Reykjavik, May 8. 2015

Wastewater treatment options in pristine natural conditions

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Department Environmental sciences
Norwegian University of Life Sciences

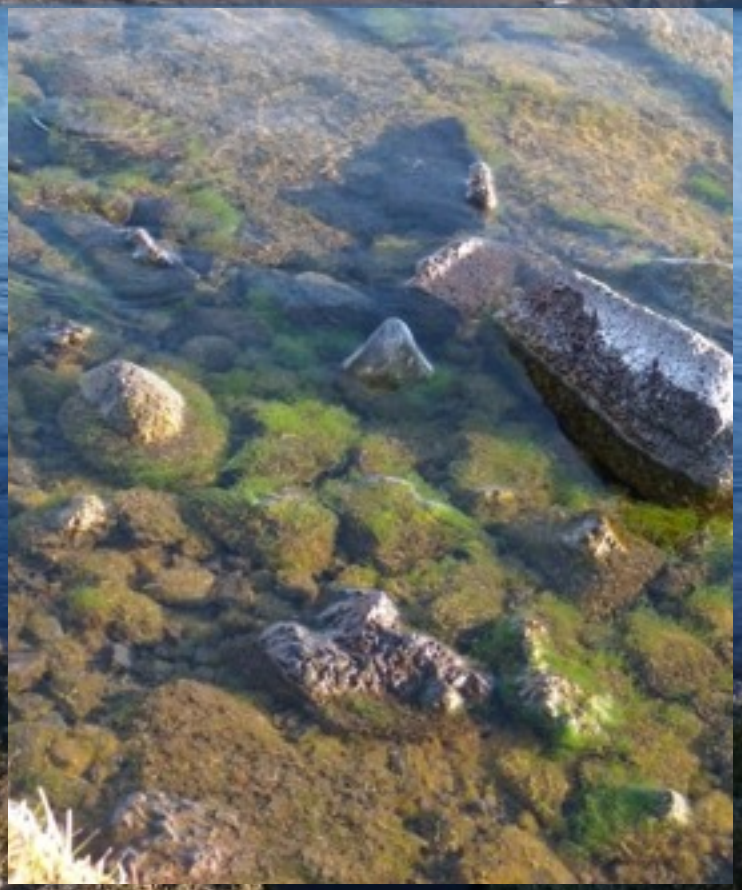
Presentation overview

Some aspects of limnology and resource recovery (brief)

