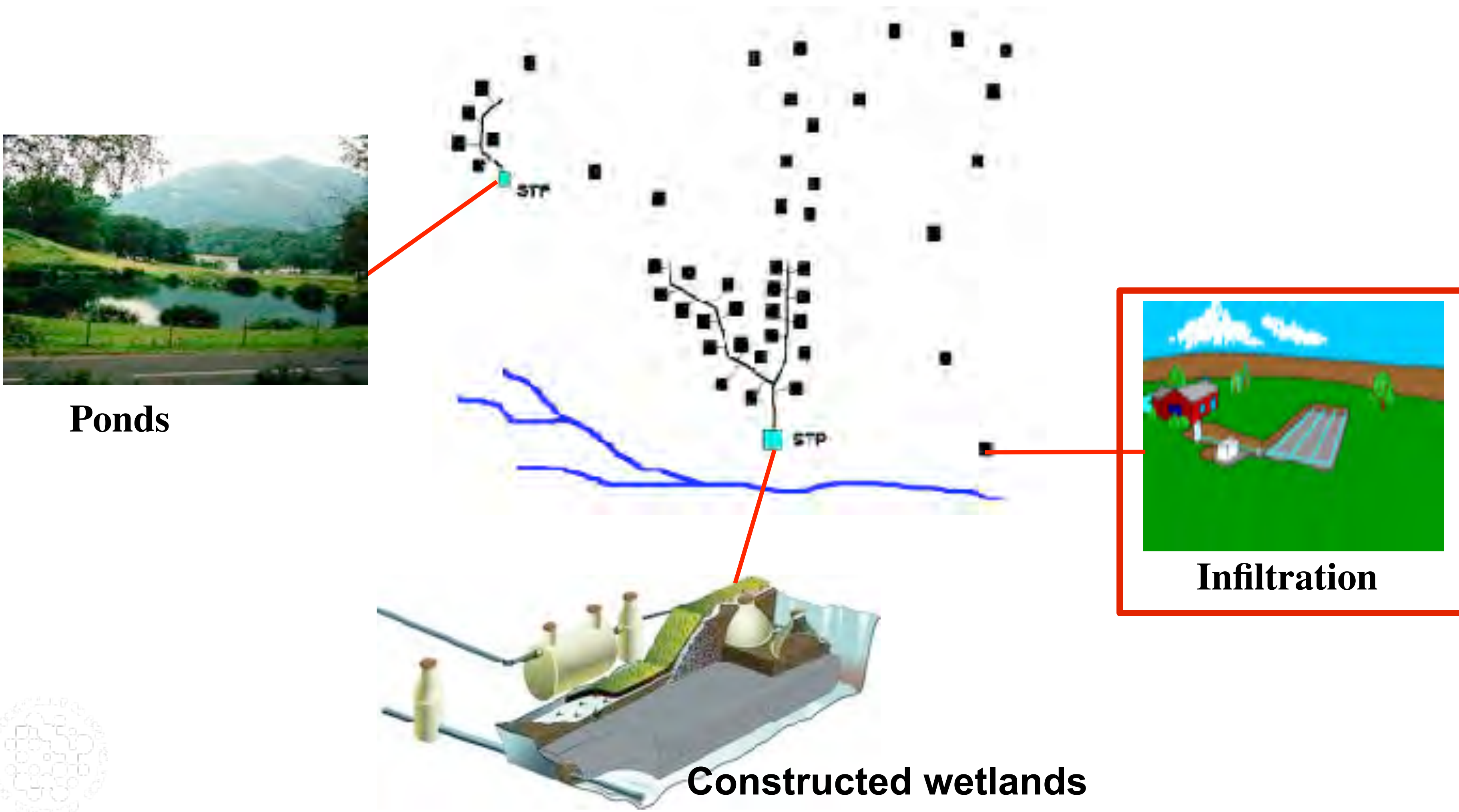
THT312: Water Management in Cold Regions

Wastewater treatment in cold climate - natural systems

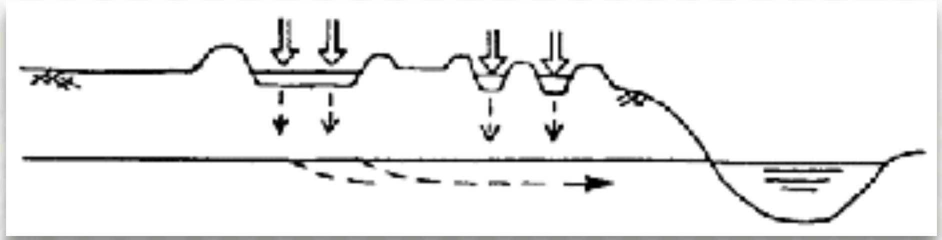
Petter D. Jenssen, Faculty of Environmental Sciences and Natural Resource Management (MINA), Norwegian University of Life Sciences (NMBU), petter.jenssen@umb.no,

Natural systems for wastewater treatment

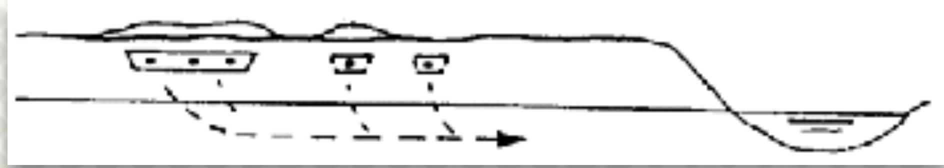


Infiltration of wastewater into soil

Open infiltration - dams



Subsurface systems - trenches/ beds



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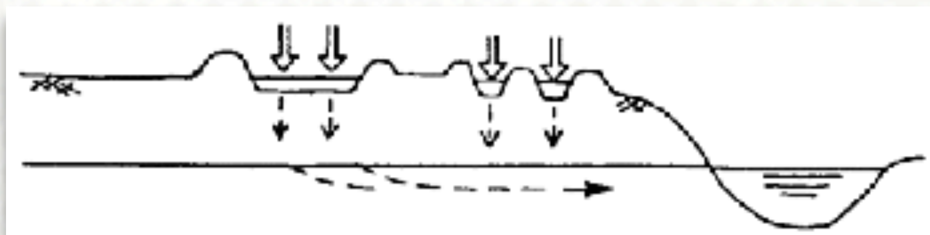
Infiltration of wastewater into soil

AREA REQUIREMENT

Open infiltration - dams

1-5m²/person



Subsurface systems - trenches/beds

5-20m²/person

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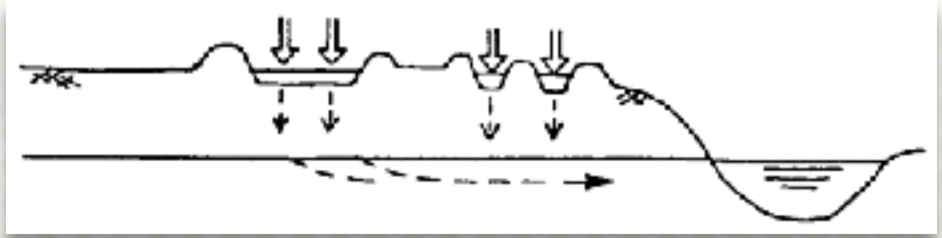
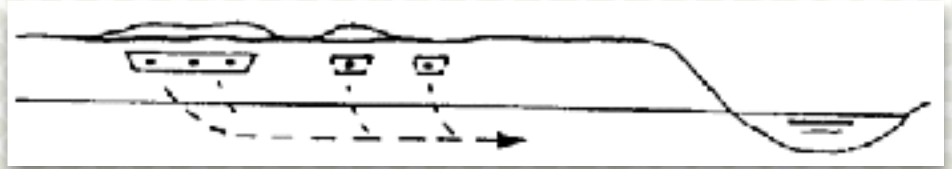
Infiltration of wastewater into soil

Open infiltration - dams



Subsurface systems - trenches/ beds



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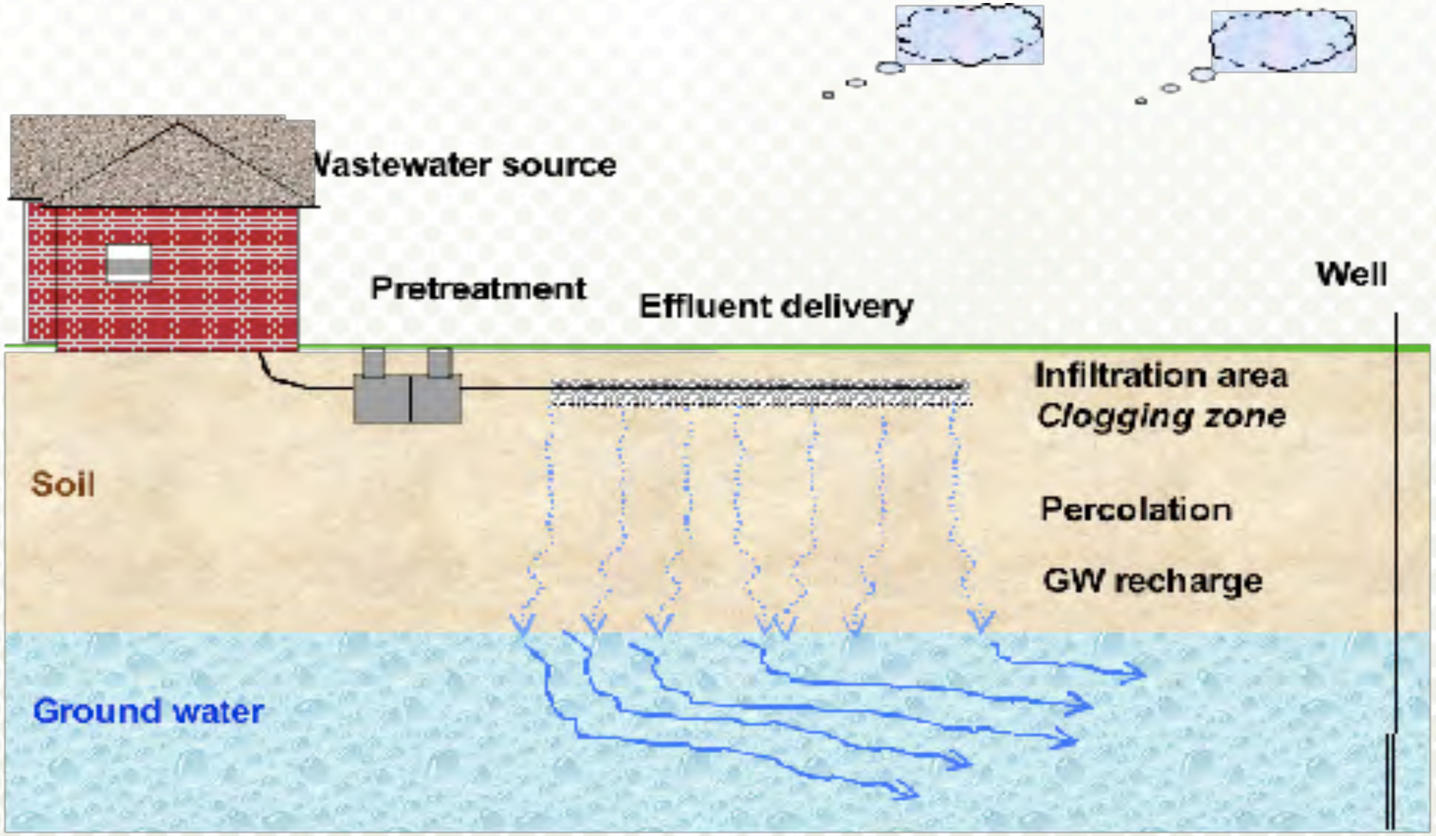
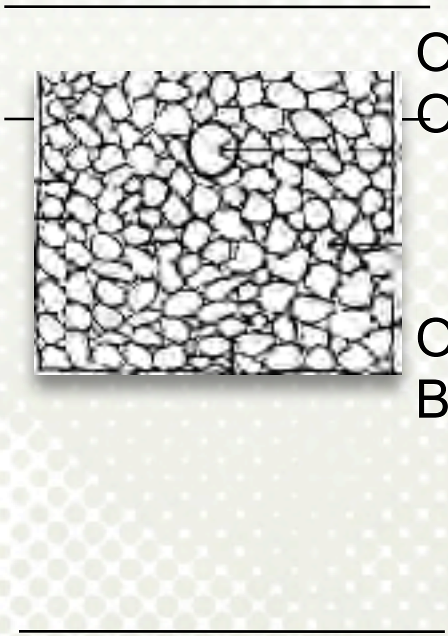
Traditional buried soil infiltration system



Siegrist et al. 2000

Traditional buried soil infiltration system



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Buried soil infiltration system - mound

Sand on top of the natural soil

Gravel and distribution pipe in place

Insulation - 5cm of expanded polystyrene

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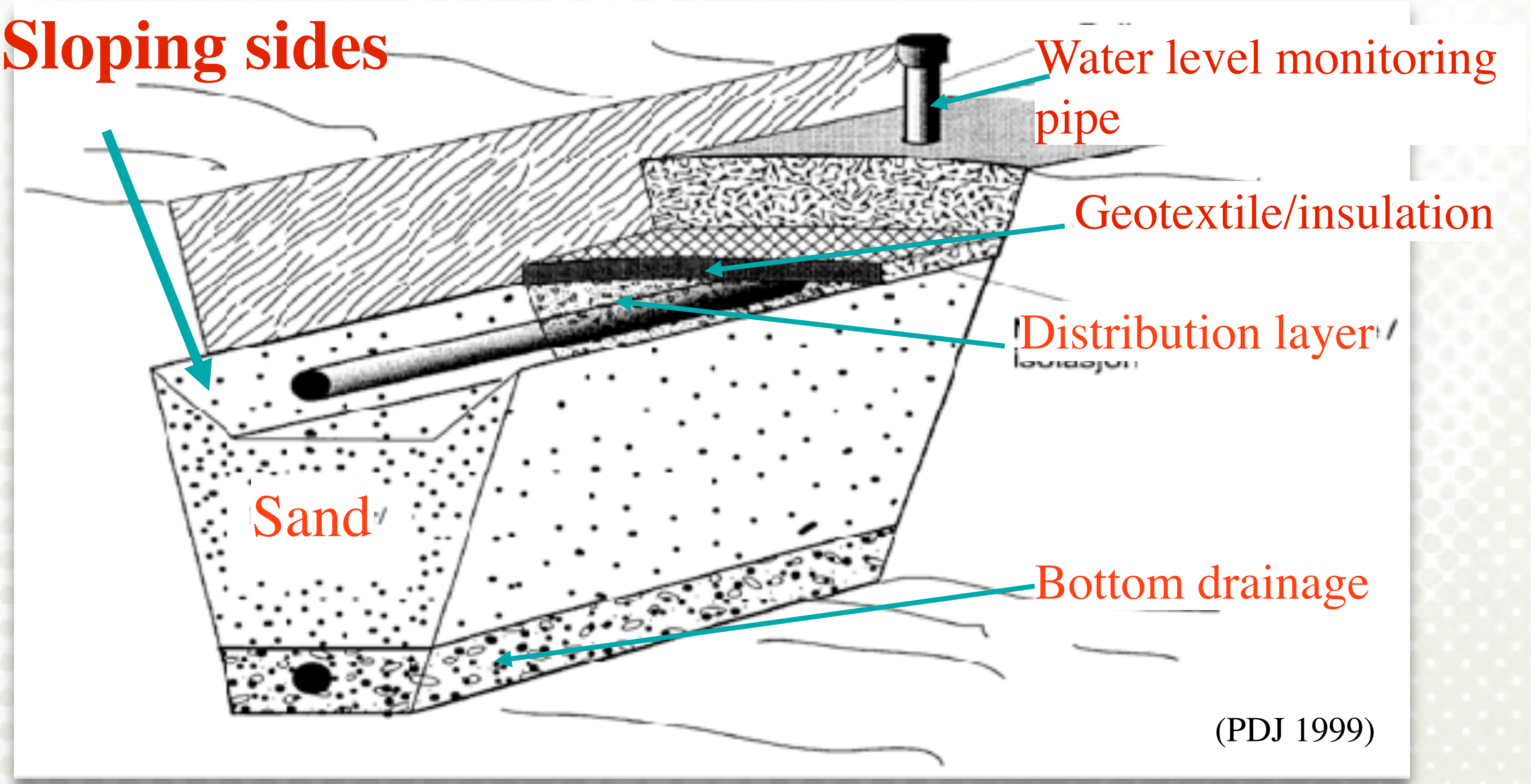
Purification through sand

Sandfilter



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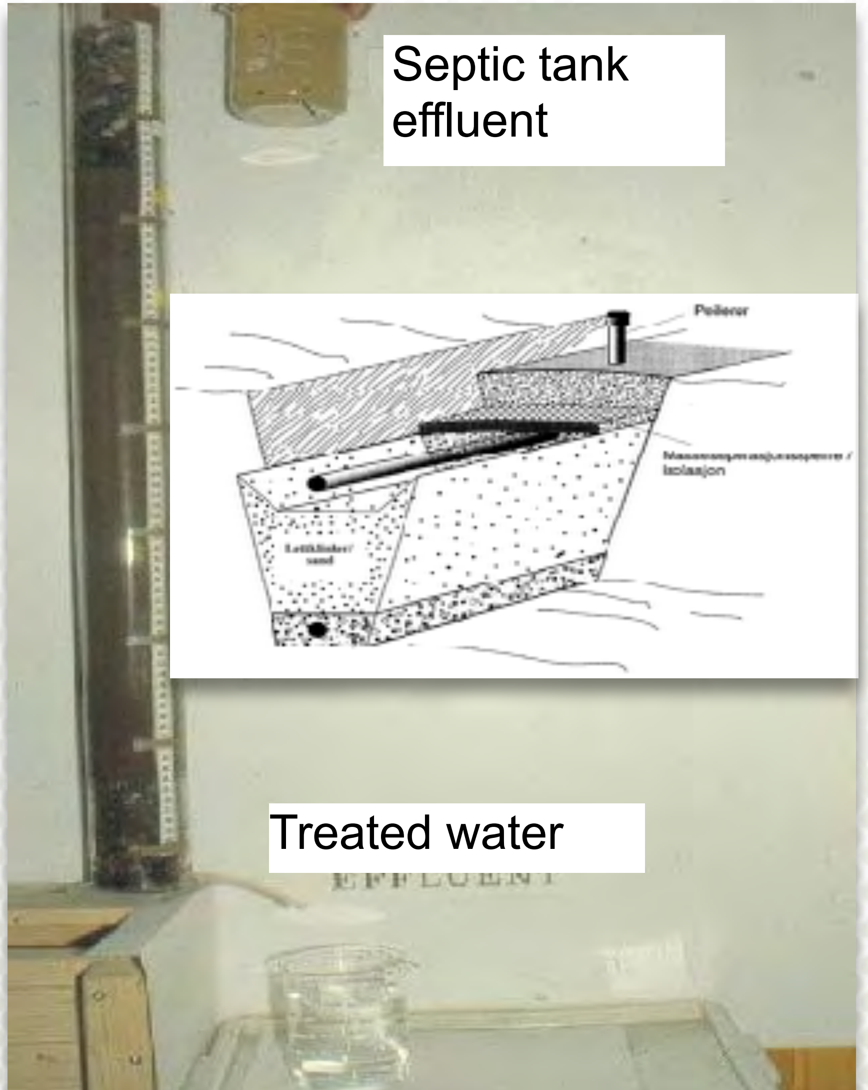
Sandfilter - performance



TREATMENT*

Organic matter (COD):

>90%

Suspended solids (SS):

> 90%

Phosphorus (P)*:

0 - 80%

Nitrogen (N)

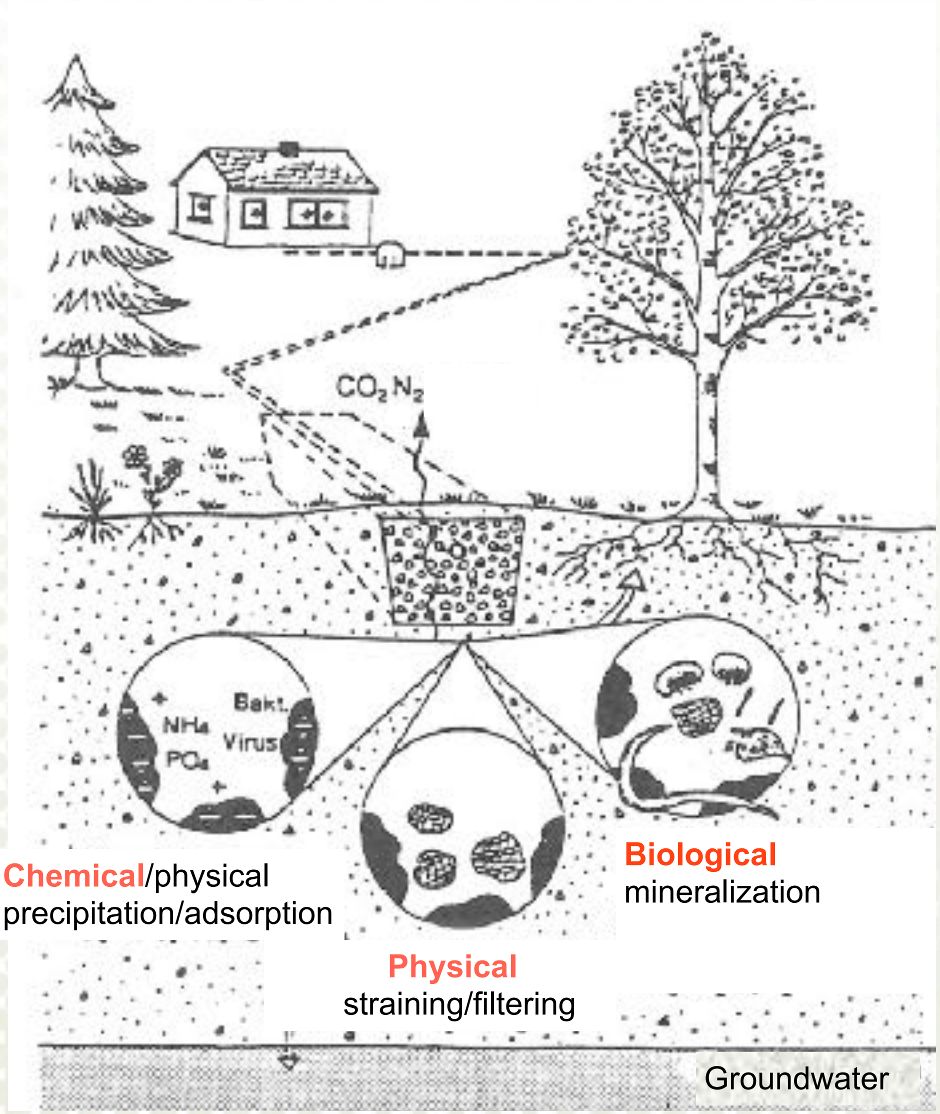
30% (20 - 50%)

Bacteria:

