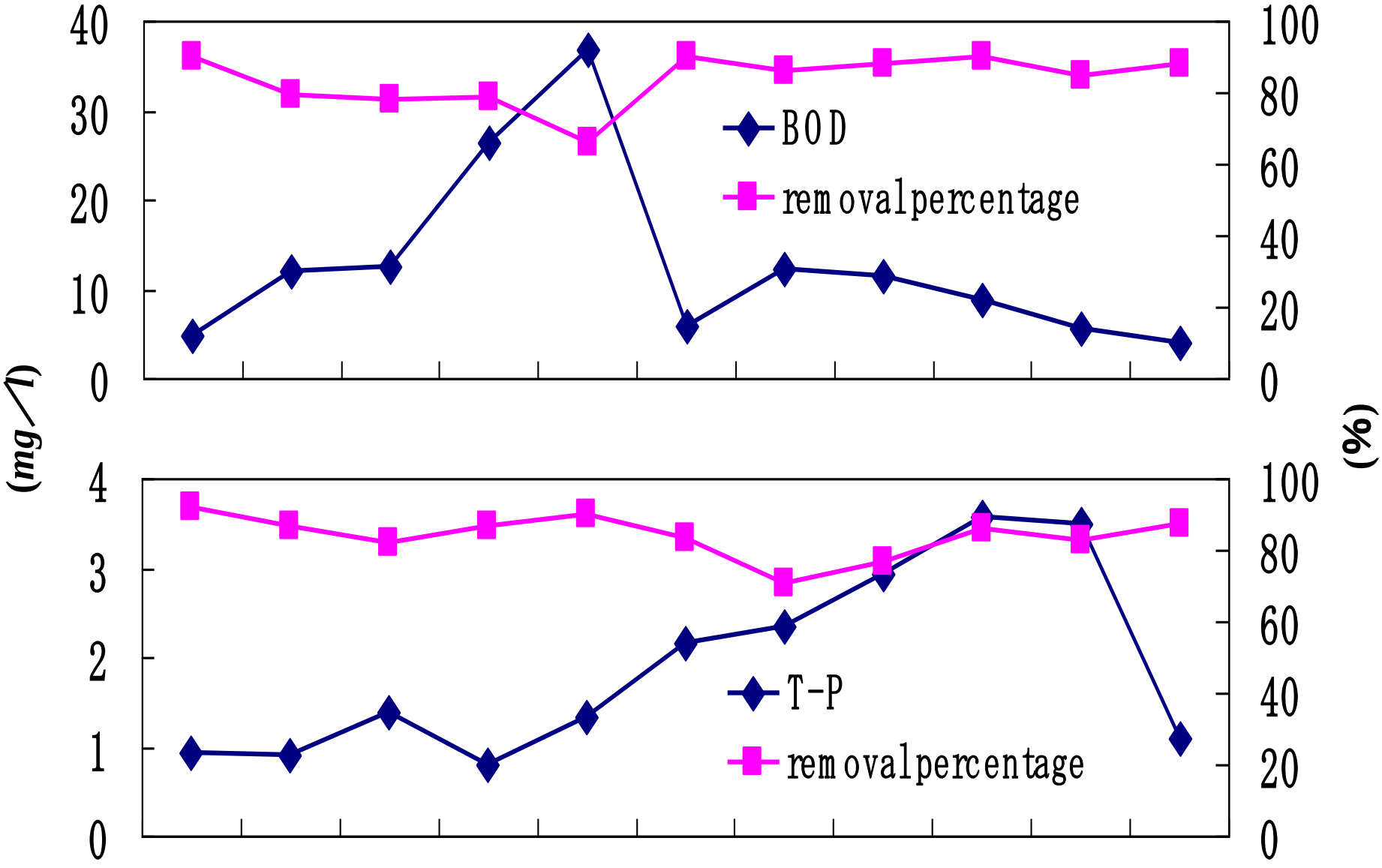
Impermeable sheet

Zeolite

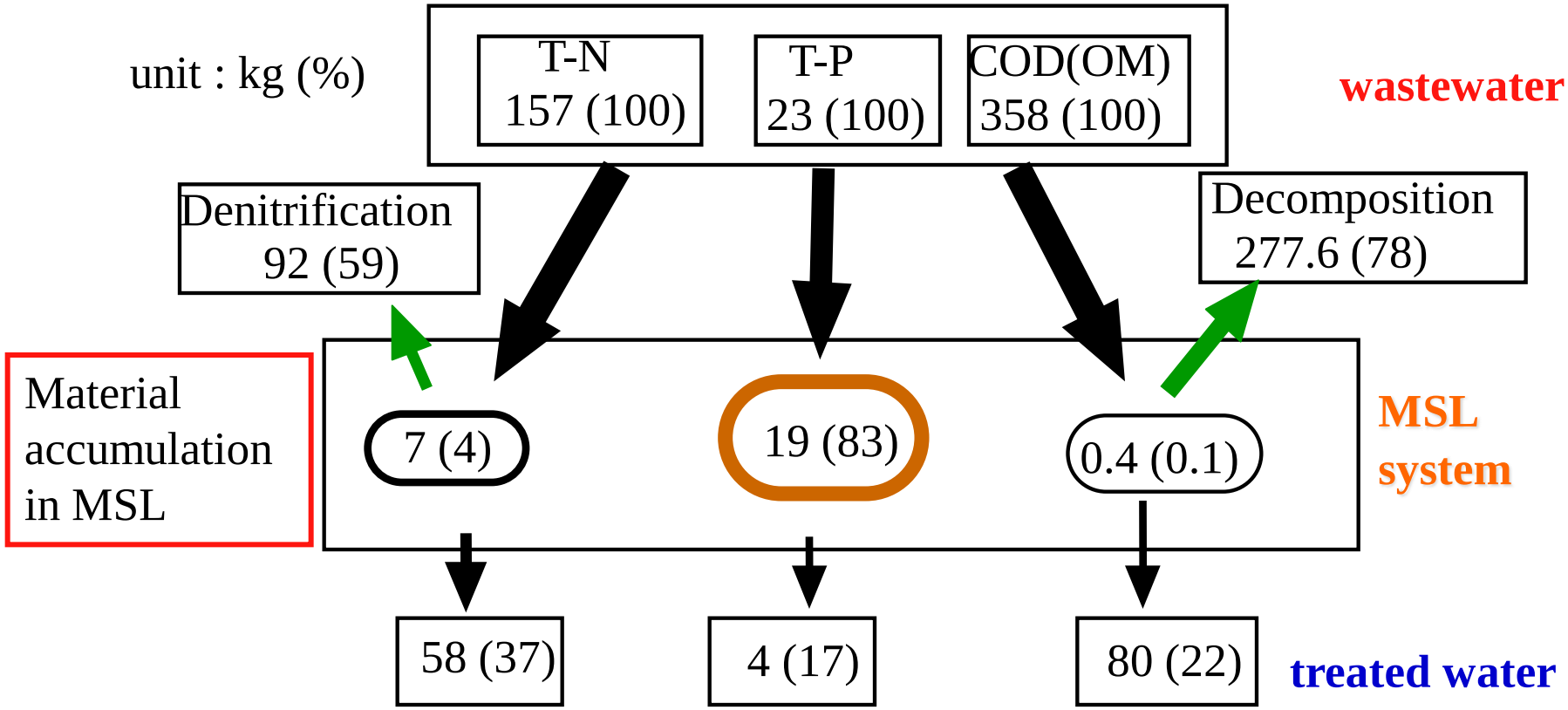
Soil mixture layer
(sandy soil mixed with
jute pellet and Iron particle)
packed in jute bags



Daily fluctuation of waste and treated water（10th year）



Concentration and removal % of BOD,T-P,T-N in treated water



Mass balances of contaminants for 10 years treatment

System's life is depending on P adsorption capacity. But, if we concern about only organic matter and N, it may be until the system physically is damaged.

Summary of wastewater types applied to MSL systems and the treatment results in previous works.

WW types and HLR		BOD	SS	T-N	T-P
Polluted river water	WW (mg/l)	25.9	25.1	11.8	2.68
Secondary treated	PLR (g/m^3/d)	65.7	63.5	8.5	6.78
swegae	TW (mg/l)	5.1	4.9	3.9	1.65
(220-4700 l/m3/d)	Removal rate (%)	77	78	52	44
Domestic or toilet	WW (mg/l)	192	89.2	58.3	6.47
WW	PLR (g/m^3/d)	76	45.3	21.3	2.37
(190-1820 l/m^3/d)	TW (mg/l)	16	6.5	29.8	1.65
	Removal rate (%)	91	90	48	75
Highly polluted WW	WW (mg/l)	1434	515	237	40.5
ex. Animal farm WW	PLR (g/m^3/d)	329	130	65.6	11.2
(30-290 l/m^3/d)	TW (mg/l)	47.4	23.8	91.9	5.37
	Removal rate (%)	96	94	61	88

WW: wastewater, TW: treated water, HLR: hydraulic loading rate, PLR: pollutants loading rate

Removal of pesticides and PCE by MSL system

(ng/l)