Wastewater treatment options in pristine areas

Þingvallavatn

Þingvallavatn



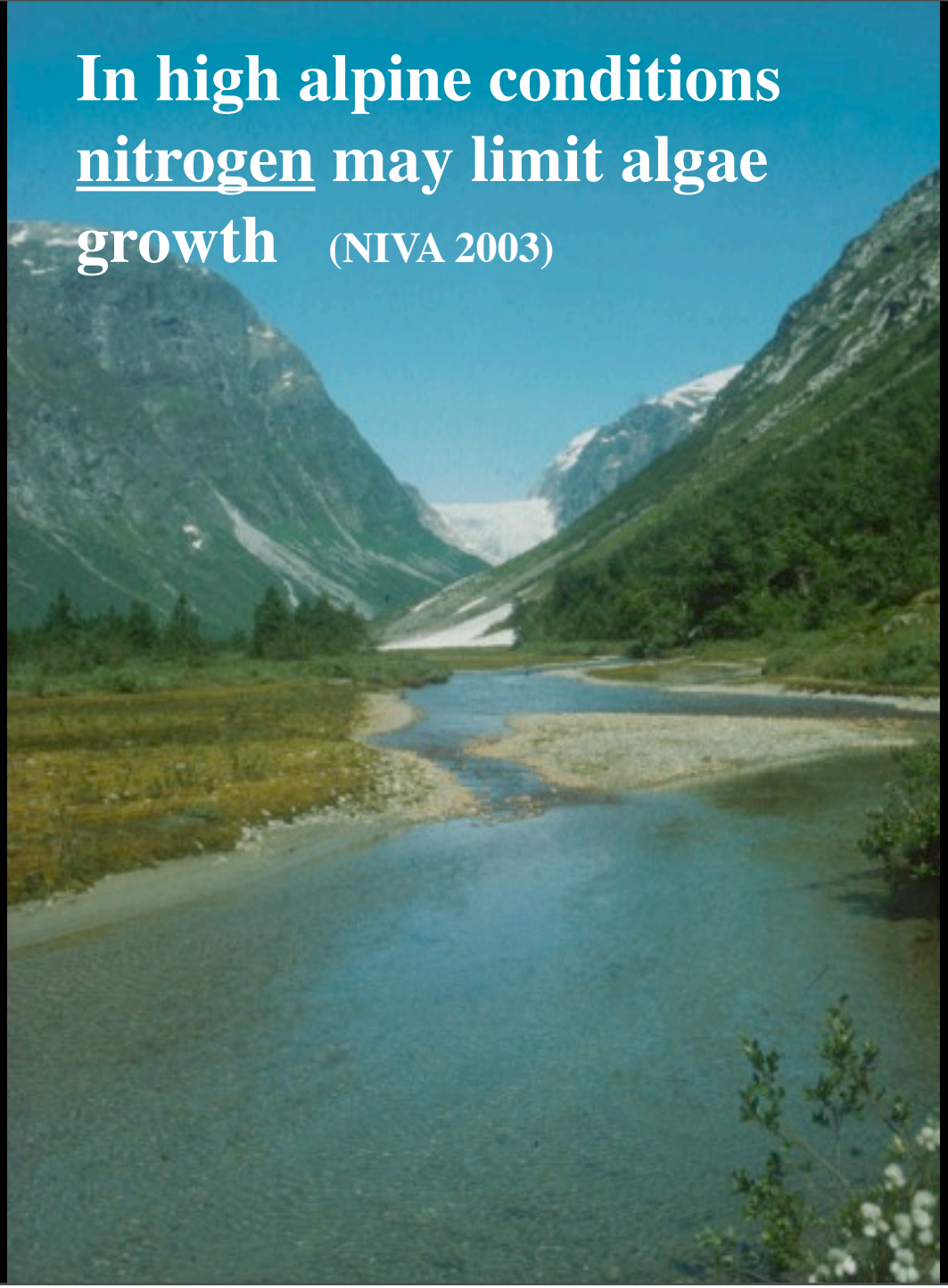
Þingvallavatn

Þingvallavatn
Tourist installations

Phosphorus is the major agent triggering eutrophication in freshwaters

Algae growth at 1300 m altitude in Norway

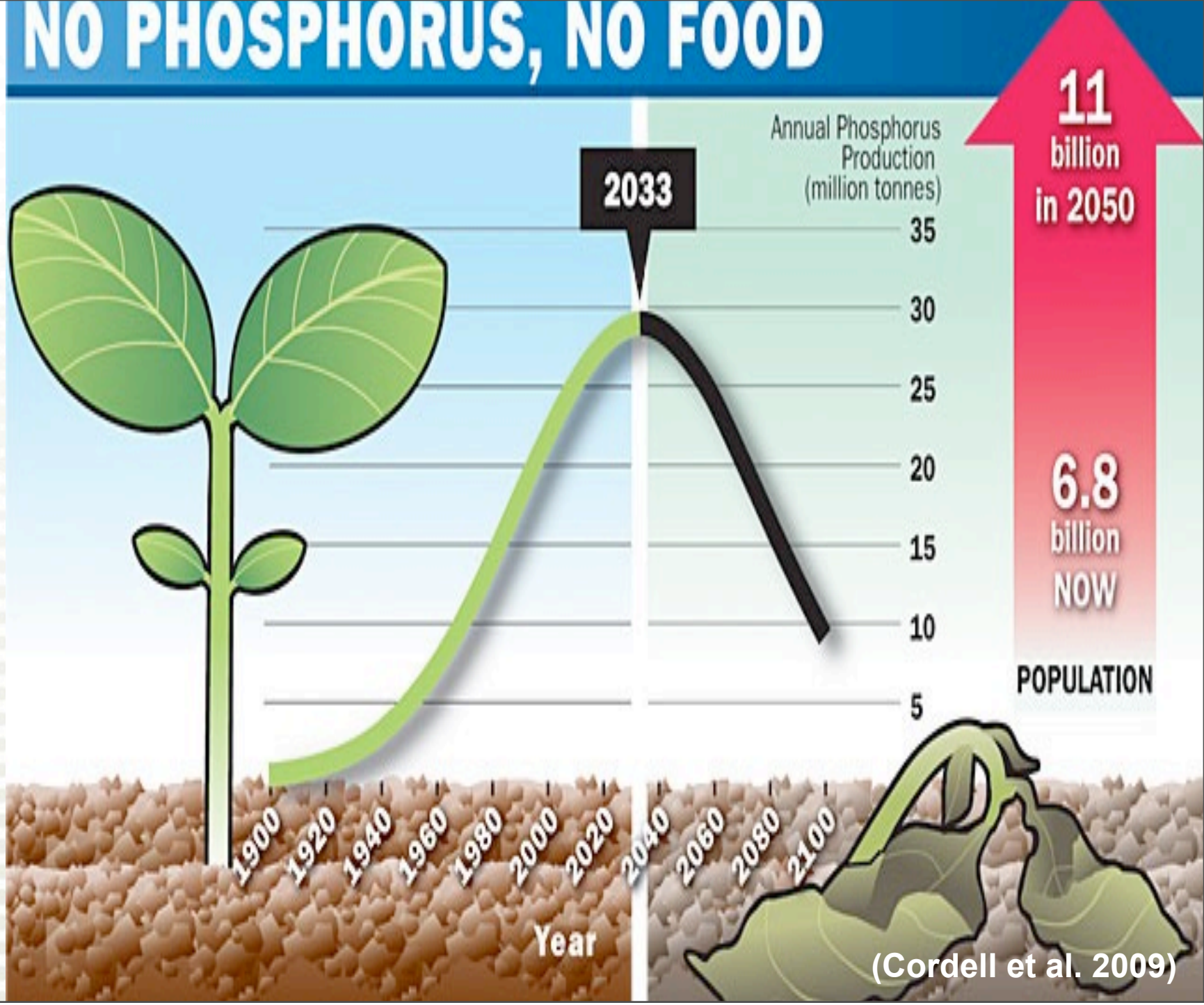
Algae growth at 1300 m altitude in Norway


In high alpine conditions
nitrogen may limit algae
growth (NIVA 2003)

Þingvallavatn

Eutrophication?

What are the major threats?
What are the mechanisms?


NO PHOSPHORUS, NO FOOD
Annual Phosphorus Production (million tonnes)
2033
35
30
25
20
15
10
5
11 billion in 2050
6.8 billion NOW
POPULATION
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100
Year
(Cordell et al. 2009)