4-6 log reduction

* Based on 8 -10 years of operation

Wastewater Treatment
Natural systems - processes



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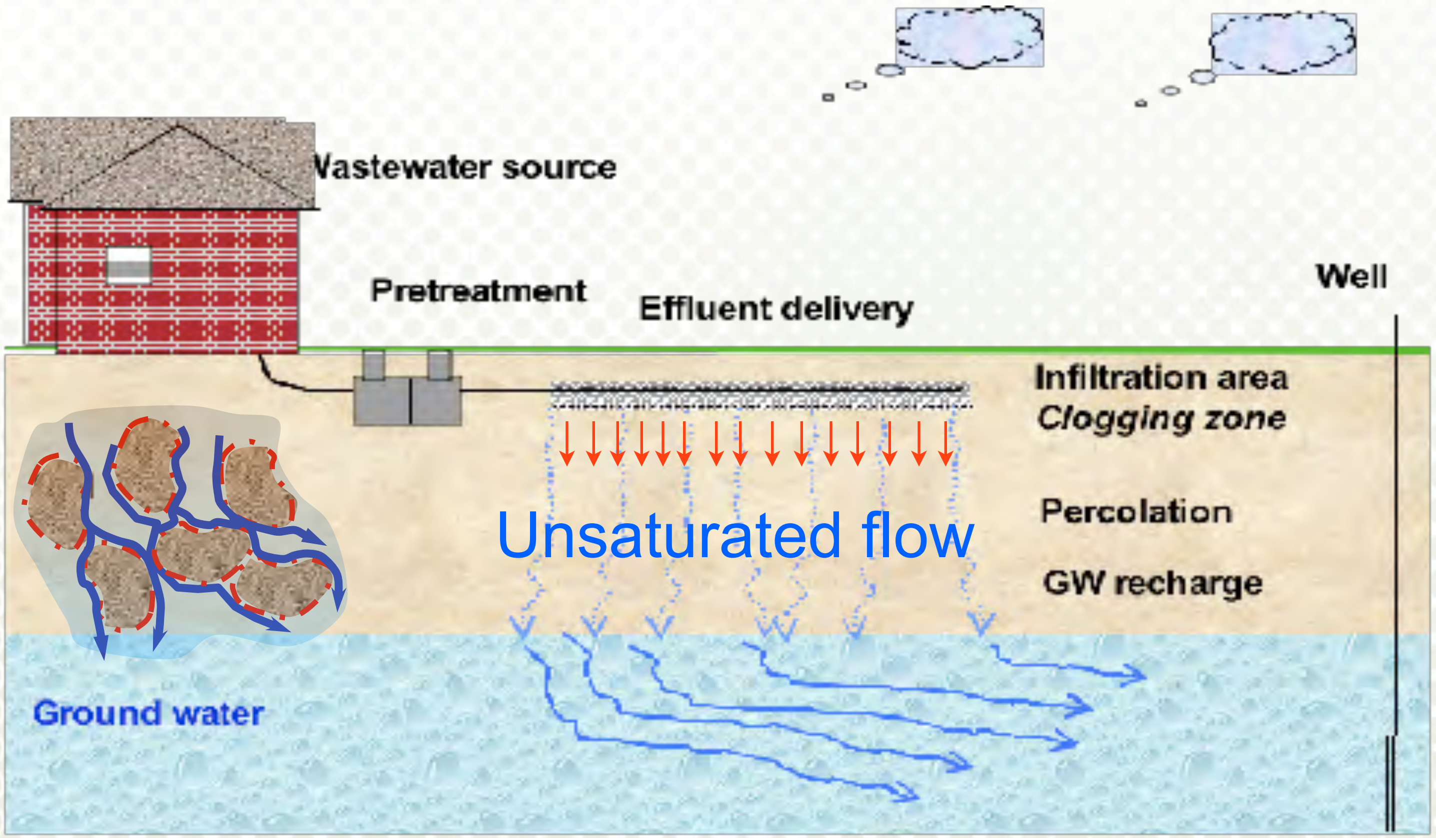
Traditional buried soil infiltration system



Siegrist et al. 2000

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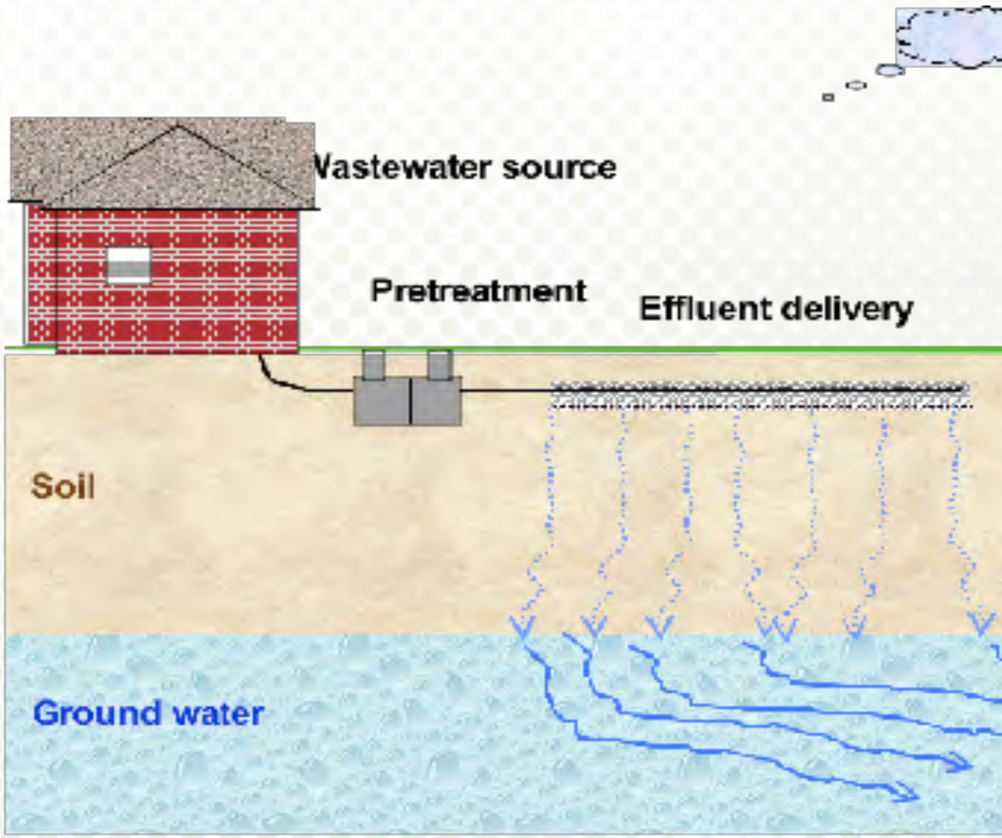
Department of Plant and Environmental Sciences, P.D. Jenssen

Traditional buried soil infiltration system



(Siegrist et al. 2000)

TREATMENT*

Organic matter(BOD):

> 90 %

Suspended solids (SS):

> 90%

Phosphorus (P):

> 90 %

Nitrogen (N)

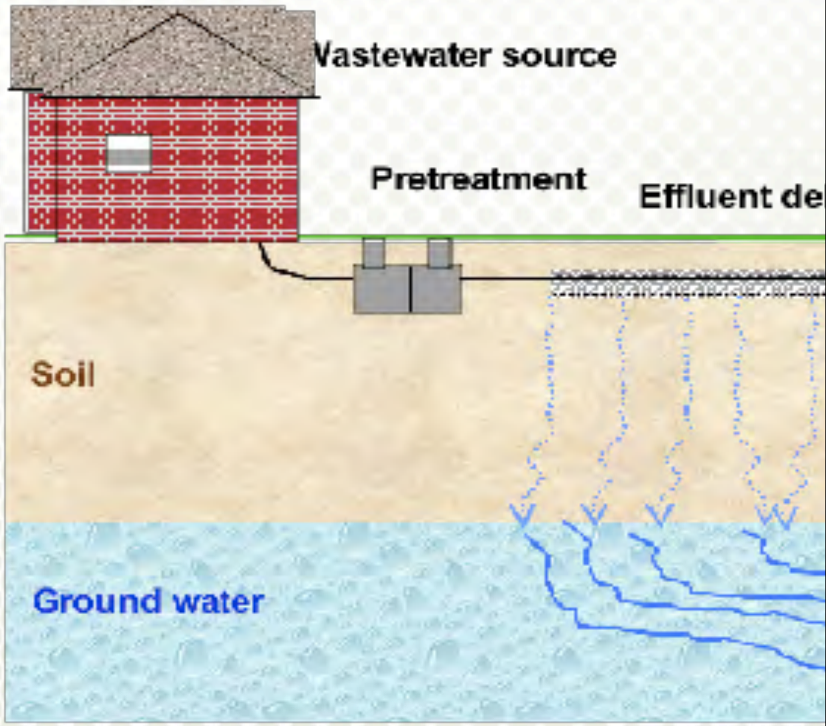
> 30% (20 - 60)

Bacteria:

4-6 log reduction

*Treatment preformance in the unsaturated zone, further treatment will occur in the saturated zone

Buried soil infiltration system - suitability in the Arctic



(Siegrist et al. 2000)

Treatment - BOD, TSS, nutrients	HIGH
Treatment - Hygiene	HIGH
Treatment - Organic micropollutants	HIGH
Investment cost	MEDIUM /LOW
O & M	LOW
Technical complexity	LOW
Suitability arctic conditions	HIGH TO LOW

*Tr
furth

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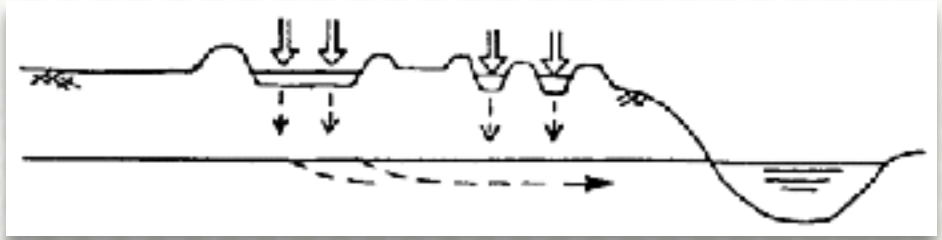
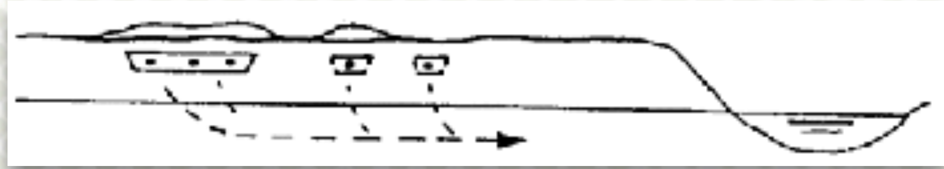
Infiltration of wastewater into soil

Open infiltration - dams



Subsurface systems - trenches/ beds



Setermoen, Bardu municipality, Norway

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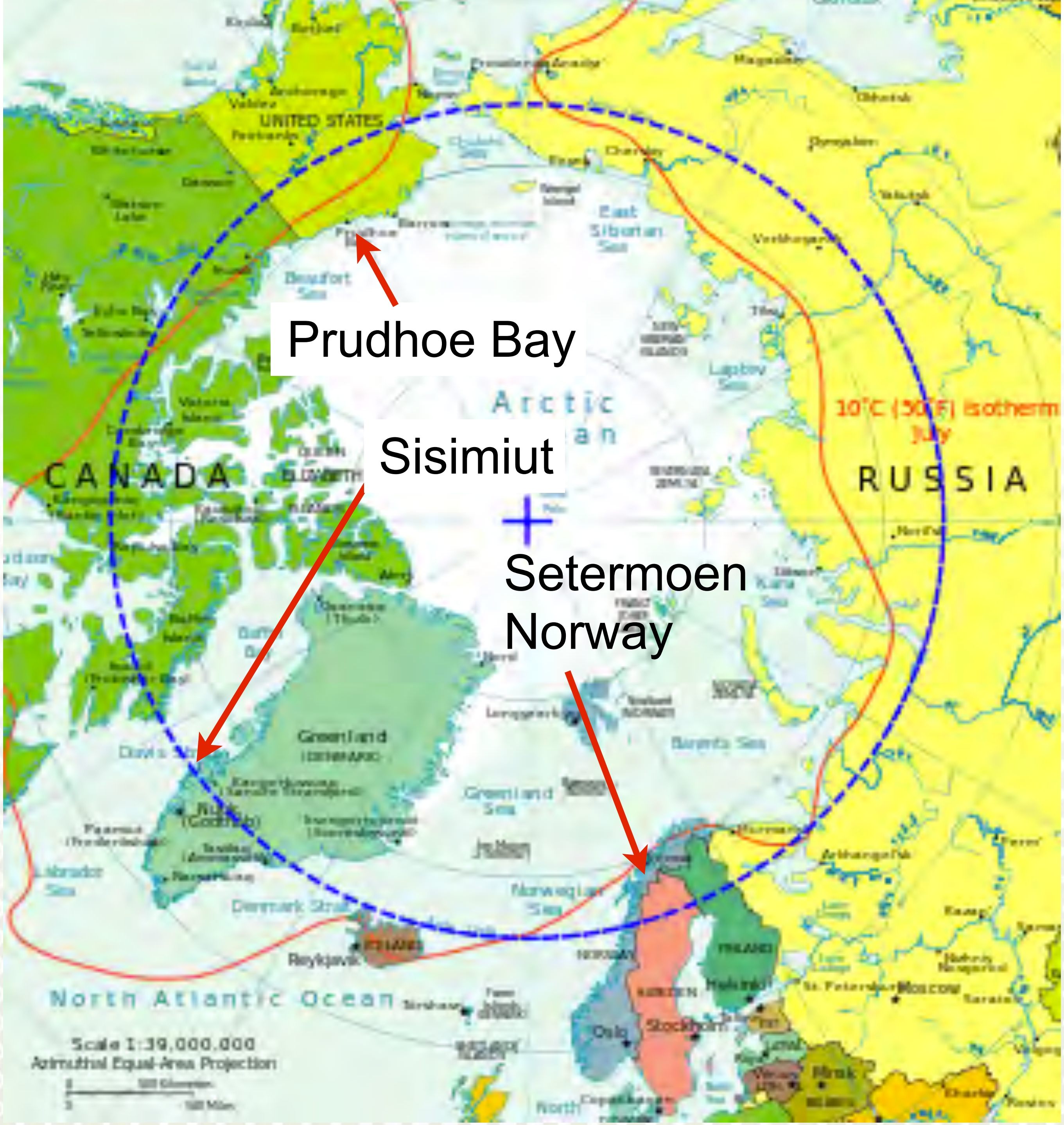
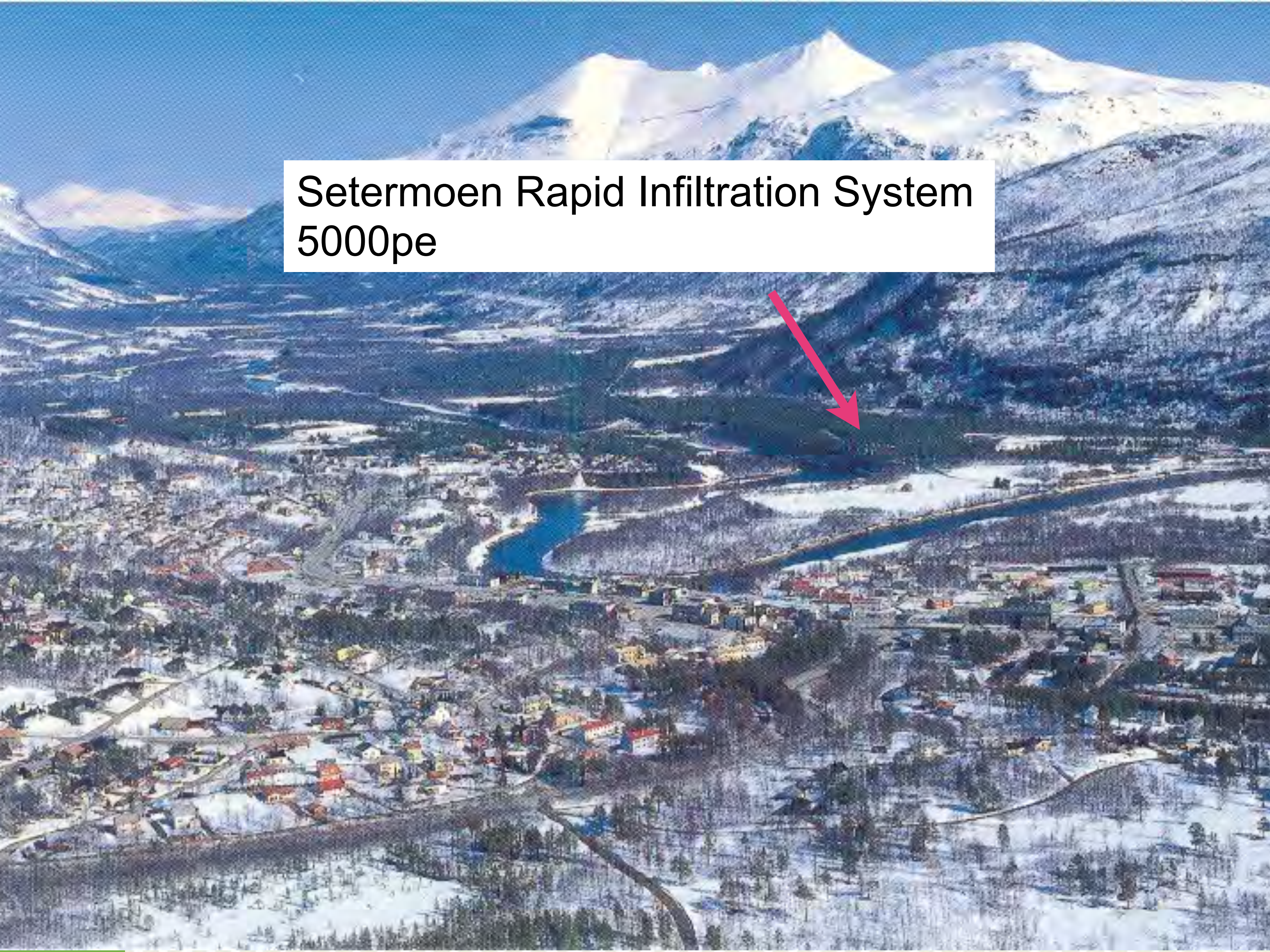
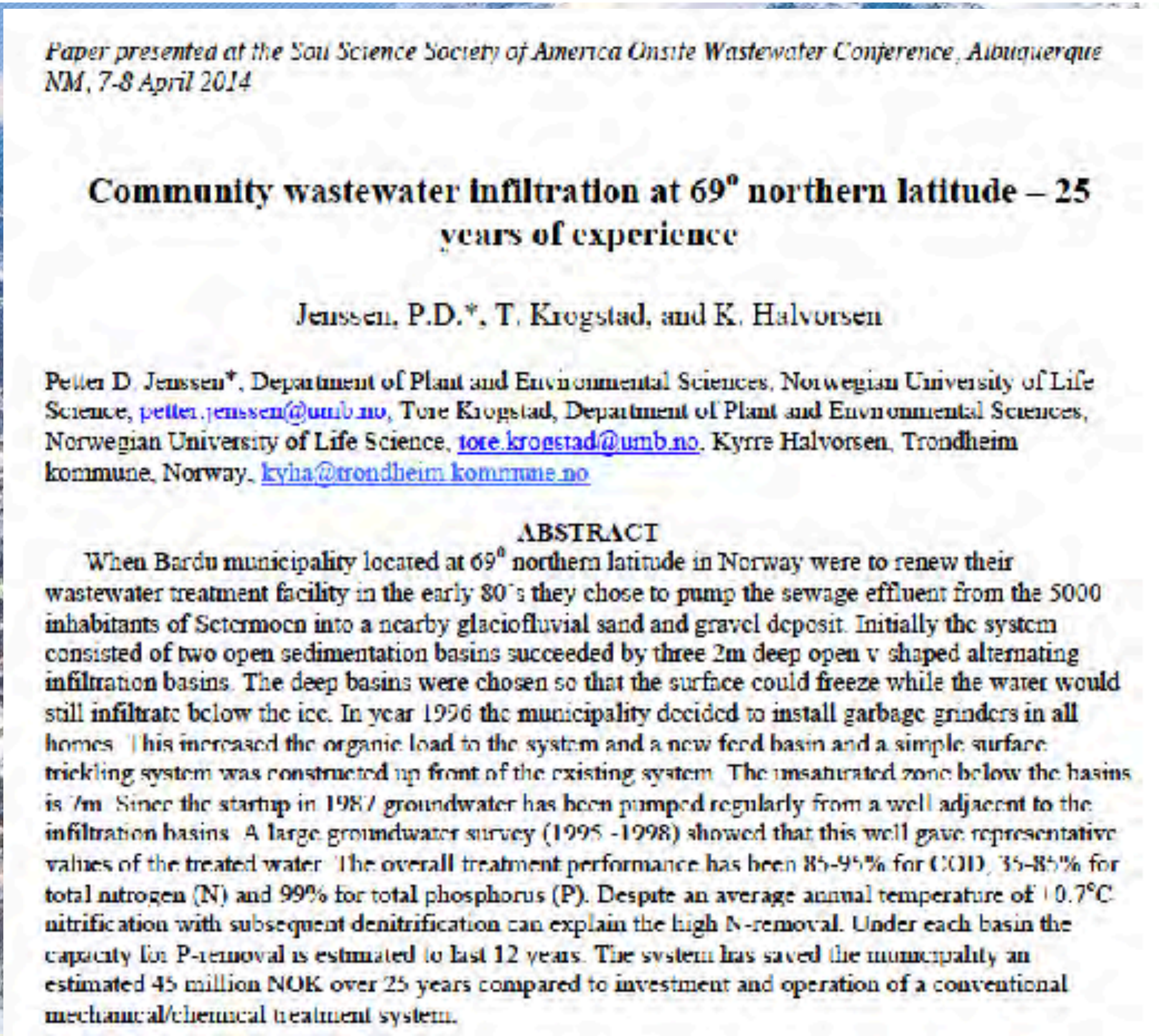



Setermoen Rapid Infiltration System
5000pe

Setermoen, Bardu municipality, Norway



Paper presented at the Soil Science Society of America Onsite Wastewater Conference, Albuquerque NM, 7-8 April 2014

Community wastewater infiltration at 69° northern latitude – 25 years of experience

Jenssen, P.D.*, T. Krogstad, and K. Halvorsen

Petter D. Jenssen*, Department of Plant and Environmental Sciences, Norwegian University of Life Science, petter.jenssen@umb.no, Tore Krogstad, Department of Plant and Environmental Sciences, Norwegian University of Life Science, tore.krogstad@umb.no, Kyrre Halvorsen, Trondheim kommune, Norway, kyha@trondheim.kommune.no

ABSTRACT

When Bardu municipality located at 69° northern latitude in Norway were to renew their wastewater treatment facility in the early 80's they chose to pump the sewage effluent from the 5000 inhabitants of Setermoen into a nearby glaciofluvial sand and gravel deposit. Initially the system consisted of two open sedimentation basins succeeded by three 2m deep open v shaped alternating infiltration basins. The deep basins were chosen so that the surface could freeze while the water would still infiltrate below the ice. In year 1996 the municipality decided to install garbage grinders in all homes. This increased the organic load to the system and a new feed basin and a simple surface trickling system was constructed up front of the existing system. The unsaturated zone below the basins is 7m. Since the startup in 1987 groundwater has been pumped regularly from a well adjacent to the infiltration basins. A large groundwater survey (1995 -1998) showed that this well gave representative values of the treated water. The overall treatment performance has been 85-95% for COD, 35-85% for total nitrogen (N) and 99% for total phosphorus (P). Despite an average annual temperature of +0.7°C nitrification with subsequent denitrification can explain the high N-removal. Under each basin the capacity for P-removal is estimated to last 12 years. The system has saved the municipality an estimated 45 million NOK over 25 years compared to investment and operation of a conventional mechanical/chemical treatment system.