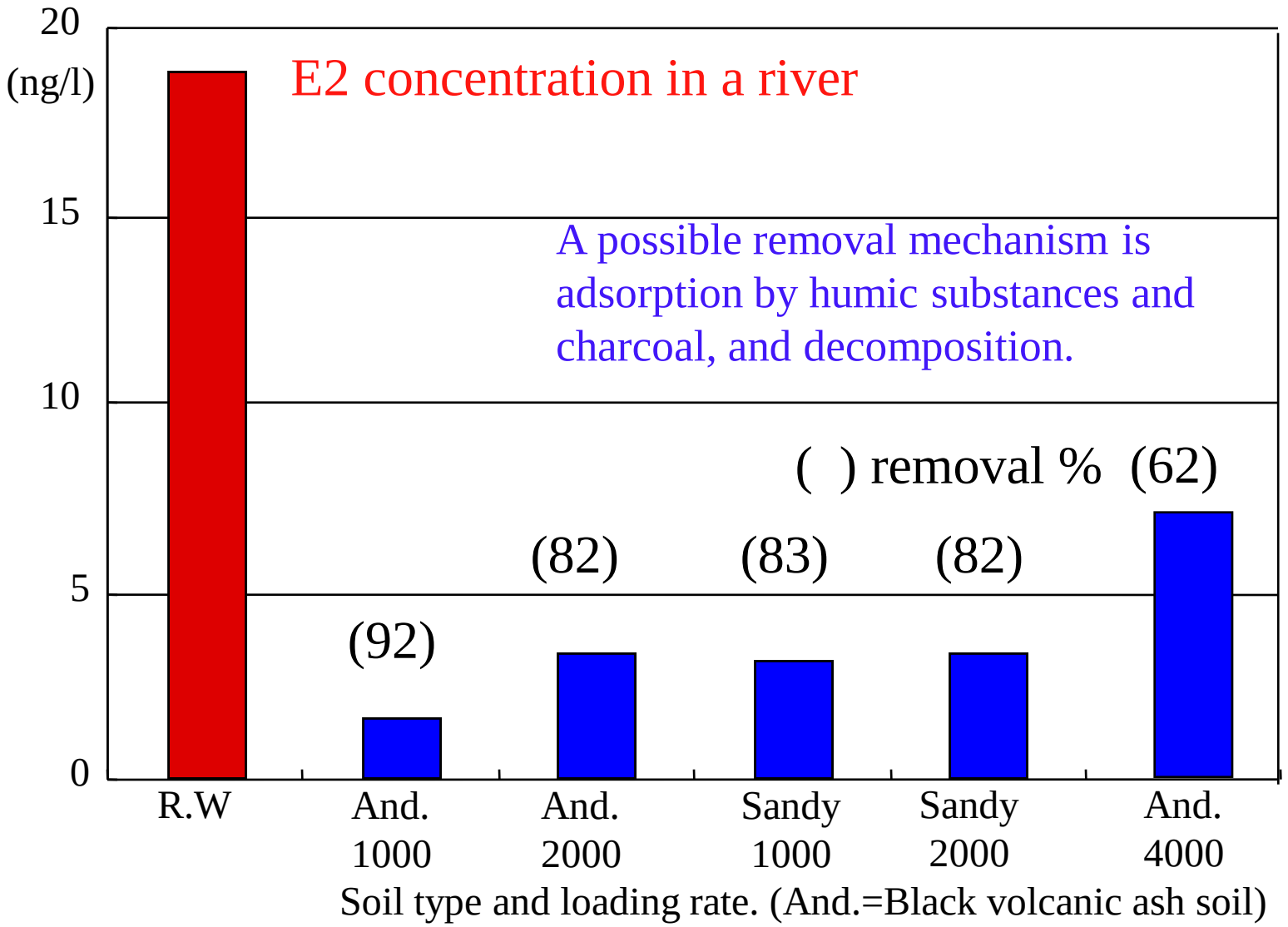
	WW	TW	Removal Rate (%)	EQS
Simazin	200	nd	100	3
Fenitrothion	910	14	99	3*
Napropamid	2000	nd	100	
PCE	93	3	97	10

PCE: Tetrachloroetylene

EQS: Environmental Quality standard

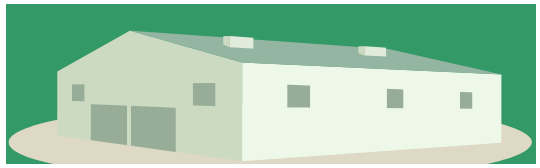
Monitoring guideline value.

MSL containing about 0.5%(w/w) of activated carbon in the soil mixture layer. HLR:250L/m^2/d



17β-Estradiol (E2) removal by MSL system.

An endocrine disrupting substance



Sewage system, community plant

Advanced treatment at pre-settled facilities

Domestic wastewater

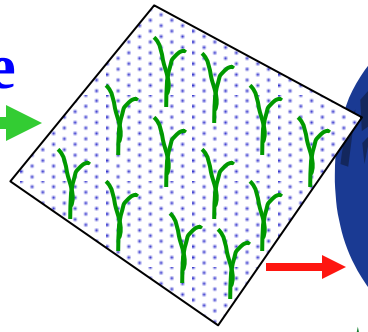
Public toilet

Restaurant

MSL system

reuse

reuse



Possible Water treatment Scheme by MSL system

For the removal of
N, P, BOD, COD, Pesticides, PCE, 17βestradiol, etc