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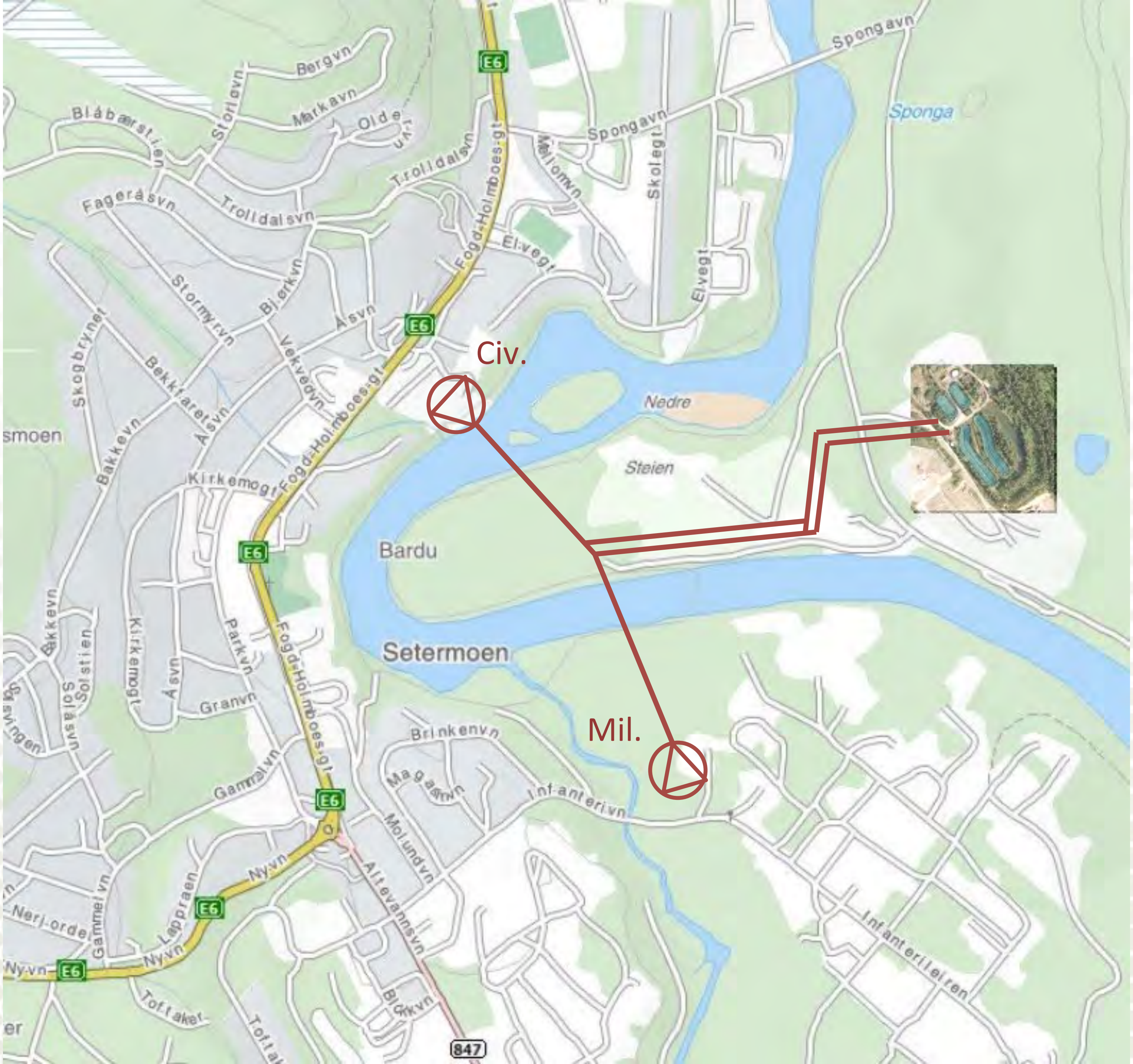
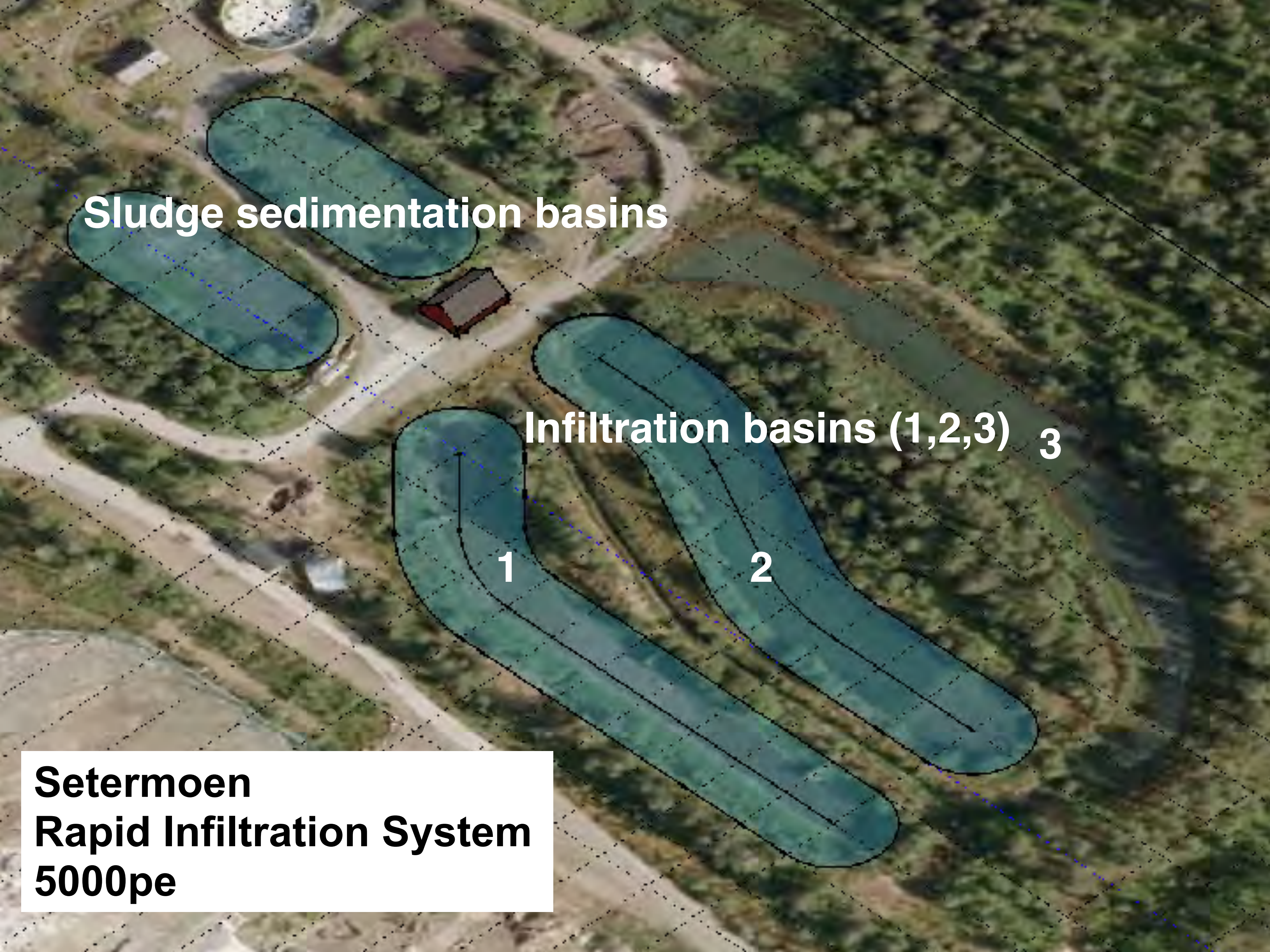
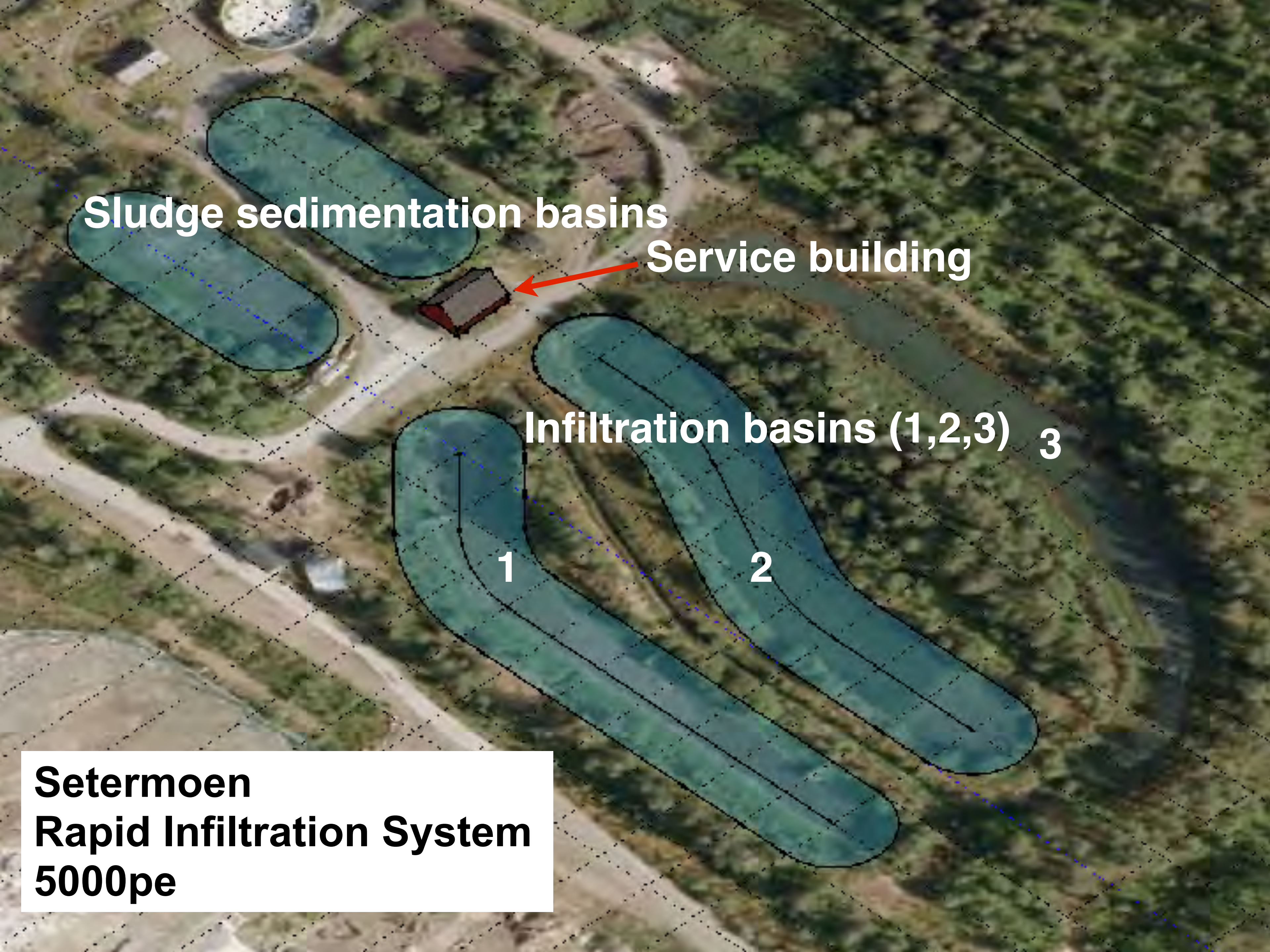



Sludge sedimentation basins
Setermoen
Rapid Infiltration System
5000pe


Sludge sedimentation basins
Infiltration basins (1,2,3)
3
1
2
Setermoen
Rapid Infiltration System
5000pe


Sludge sedimentation basins
Service building
Infiltration basins (1,2,3)
1
2
3
Setermoen
Rapid Infiltration System
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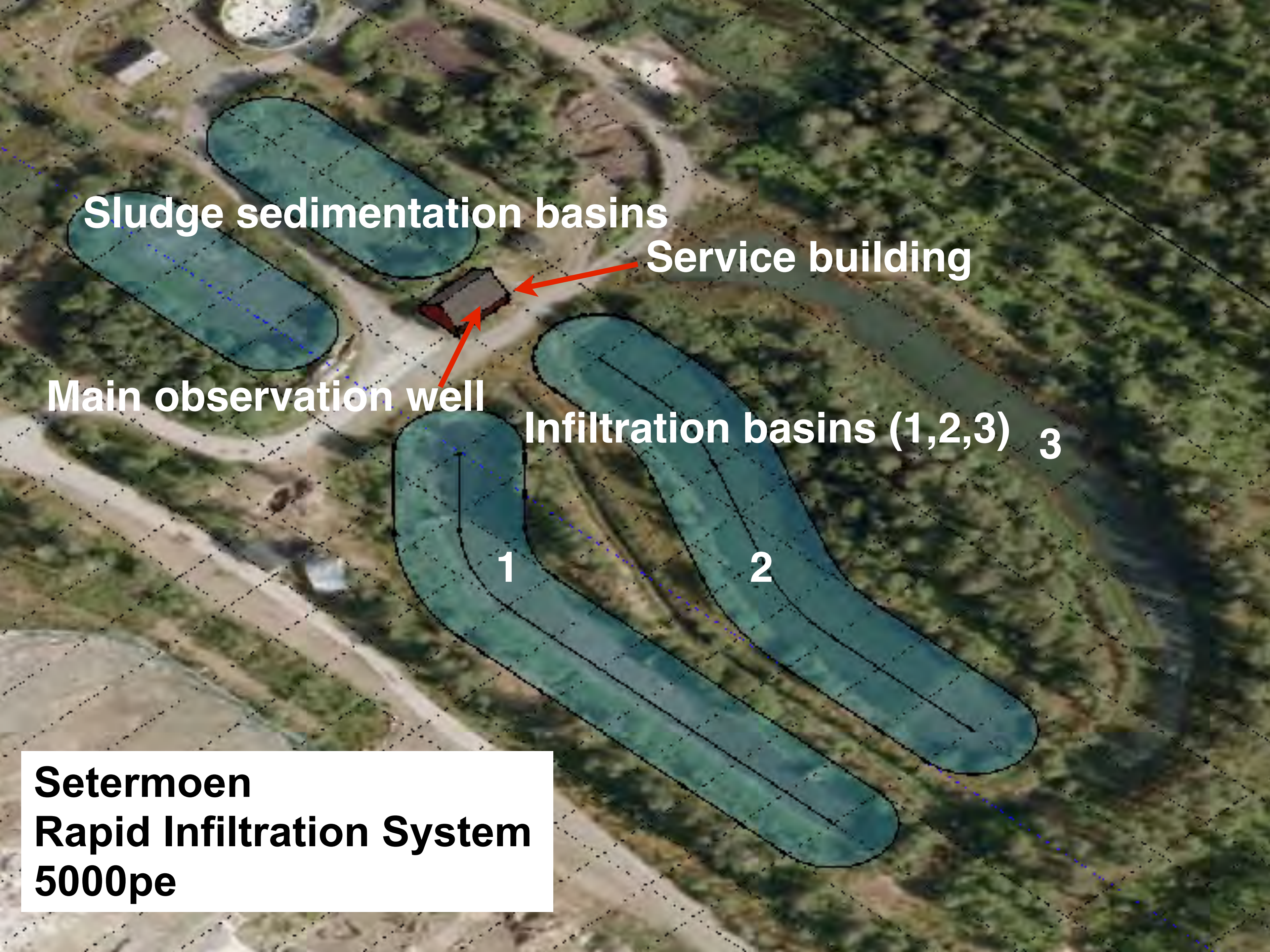
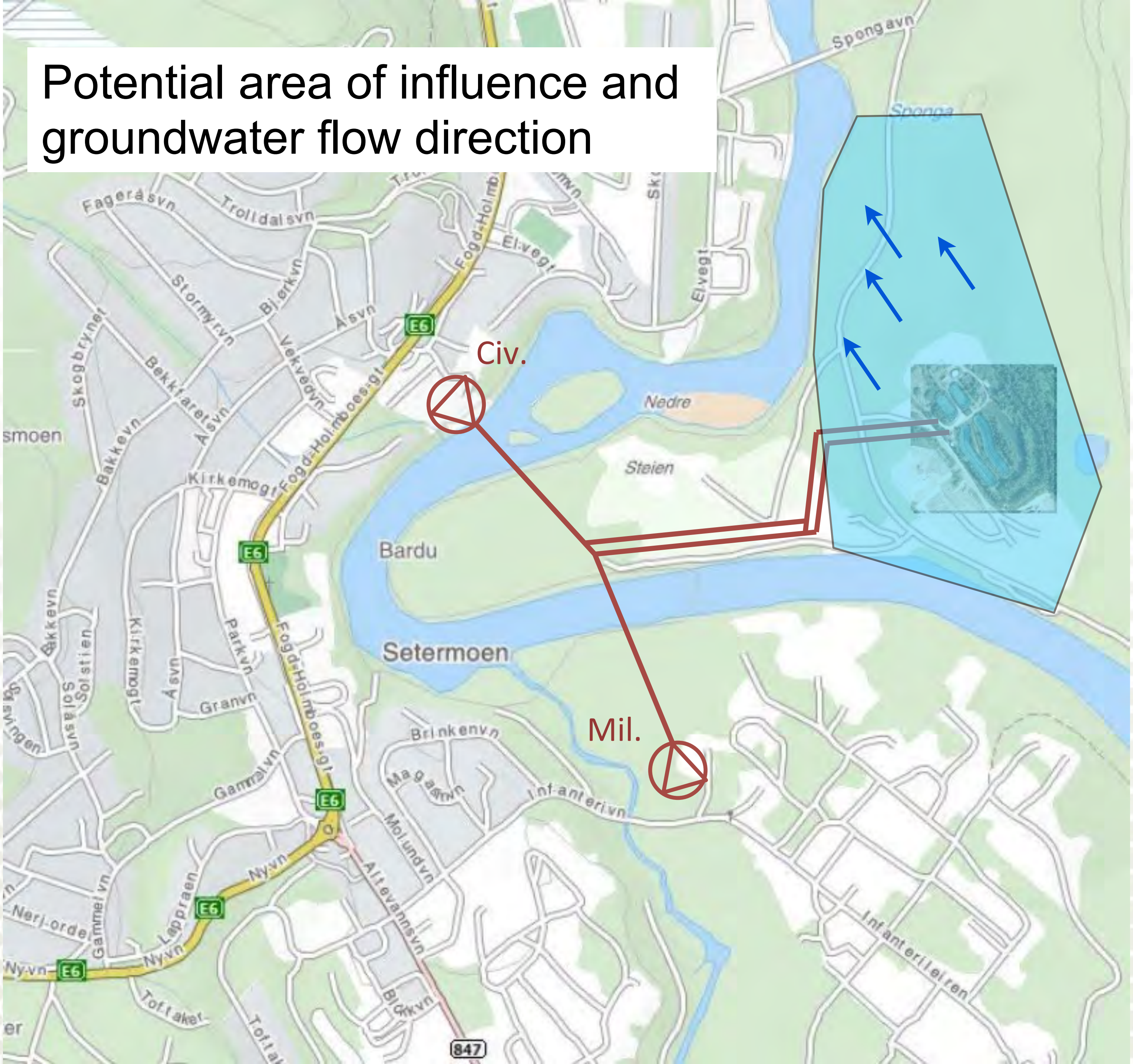


Setermoen
Rapid Infiltration System
5000pe


Direction of groundwater flow
Setermoen
Rapid Infiltration System
5000pe

Potential area of influence and groundwater flow direction



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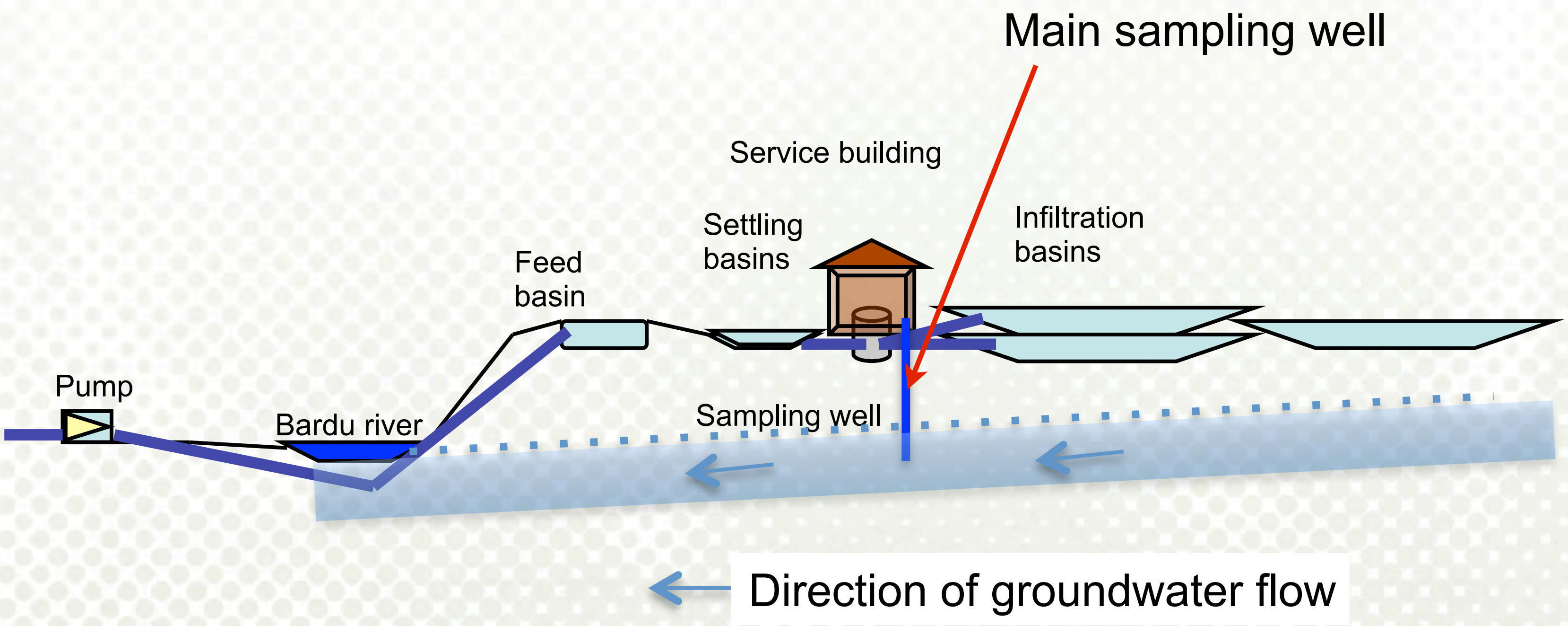
Setermoen rapid infiltration system
Vertical view



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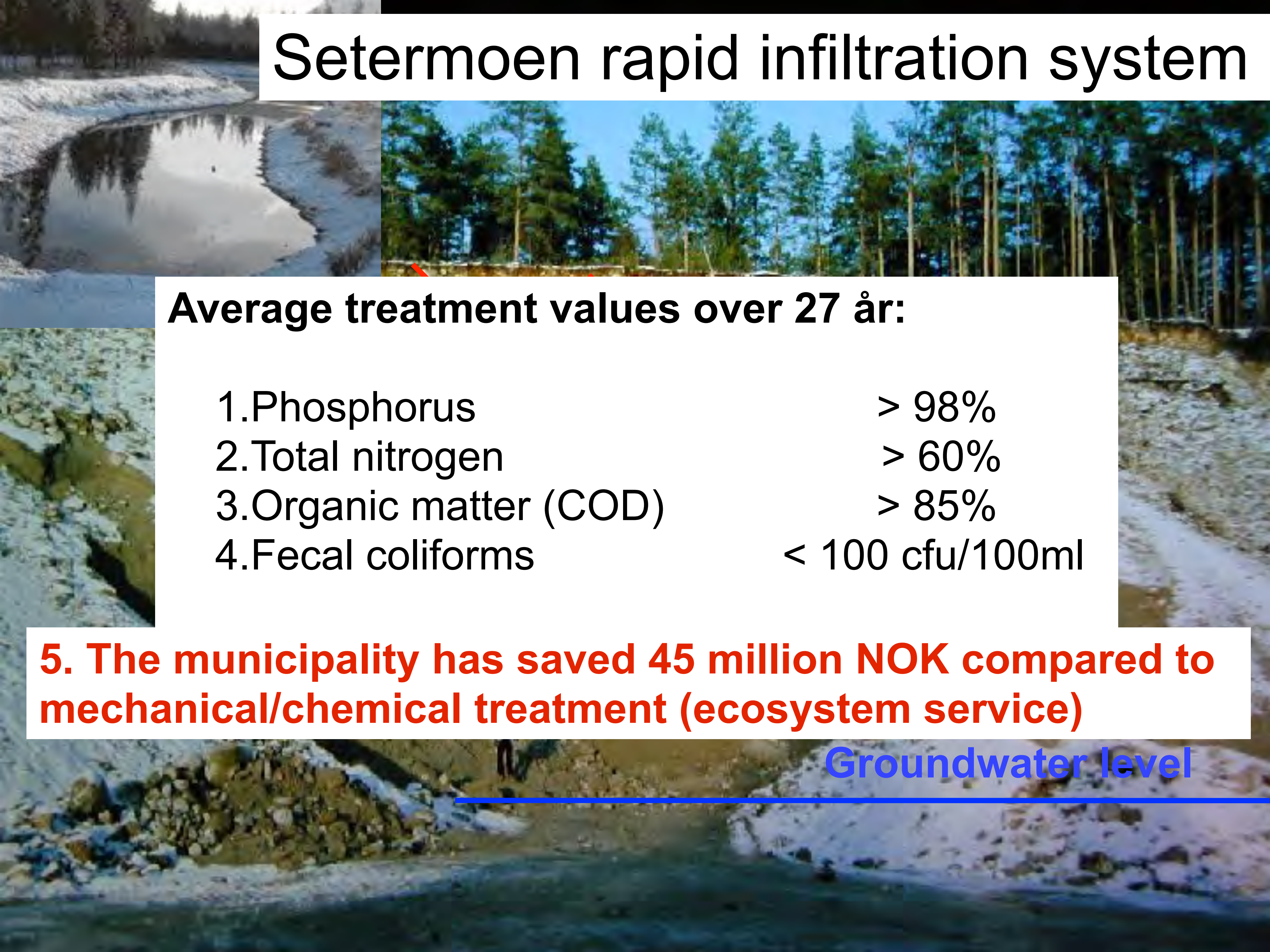
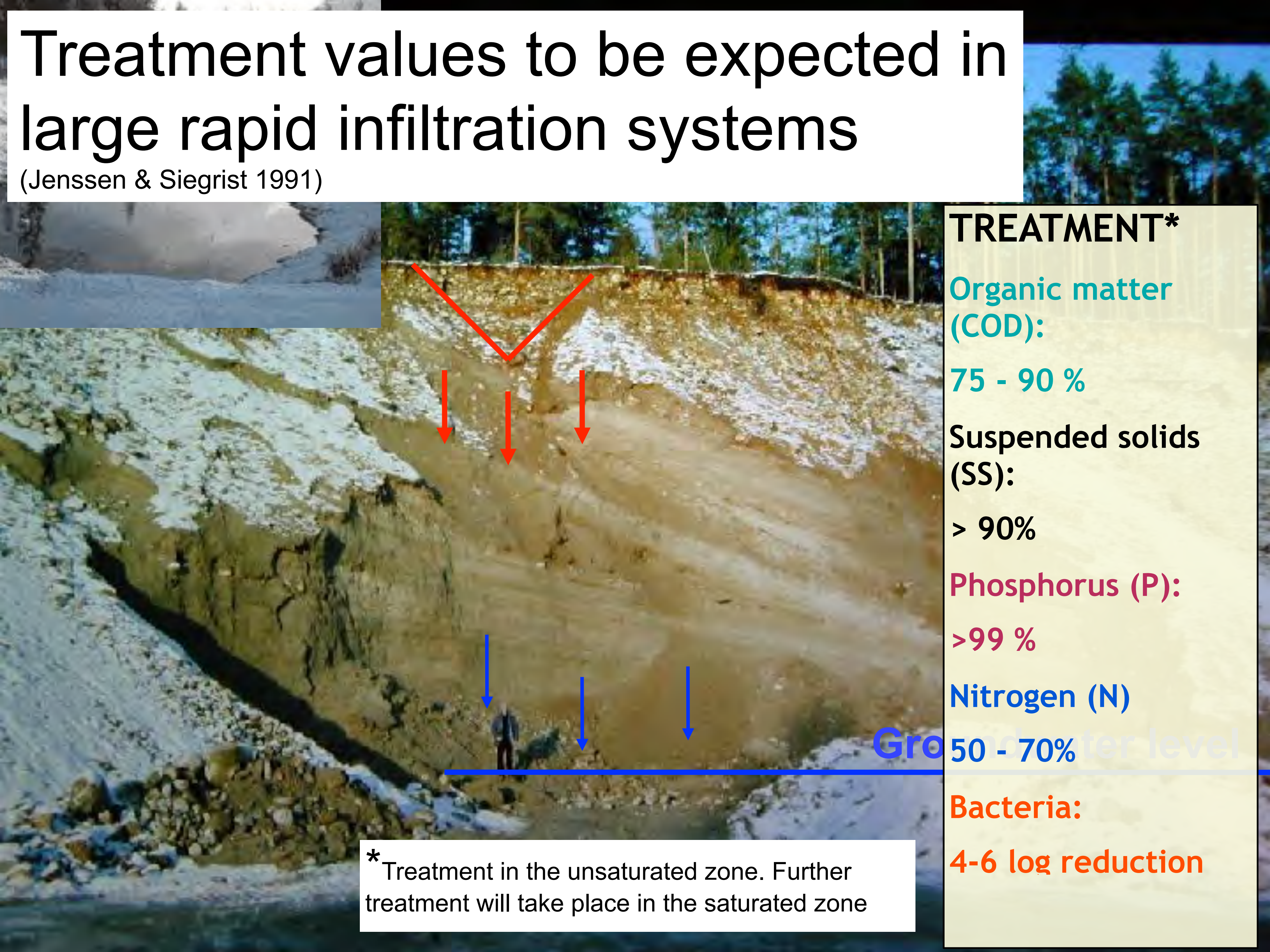
Groundwater level


2 m
7 m
Groundwater level


Setermoen rapid infiltration system
Average treatment values over 27 år:
1.Phosphorus > 98%
2.Total nitrogen > 60%
3.Organic matter (COD) > 85%
4.Fecal coliforms < 100 cfu/100ml
5. The municipality has saved 45 million NOK compared to mechanical/chemical treatment (ecosystem service)
Groundwater level

Treatment values to be expected in large rapid infiltration systems

(Jenssen & Siegrist 1991)



TREATMENT*

Organic matter (COD):

75 - 90 %

Suspended solids (SS):

> 90%

Phosphorus (P):

>99 %

Nitrogen (N)

50 - 70%

Bacteria:

4-6 log reduction

*Treatment in the unsaturated zone. Further treatment will take place in the saturated zone

Open rapid infiltration systems - suitability in Arctic conditions

Treatment - BOD, TSS, nutrients	HIGH
Treatment - Hygiene	HIGH
Treatment - Organic micropollutants	HIGH
Investment cost	MEDIUM /LOW
O & M	LOW
Technical complexity	LOW
Suitability arctic conditions	HIGH TO LOW

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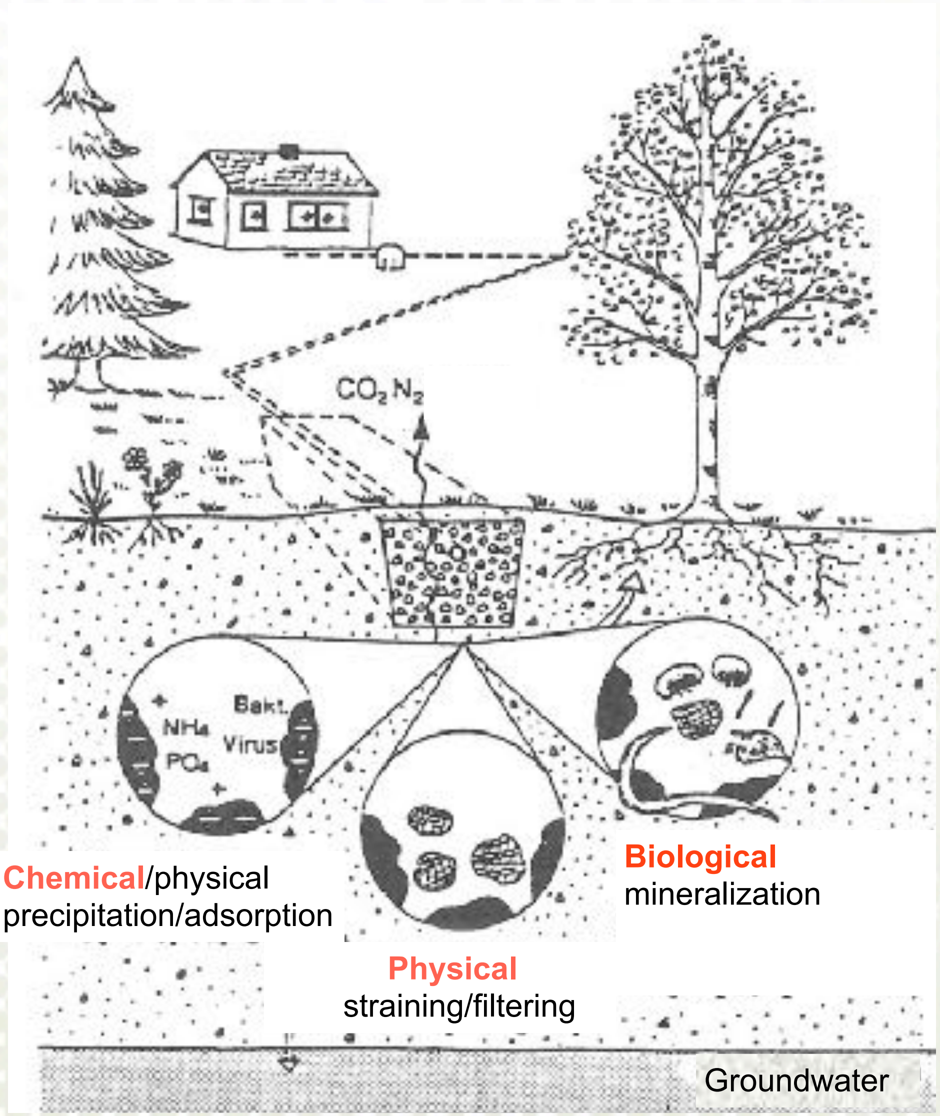
Wastewater Treatment
Natural systems - processes



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Removal mechanisms in natural systems

- Removal of organic matter
- Removal of phosphorus
- Removal of nitrogen
- Removal of microorganisms

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Reduction of organic matter by percolation through sand/soils

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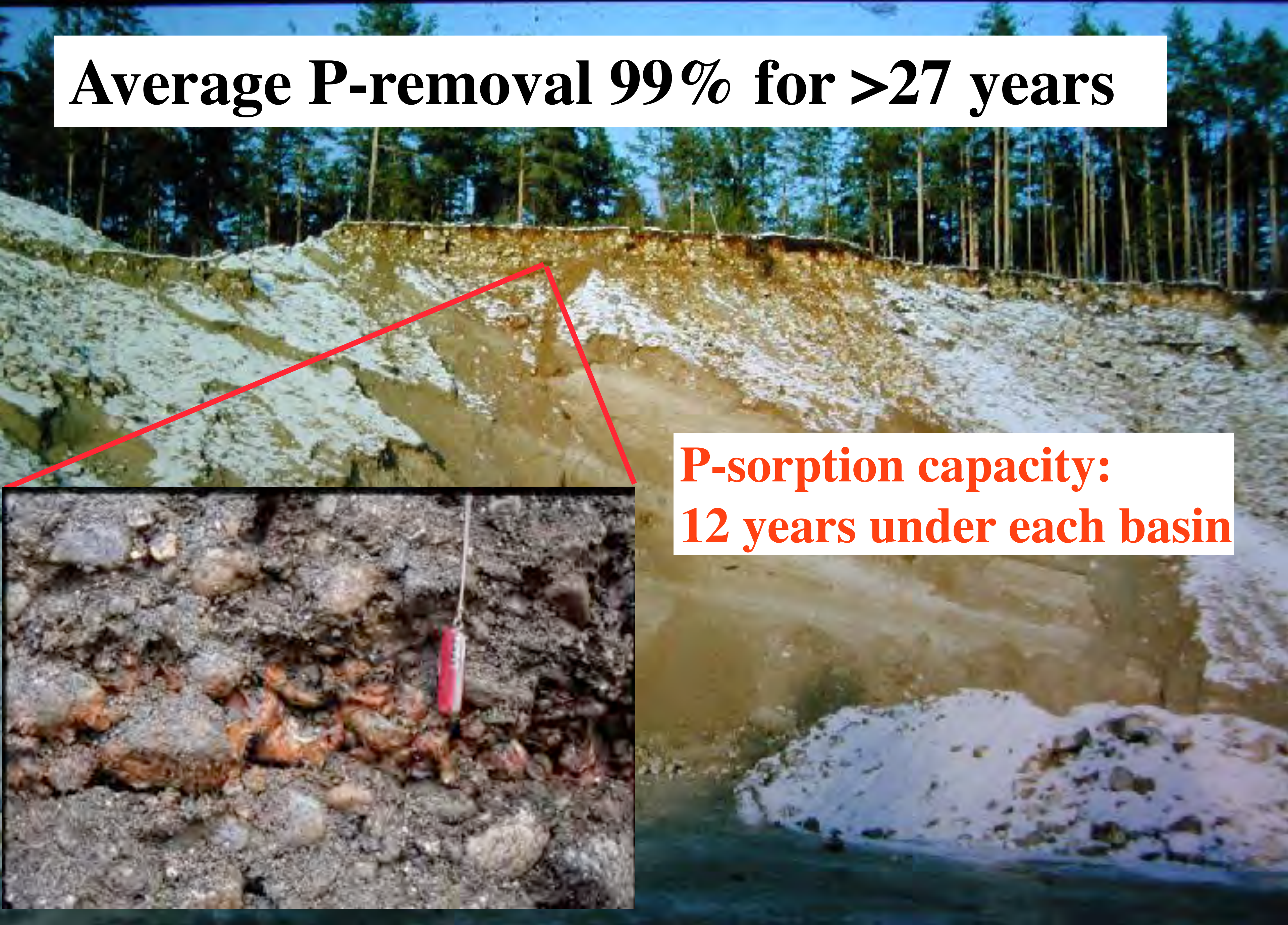
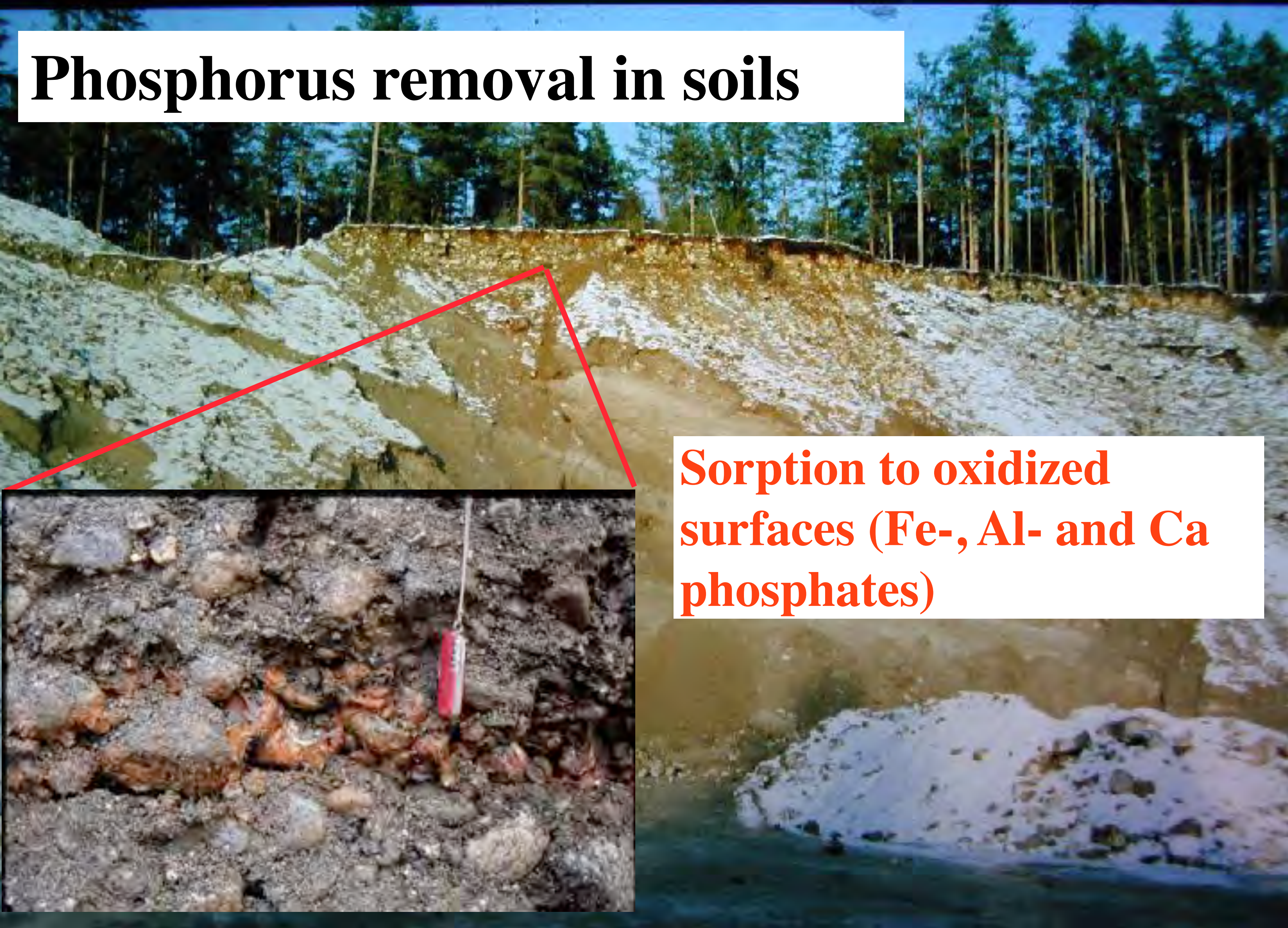
Reduction of organic matter by percolation through sand/soils

* Area for biofilm growth
* Retention time


Average P-removal 99% for >27 years
P-sorption capacity:
12 years under each basin

Phosphorus removal in soils



Sorption to oxidized surfaces (Fe-, Al- and Ca phosphates)

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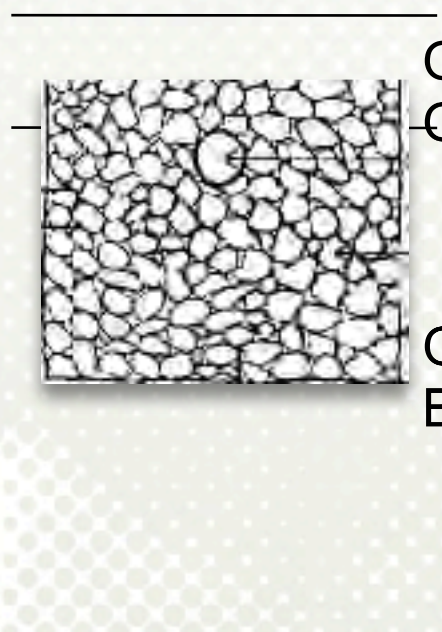
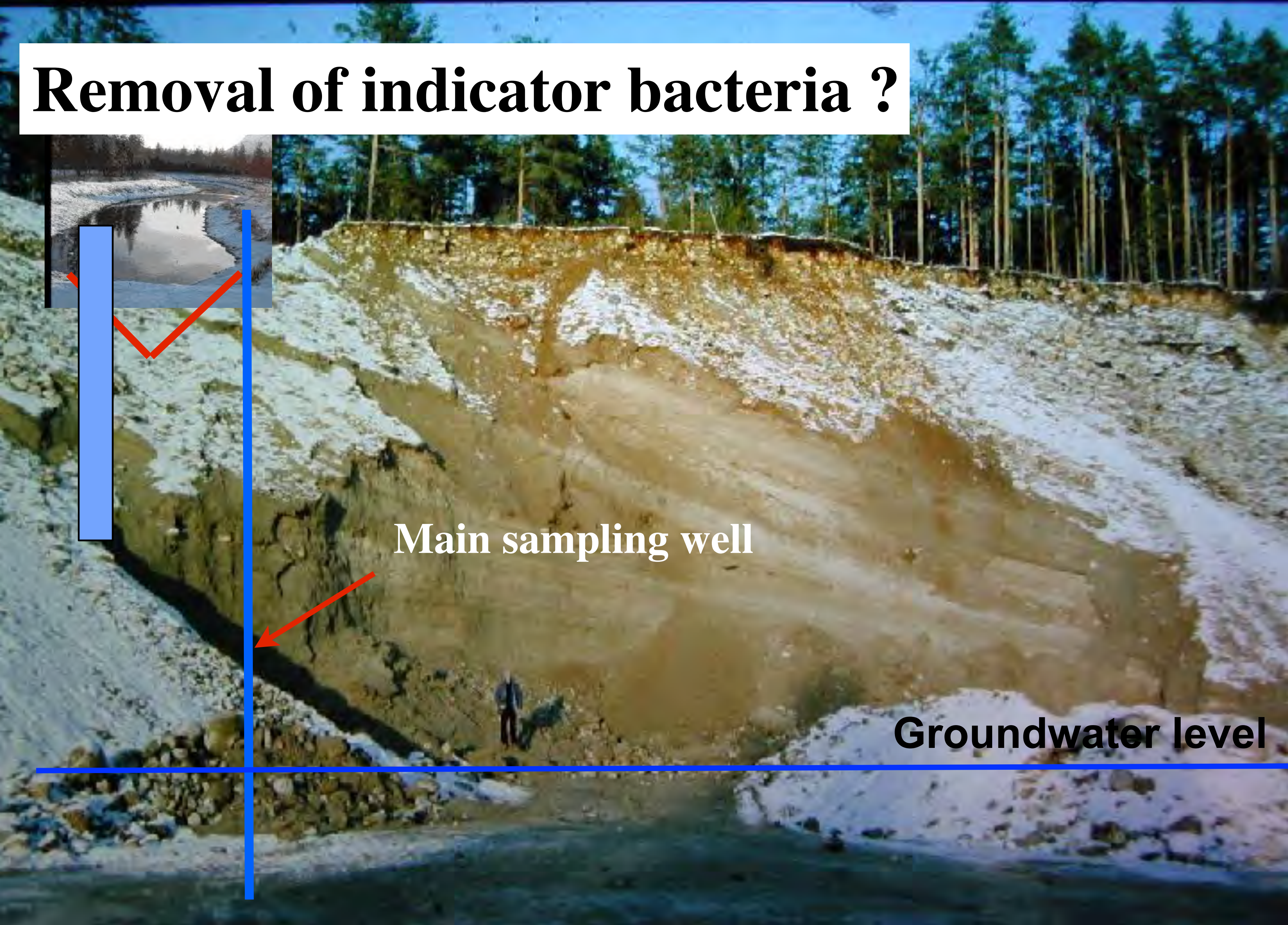
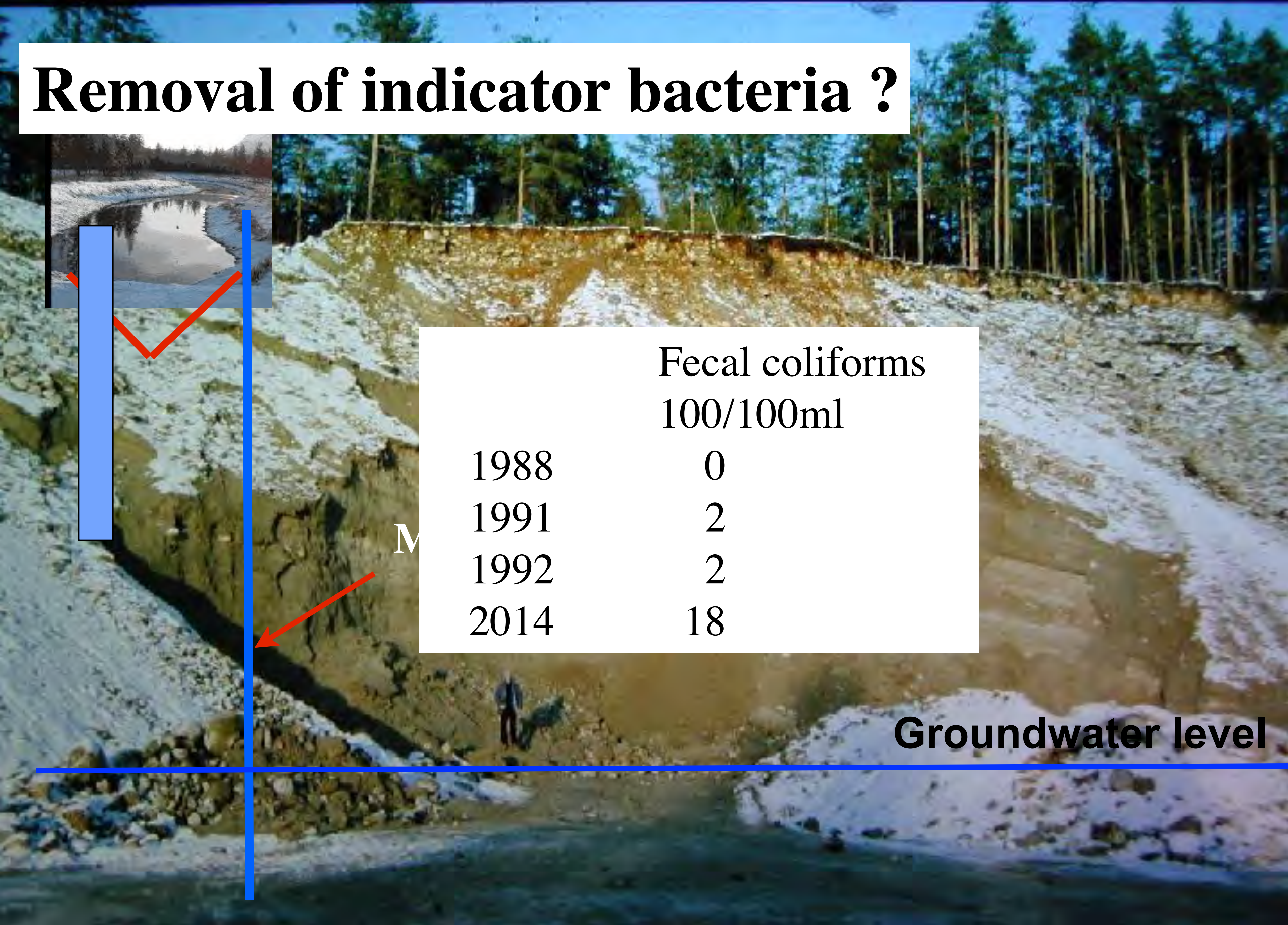
Phosphorus removal in soils
depth of infiltration trenches



Removal of indicator bacteria ?

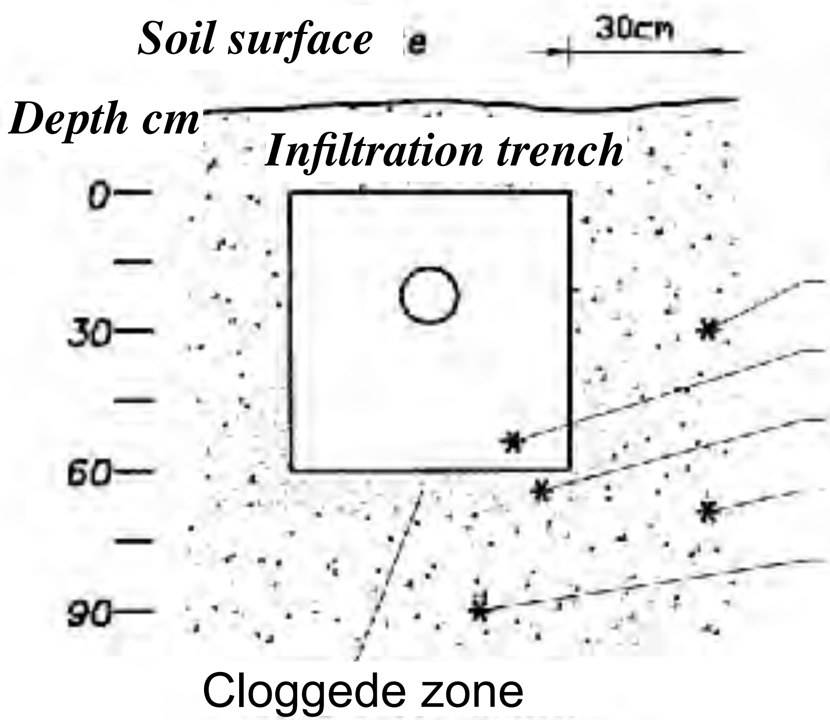


Removal of indicator bacteria ?



	Fecal coliforms 100/100ml
1988	0
1991	2
1992	2
2014	18

Infiltration systems bacteria removal



Bacteria/100ml or 100g of soil

E coli	Total coli	Total bacteria $x10^7$
< 200	< 600	< 0,6
1,900,000	5,700,000	3,0
4,000,000	23,000,000	4,400
17,000	23,000	6,7
< 200	< 600	3,7

(McCoy and Ziebell 1975)

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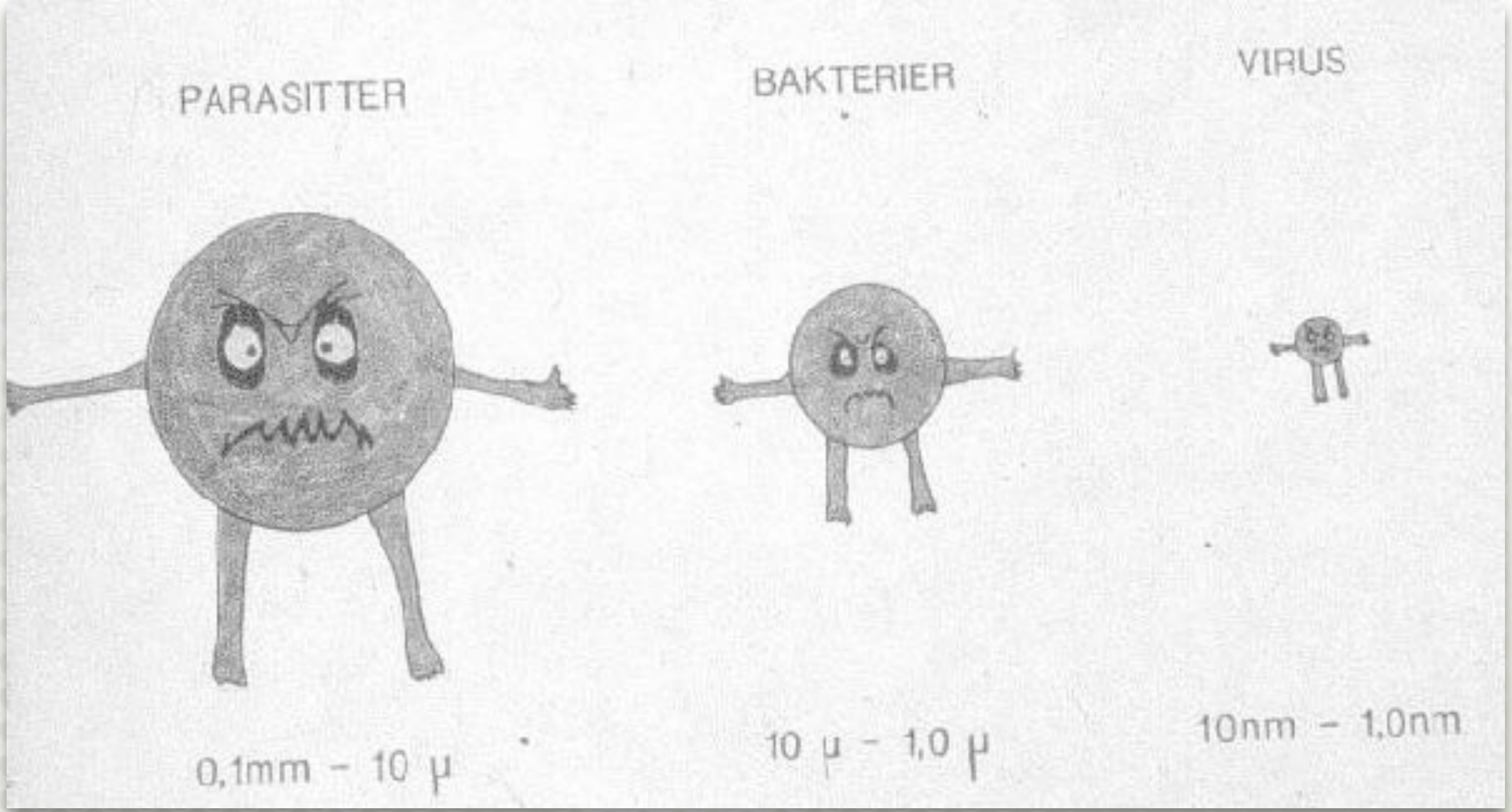
The fate of microorganisms in soil



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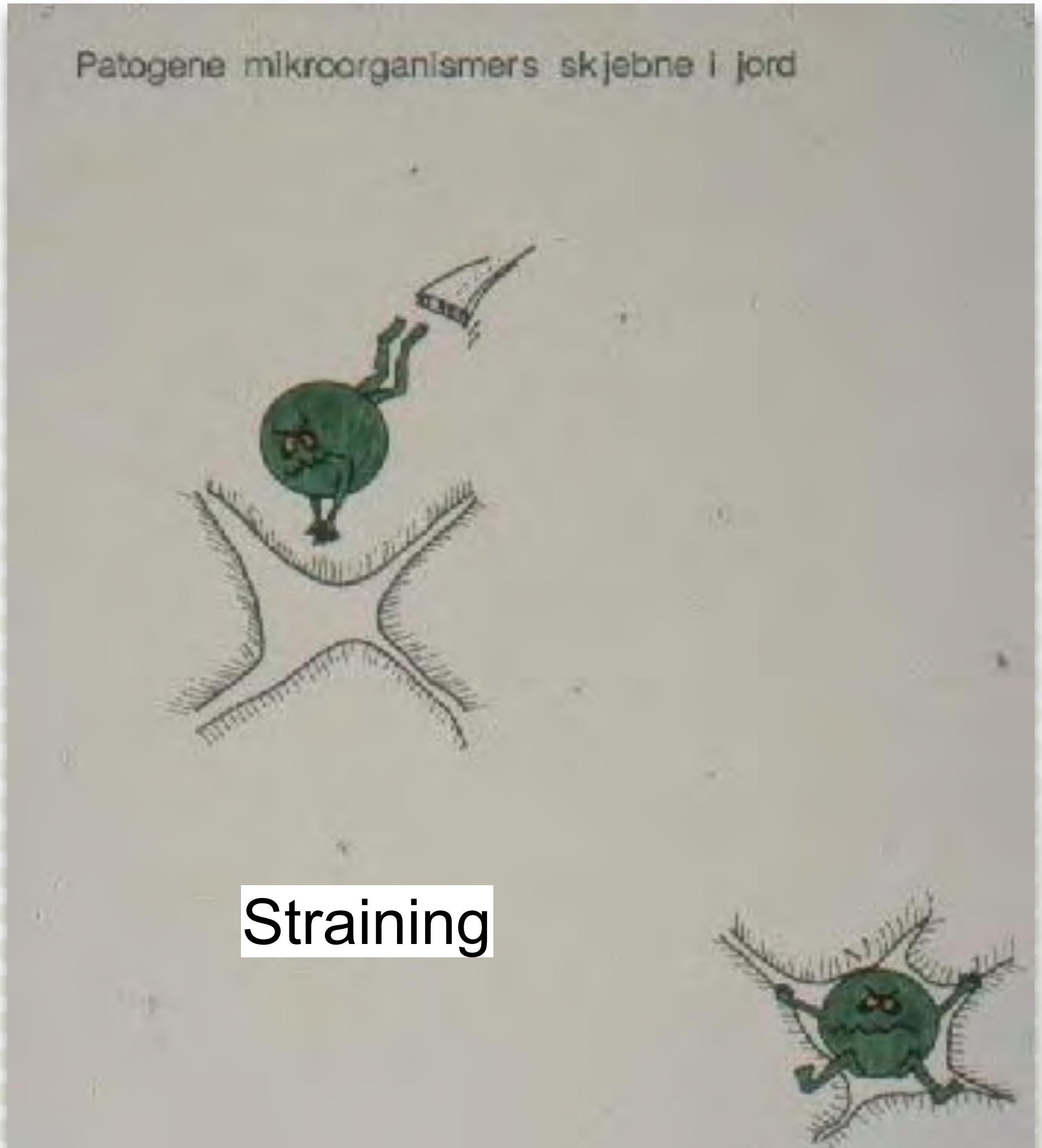
The fate of microorganisms in soil



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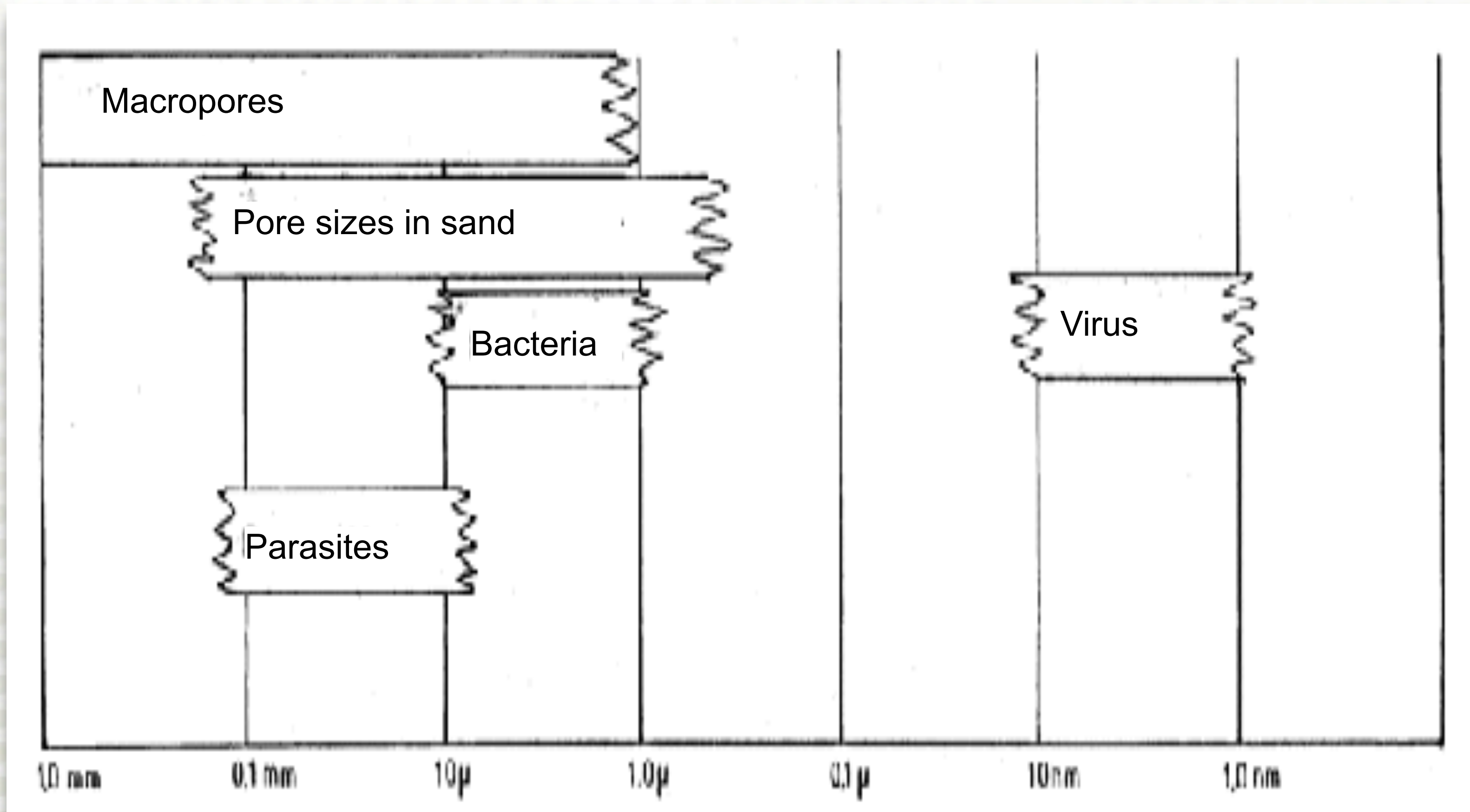
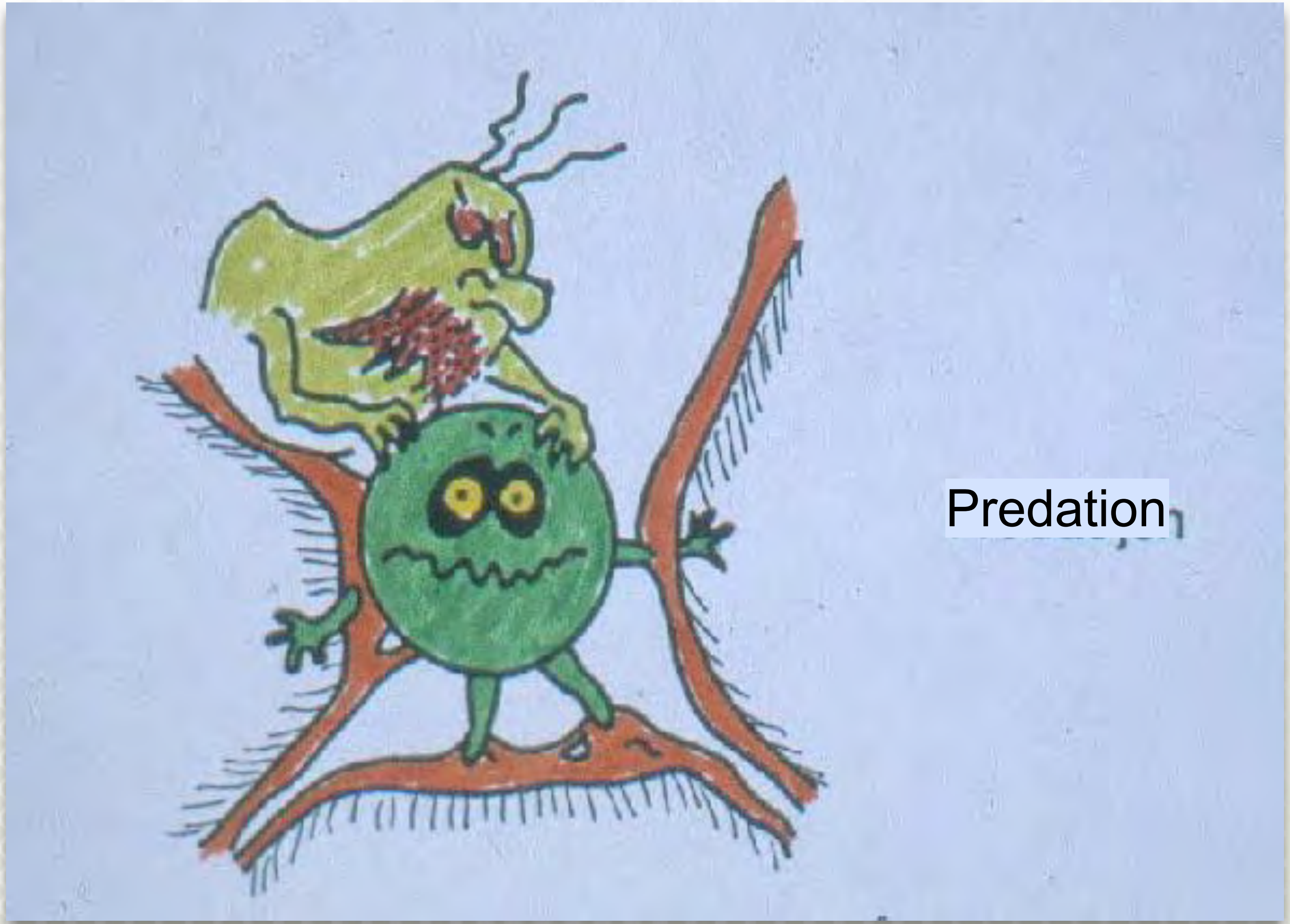
Size of soil pores vs. size of microorganisms



(Edworthy 1979 in Englund 1980)

The fate of microorganisms in soil



Predation

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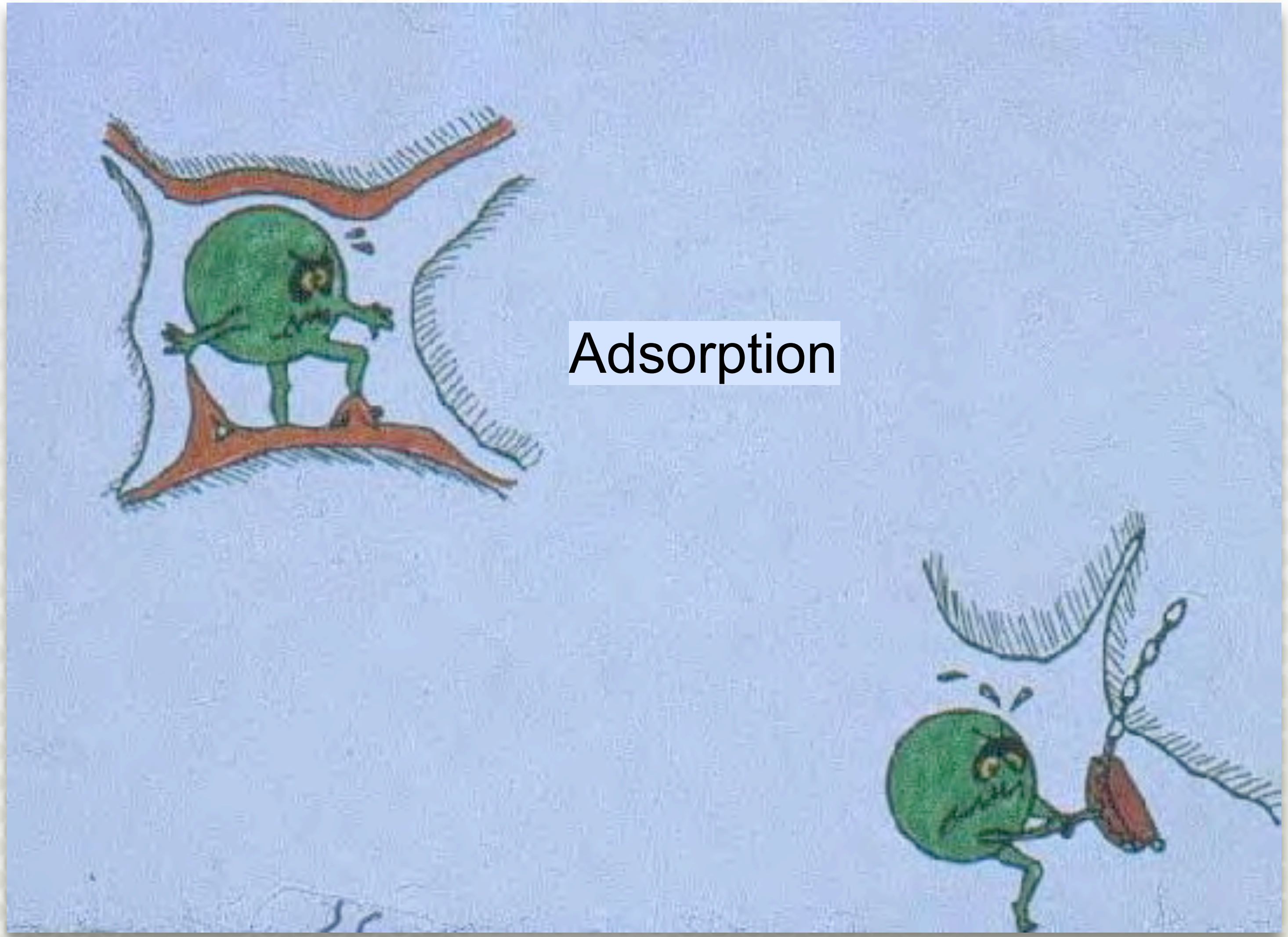
The fate of microorganisms in soil



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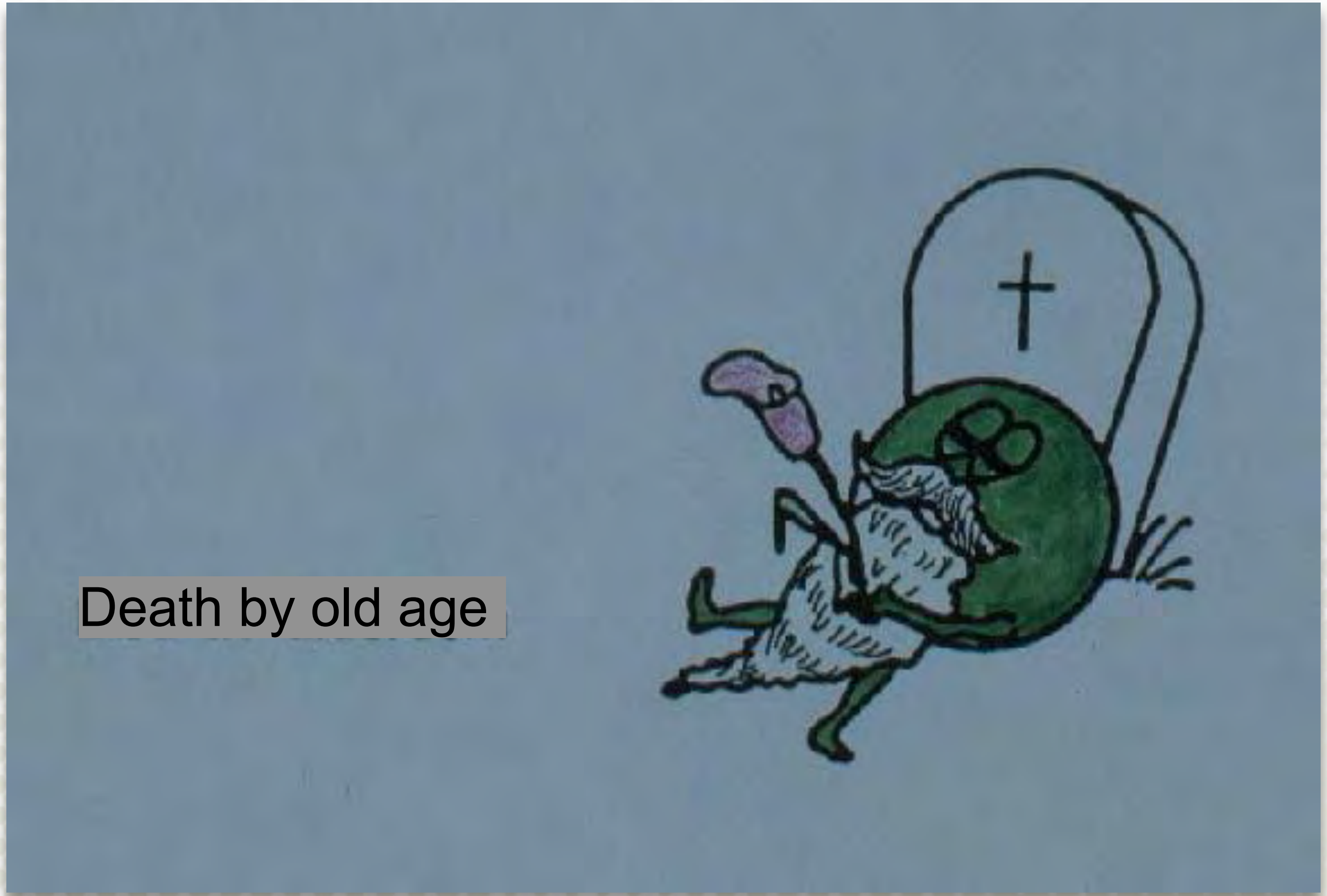
The fate of microorganisms in soil



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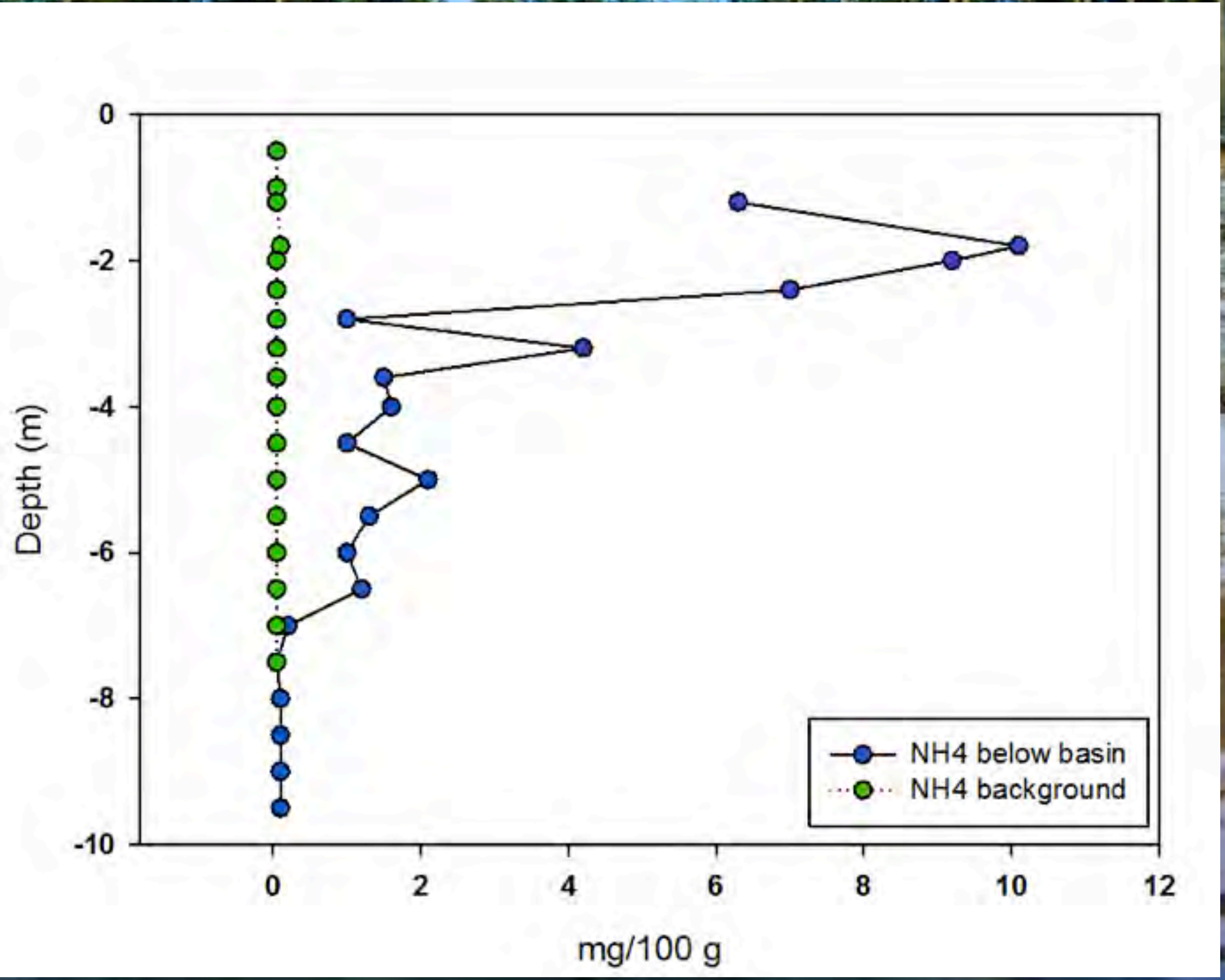
Removal mechanisms in natural systems

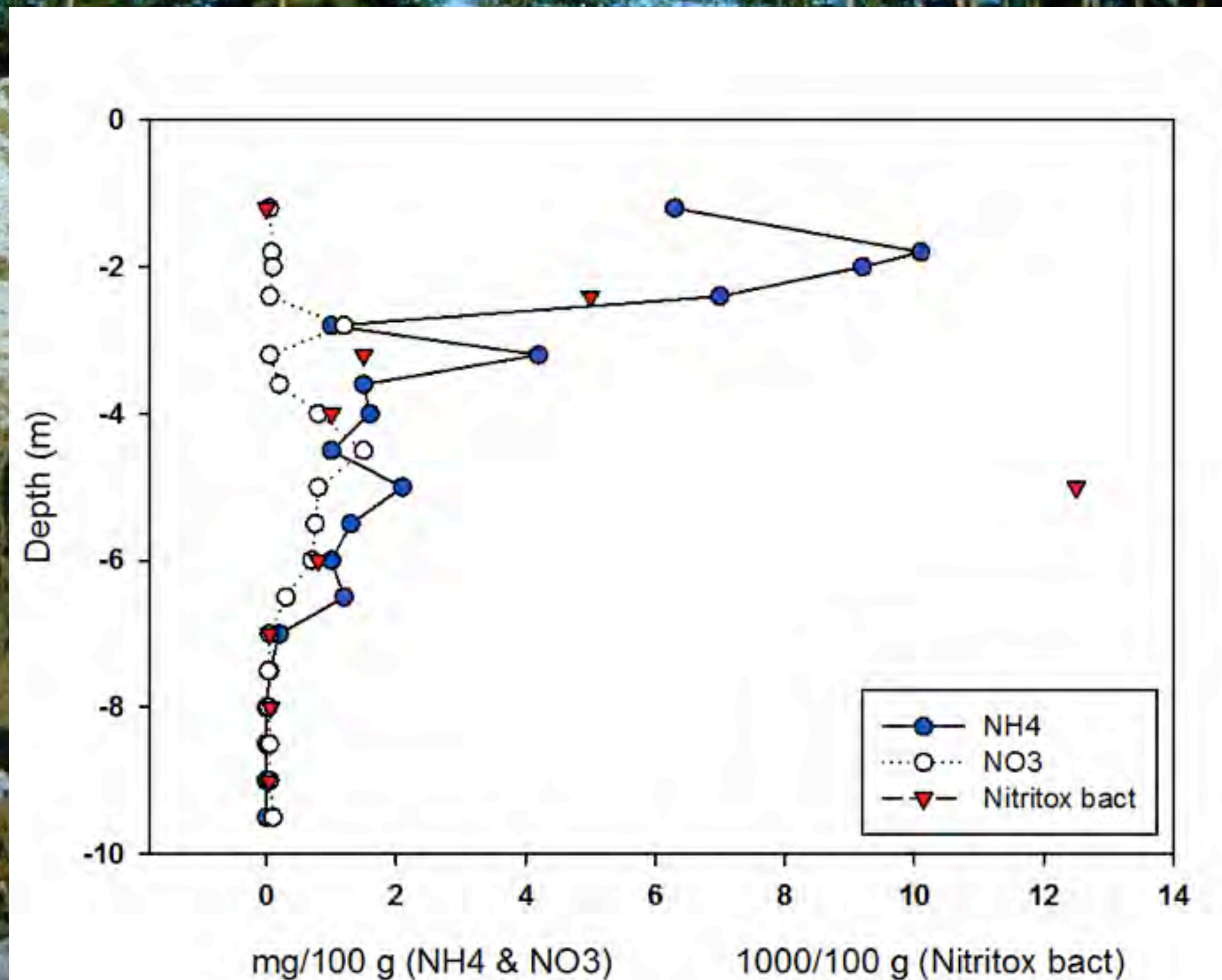
- Removal of organic matter
- Removal of phosphorus
- Removal of microorganisms
- **Removal of nitrogen**

Total nitrogen removal average > 60%

Total nitrogen removal 35 - 85%



Total nitrogen removal 35 - 85%



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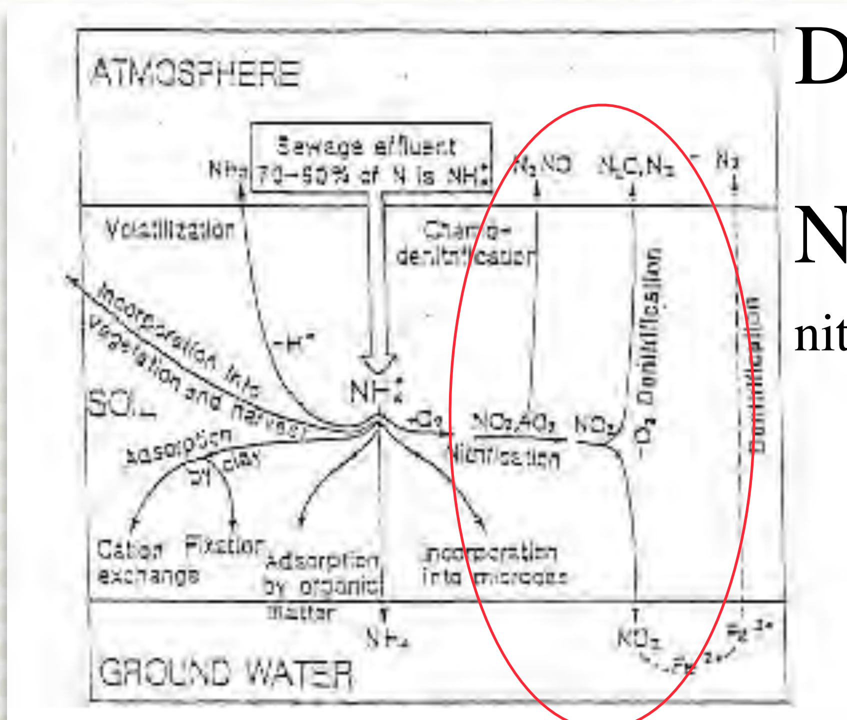
Nitrogen transformations in soils



Denitrification

NO_3 --> N_2O --> N_2

nitrate nitrous oxide nitrogen gas

Prerequisites biological denitrification:

1. Anerobic or anoxic conditions
2. Carbon source

Setermoen rapid infiltration plant
Nitrogen removal

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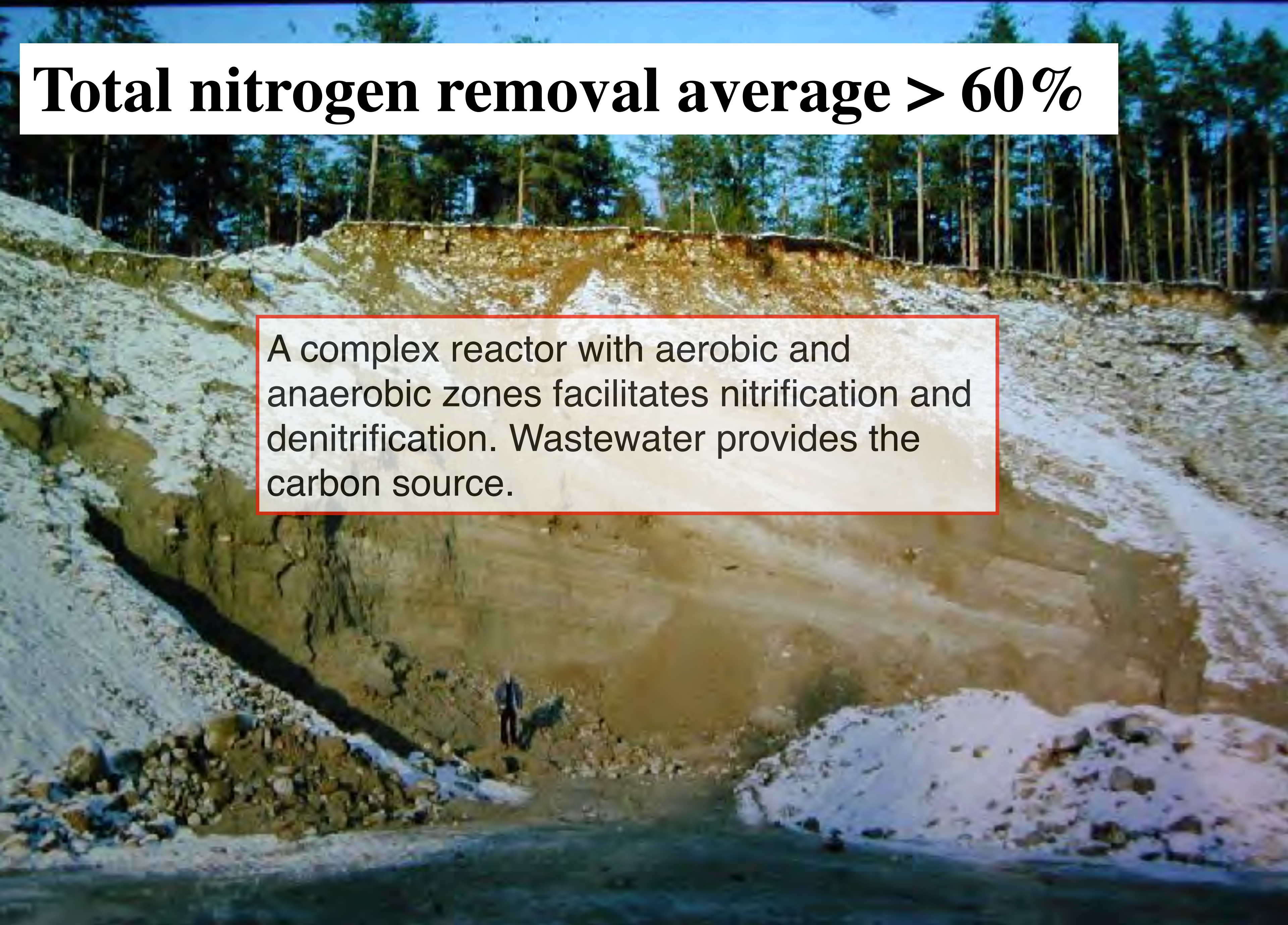
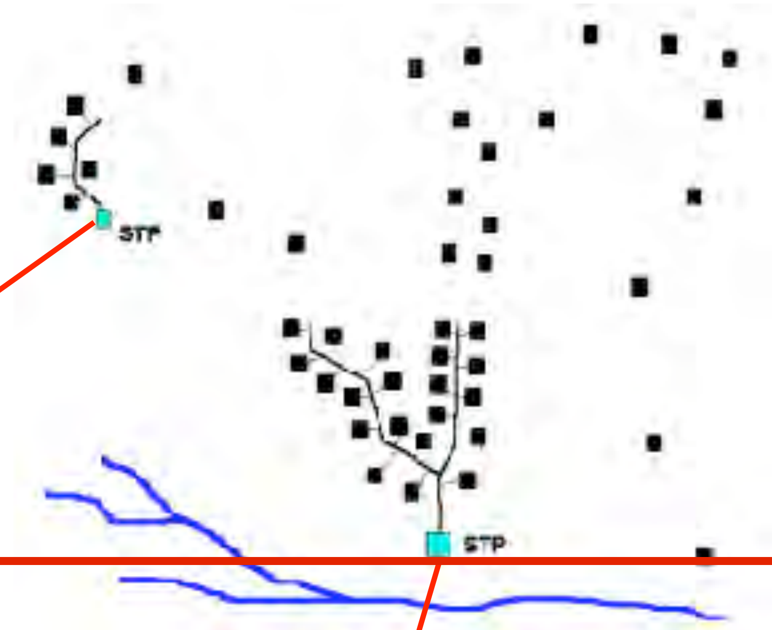
Total nitrogen removal average > 60%



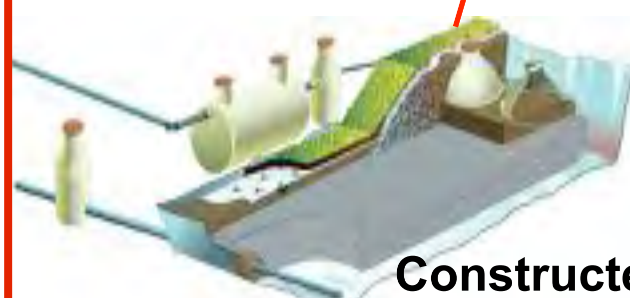
A complex reactor with aerobic and anaerobic zones facilitates nitrification and denitrification. Wastewater provides the carbon source.

Natural systems for wastewater treatment

Ponds



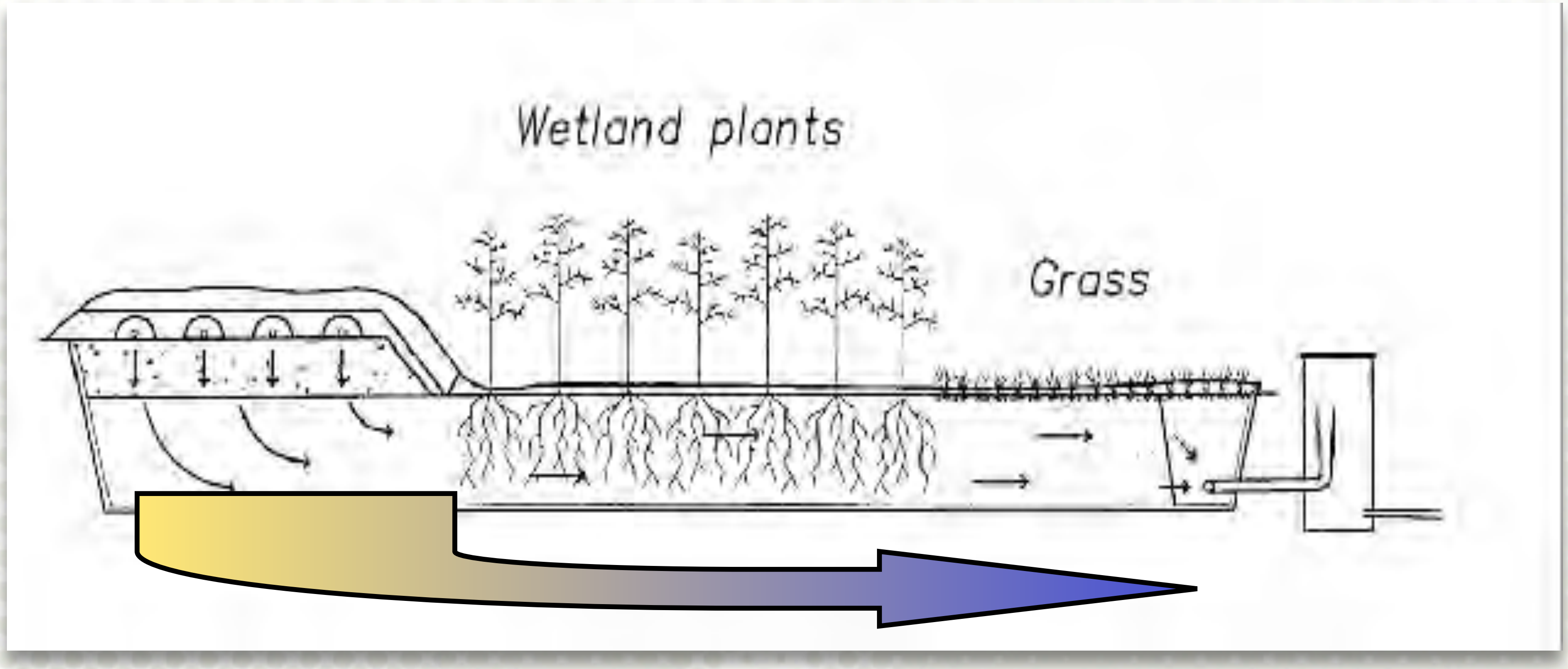
Infiltration



Constructed wetlands

Photo: T. Mæhlum

Constructed wetland
flow direction/purification



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Constructed wetland

treating wastewater from 2 homes

maxit
filtralite

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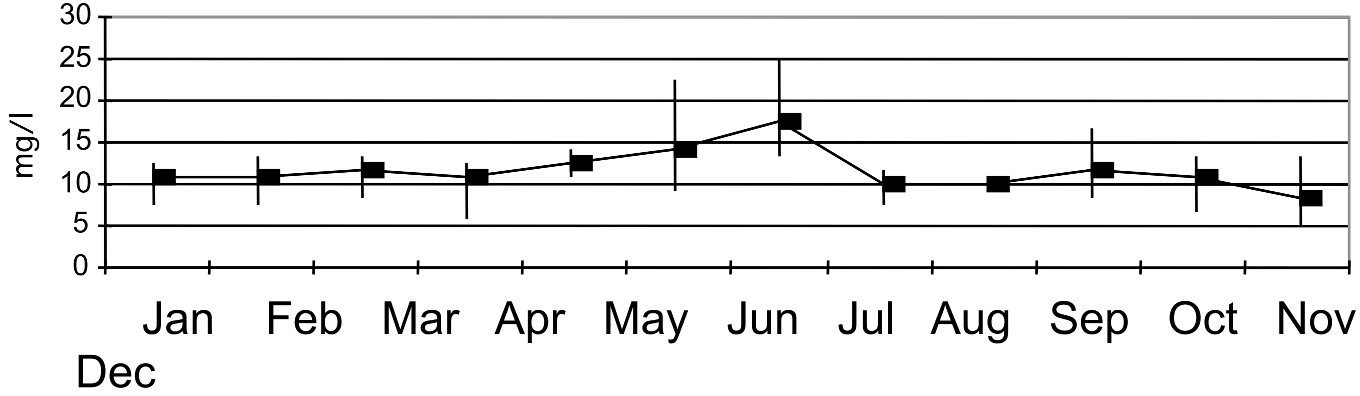
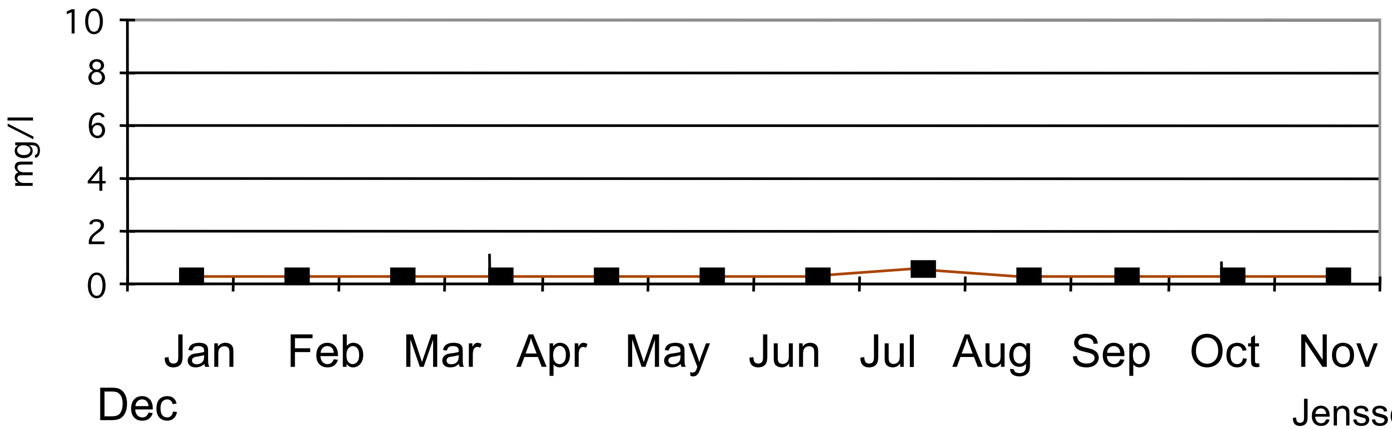
Total-P monthly average and variation 1991 - 2001

Haugstein multistage constructed wetland



Influent (STE)



Effluent

Jenssen et al. (2005)

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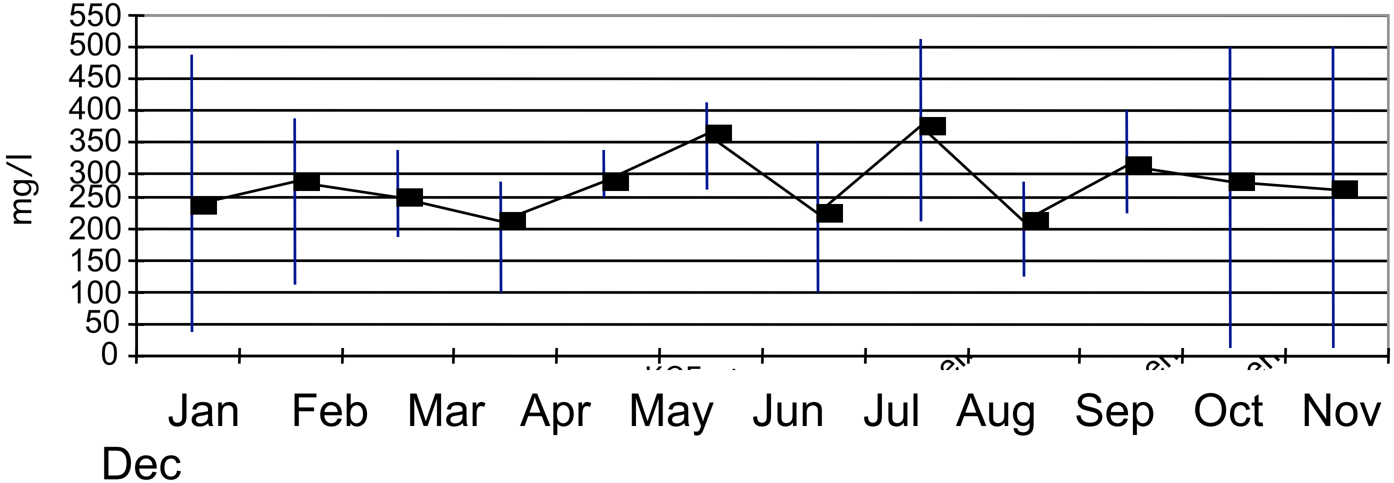
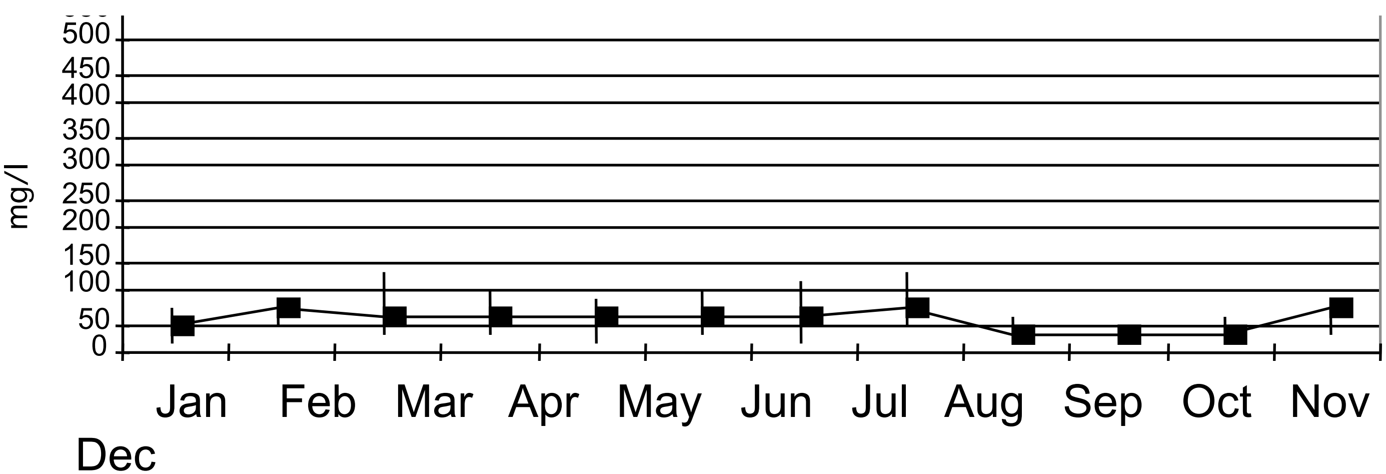
COD monthly average and variation
1991 - 2001
Haugstein multistage constructed wetland



Influent (STE)



Effluent

Jenssen et al. (2005)

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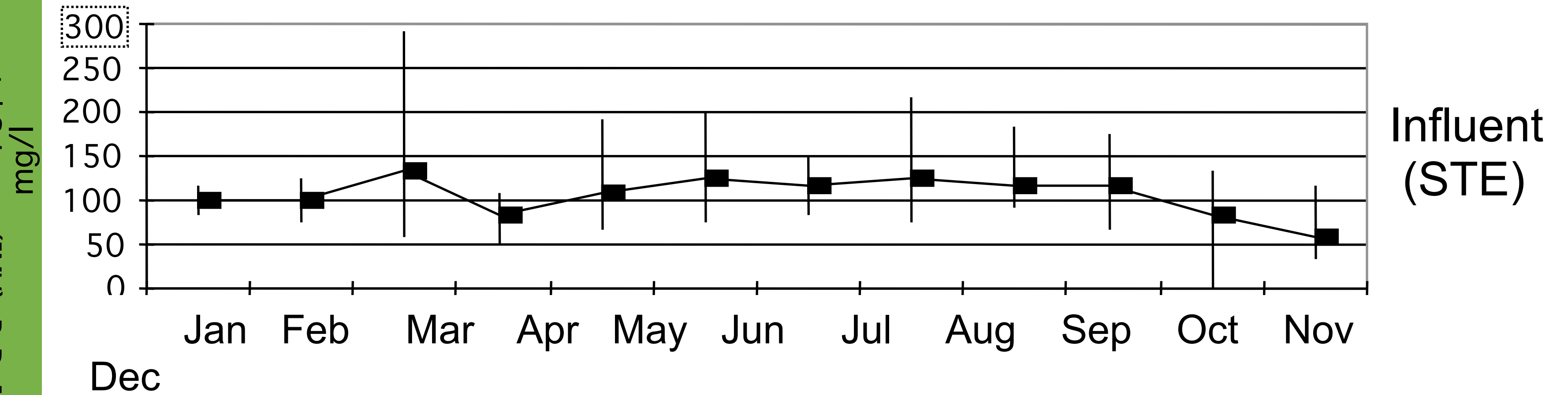
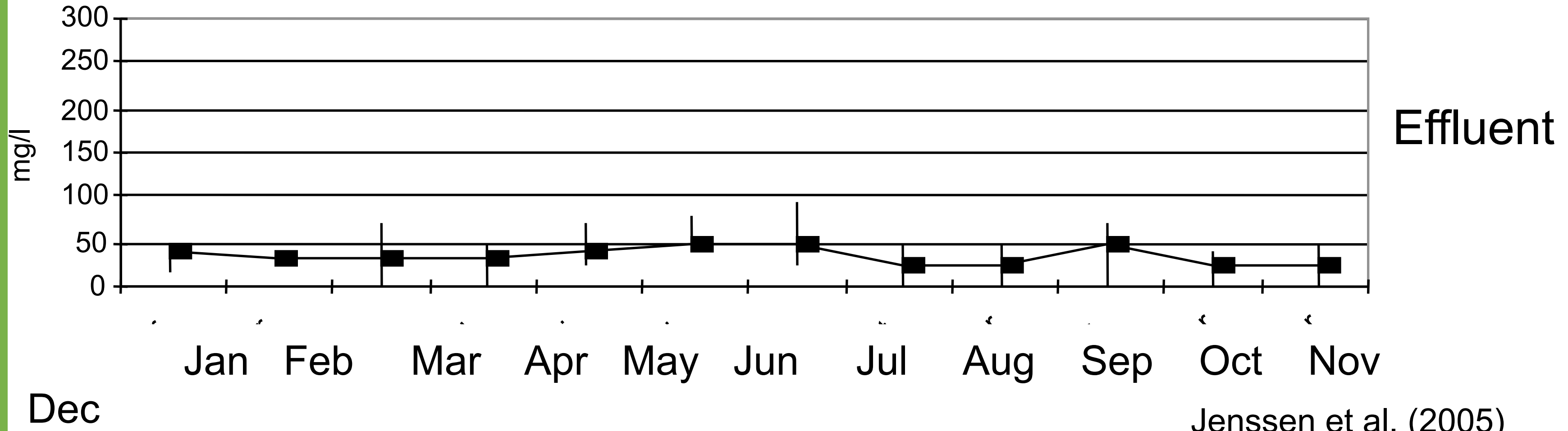
Total-N monthly average and variation 1991 - 2001

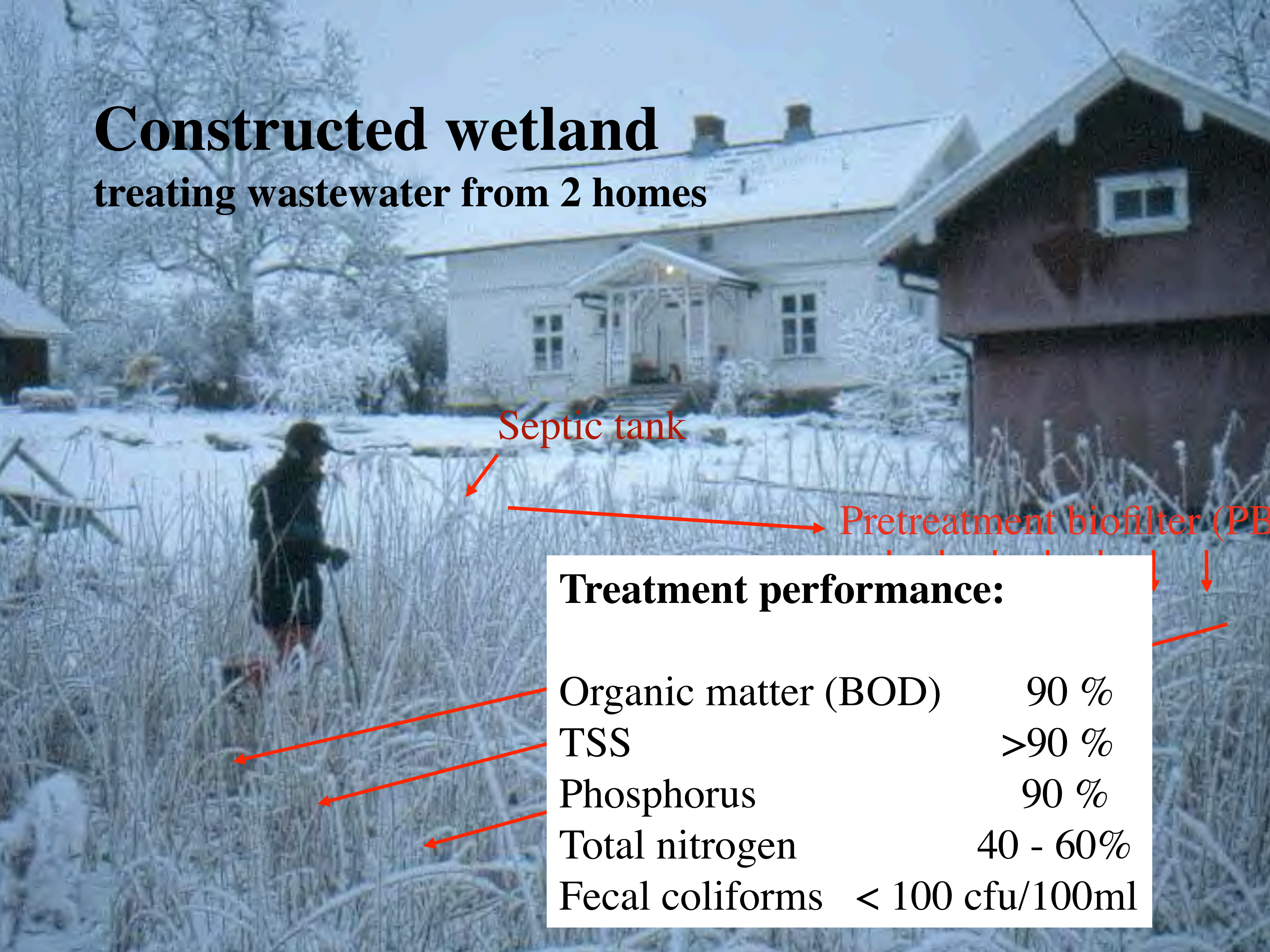
Haugstein multistage constructed wetland





Jenssen et al. (2005)

Constructed wetland
treating wastewater from 2 homes

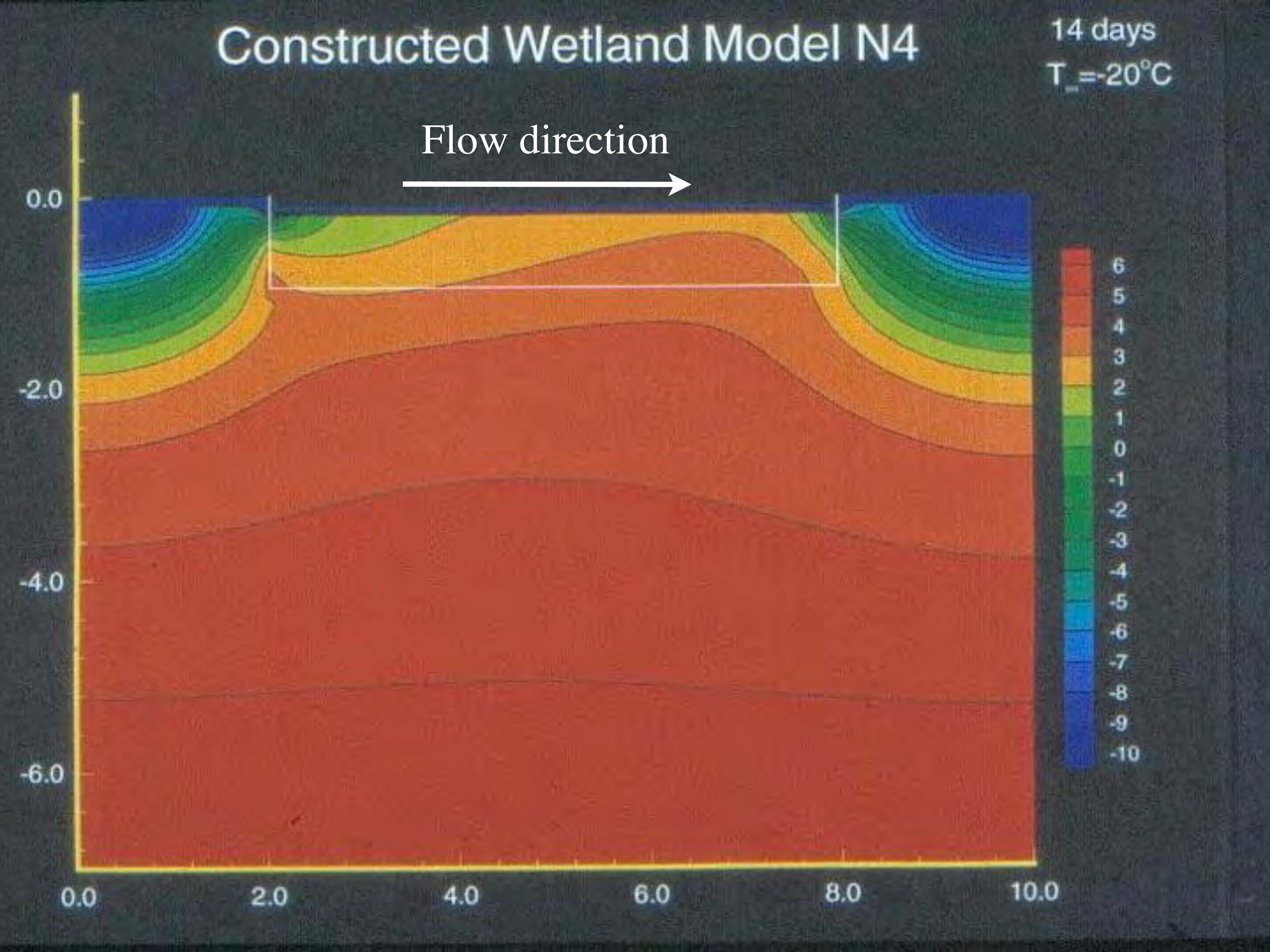


Treatment performance:

Organic matter (BOD)	90 %
TSS	>90 %
Phosphorus	90 %
Total nitrogen	40 - 60%
Fecal coliforms	< 100 cfu/100ml

Constructed wetland - Norway

Domestic WW: 7 - 9 m3/person
Greywater: 2- 3 m3/person


Constructed Wetland Model N4
14 days
T=-20°C
Flow direction
0.0
-2.0
-4.0
-6.0
0.0
2.0
4.0
6.0
8.0
10.0
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10

Thermal properties of various insulation materials

Table 2. Thermal properties[a)] of various materials and insulation equivalent to the insulation provided by 10 cm of XPS.

Material	Therm. cond (W/mK)	Density (kg/m^3)	Eq. thickness to 10 cm XPS (cm)
XPS	0,030*	28-50*	10
Air	0,025		8,3
Water	0,57	1000	190
Ice	2,2	920	733
Snow	0,049 - 1,28	100-800	16 - 426
Peat dry	0,06	100-300	20
Peat fc [b)]	0,29		97
Peat sat [c)]	0,5-1,25	900-1200	167 - 415
Straw dry	0,09		30
Sand Haugstein sat [c)]	1,77#	1710 dry	590
Sand Haugstein fc [b)]	1,78#		590
Leca (0- 4 mm) sat [c)]	0,56#	350 dry	186
Leca (0- 4 mm) fc [b)]	0,07#		23
Leca (2-6 mm) dry	0,12 *	489 *	40
Leca (2-6 mm) wet [d)]	0,18 *	539 *	60

(Jenssen et al. 1996)

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Size for domestic
greywater

Reuse of P-saturated filter material

The P fertilizer value of P-saturated filter material (FiltraliteP) is comparable to mineral fertilizer.
(Jenssen et al. 2010)

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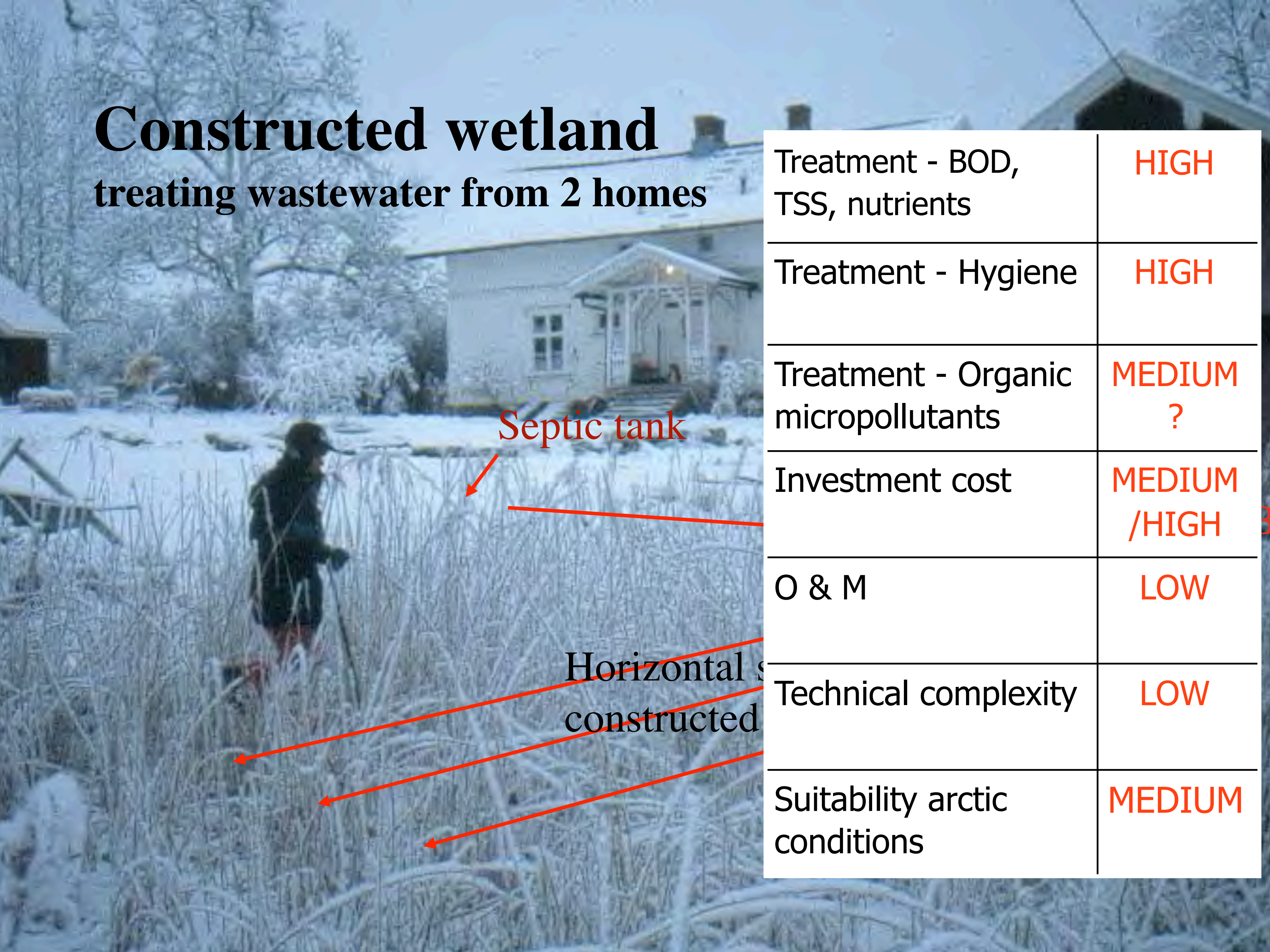
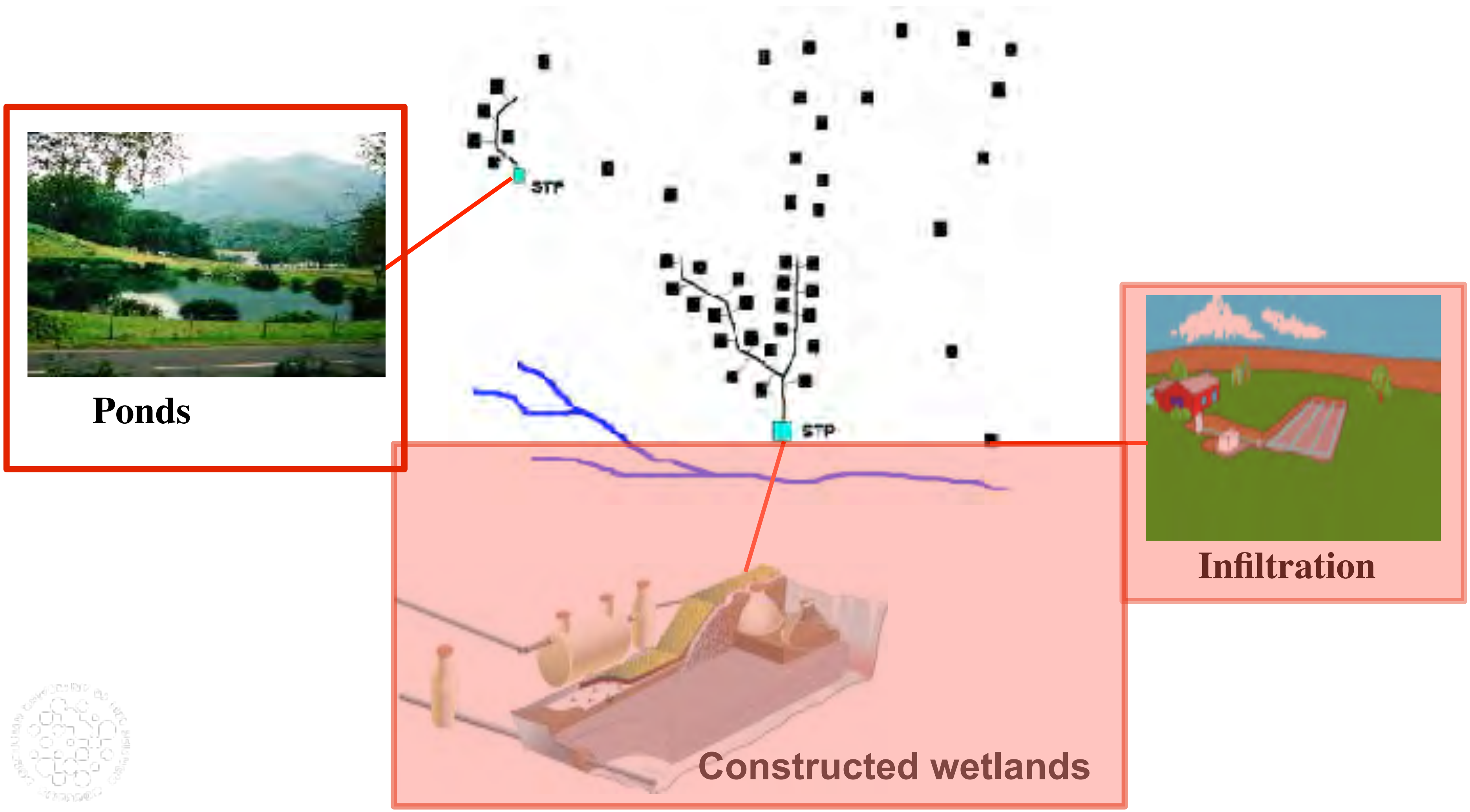
Constructed wetland

treating wastewater from 2 homes



Treatment - BOD, TSS, nutrients	HIGH
Treatment - Hygiene	HIGH
Treatment - Organic micropollutants	MEDIUM ?
Investment cost	MEDIUM /HIGH
O & M	LOW
Technical complexity	LOW
Suitability arctic conditions	MEDIUM

Natural systems for wastewater treatment



Sewage lagoons/ponds

Photo: F. Reinhardt

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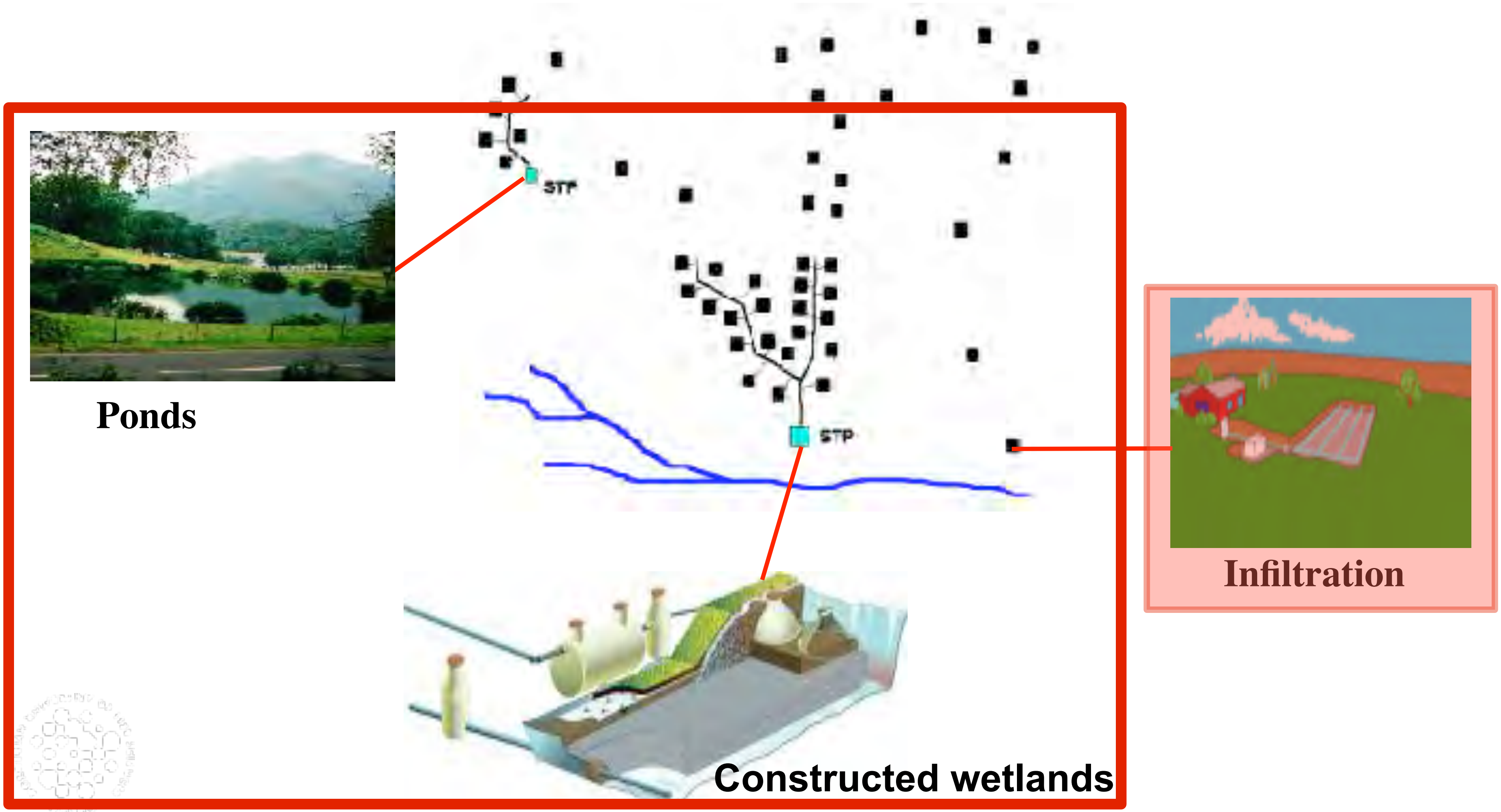
Sewage lagoons/ponds

Photo: F. Reinhardt

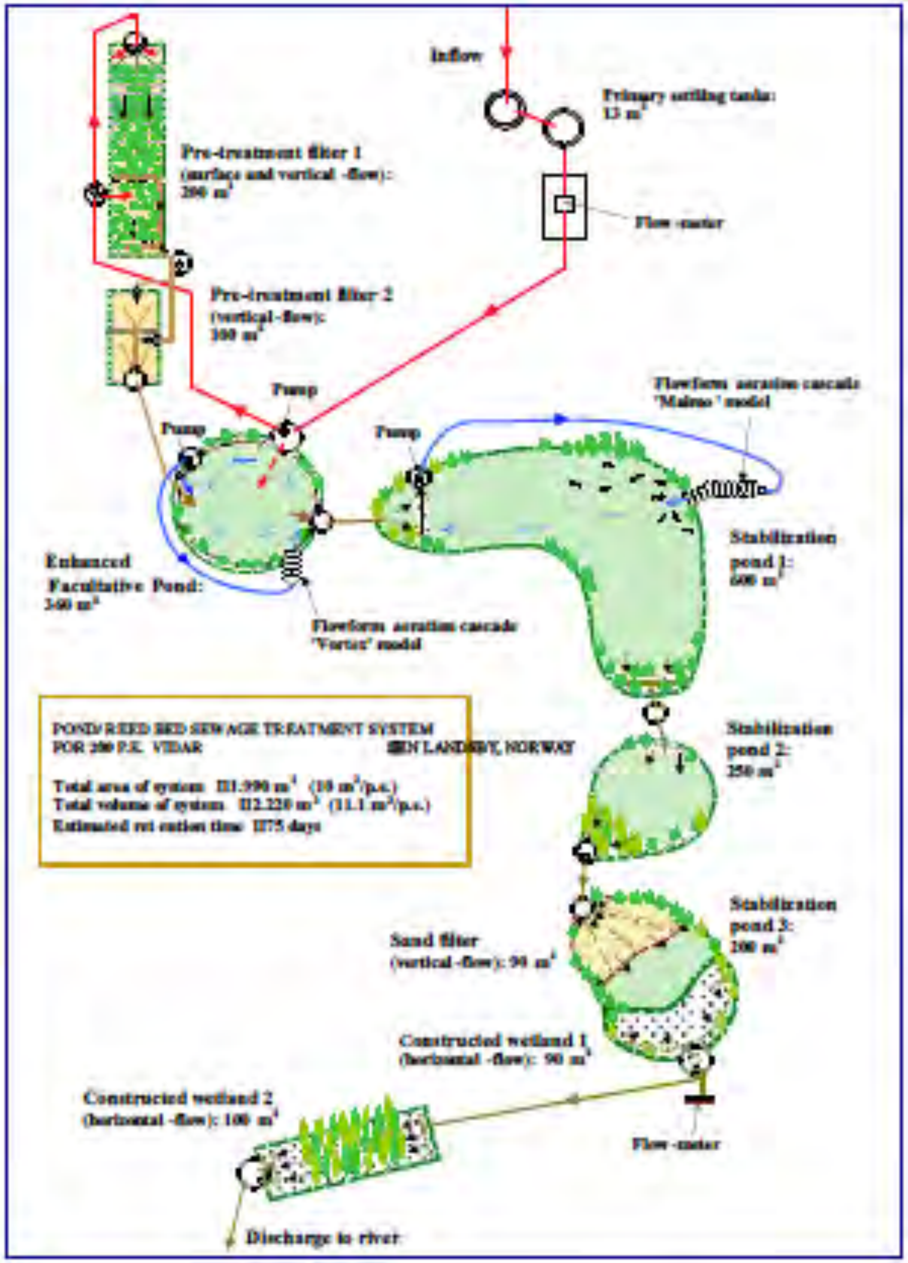
Treatment - BOD, TSS, nutrients	LOW
Treatment - Hygiene	LOW
Treatment - Organic micropollutants	LOW
Investment cost	LOW/ HIGH
O & M	LOW
Technical complexity	LOW
Suitability arctic conditions	?

Natural systems for wastewater treatment




A pond/
wetland
system in
Norway

Pond/wetland system - Norway



Effluent load:
- * 200 people
- * a dairy
- * a bakery

System age:
- * 18 years

Footprint:
- * 12m²/pe

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The pond/wetland system at Vidaråsen Camphill

Pretreatment wetlands

Constructed wetlands

Ponds

Enhanced facultative pond

Treatment results 1996 - 2015

	TOC mg/l	P mg/l	Tot-N mg/l	NH_4 mg/l	TSS mg/l	Fecal coli /100ml
Inlet	76	6.2	47	46		
Out	**5**	**0.24**	**4**	**0.11**	**< 5**	**<100**
Remo-val (%)	**93**	**96**	**91**	**99.8**		

References: Browne and Jenssen (2004), Pandey (2016)

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Treatment re

Norway´s best performing treatment system?

	TOC mg/l	P mg/l	Tot-N mg/l	NH_4 mg/l	TSS mg/l	Fecal coli /100ml
Inlet	76	6.2	47	46		
Out	**5**	**0.24**	**4**	**0.11**	**< 5**	**<100**
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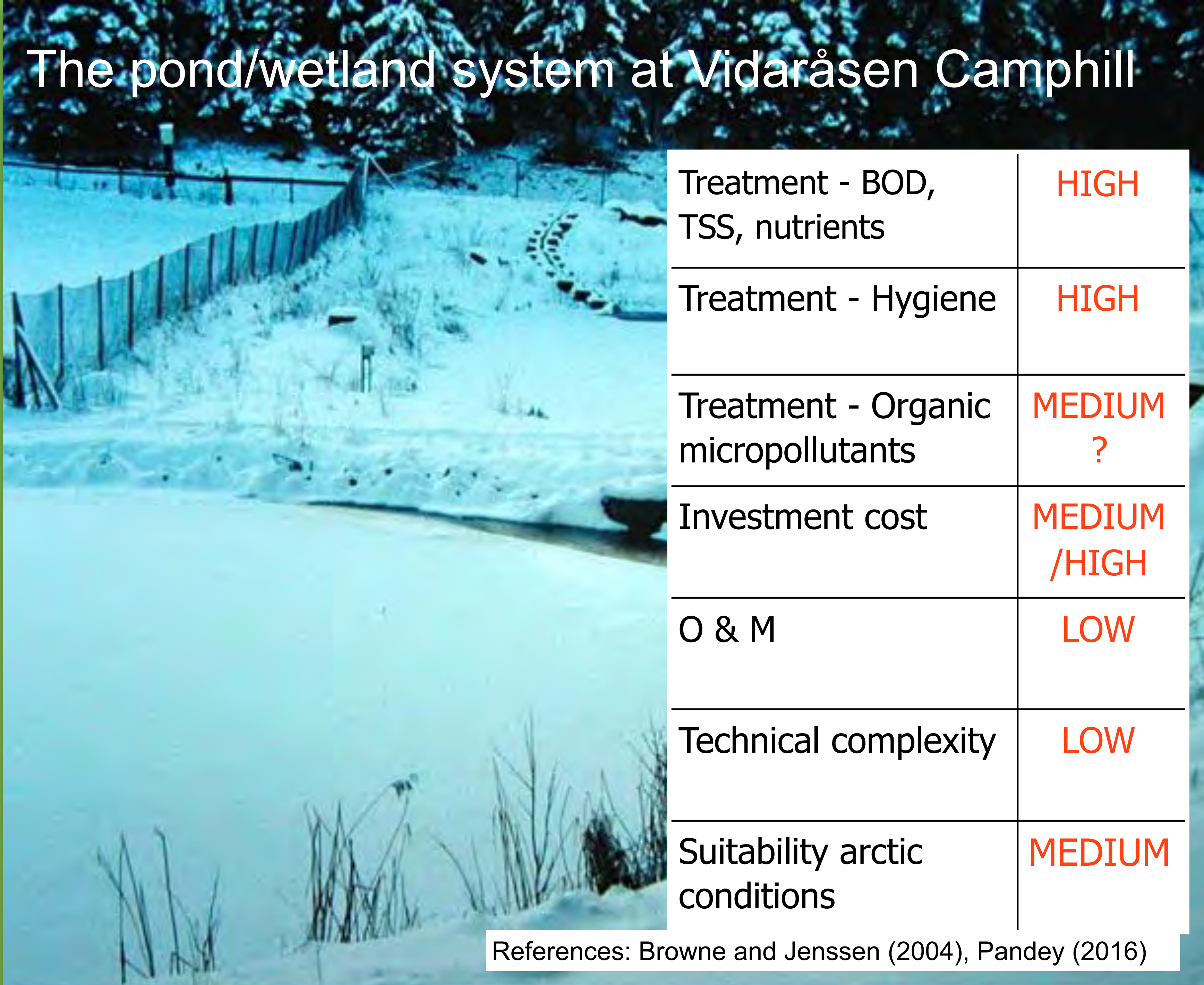
References: Browne and Jenssen (2004), Pandey (2016)

The pond/wetland system at Vidaråsen Camphill



Treatment - BOD, TSS, nutrients	HIGH
Treatment - Hygiene	HIGH
Treatment - Organic micropollutants	MEDIUM ?
Investment cost	MEDIUM /HIGH
O & M	LOW
Technical complexity	LOW
Suitability arctic conditions	MEDIUM

References: Browne and Jenssen (2004), Pandey (2016)

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Conclusions

- Natural systems (infiltration, wetlands, ponds) have treatment performance equal to conventional (mechanical/technical) systems
- The phosphorus removal capacity depends on the surface chemistry of the soil/porous media particles
- Natural systems have a low O&M cost and is often cheaper to build than conventional systems
- Natural systems are robust, have a stable treatment performance and and tolerate large fluctuations in inflow

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Conclusions

- The Setermoen rapid infiltration plant has for over 25 years consistently removed more than 98% of the total phosphorus and more than 85% of the COD.
- The phosphorus removal capacity is predicted to last 12 years below each basin and the treatment results seems to confirm the prediction.
- Annual removal of total nitrogen has varied from 35 to above 80%. The nitrogen removal seems to have dropped after the municipality introduced garbage grinders.
- The system has saved the municipality an estimated 45 million NOK over 25 years compared to investment and operation of a conventional mechanical/chemical treatment system.

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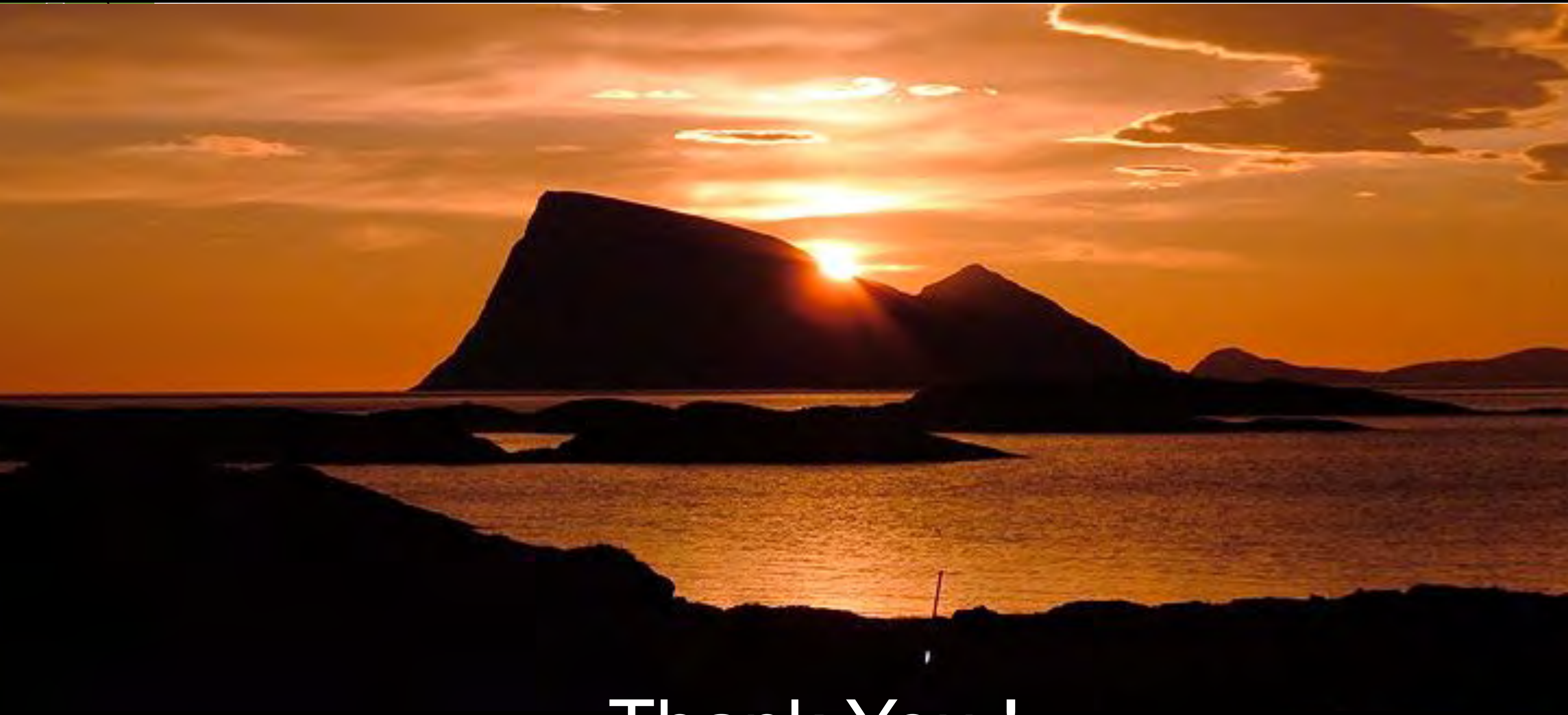

Thank You !

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