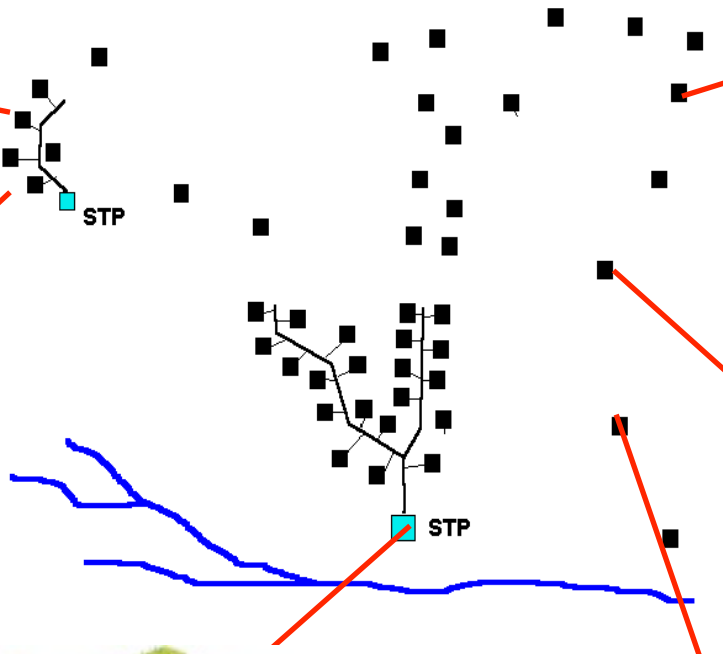
Presentation overview

Some aspects of limnology and resource recovery (brief)

Wastewater treatment options in pristine areas

Decentralized treatment systems

Systems with source separation

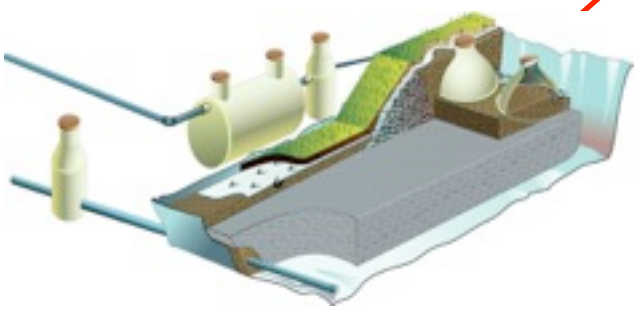


Package treatment plants

Septic tanks

Ponds

Biofilters

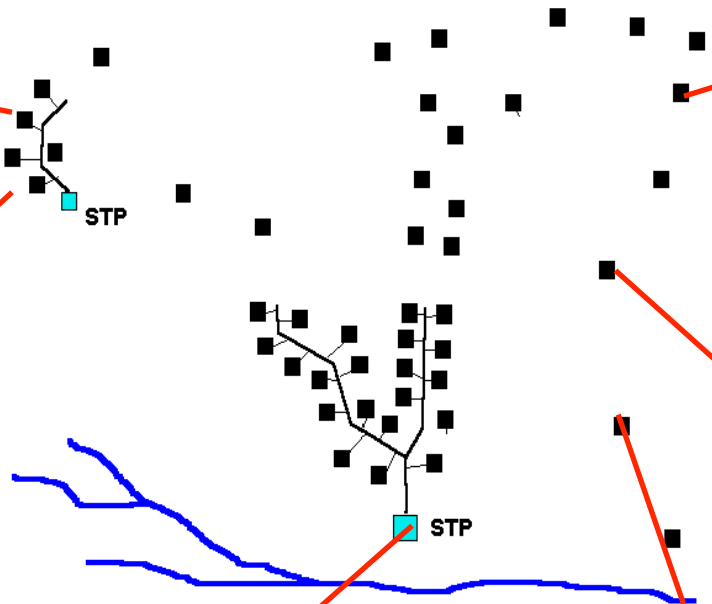


Constructed wetlands

Soil infiltration

Decentralized treatment systems

Systems with source separation



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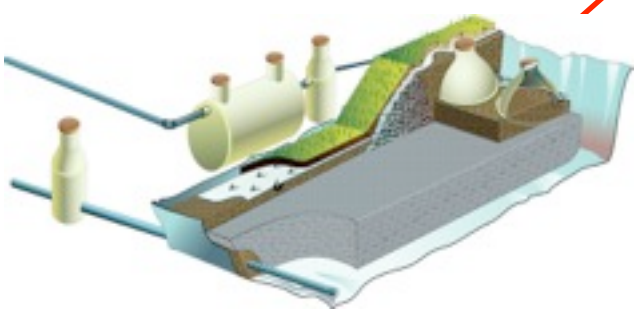


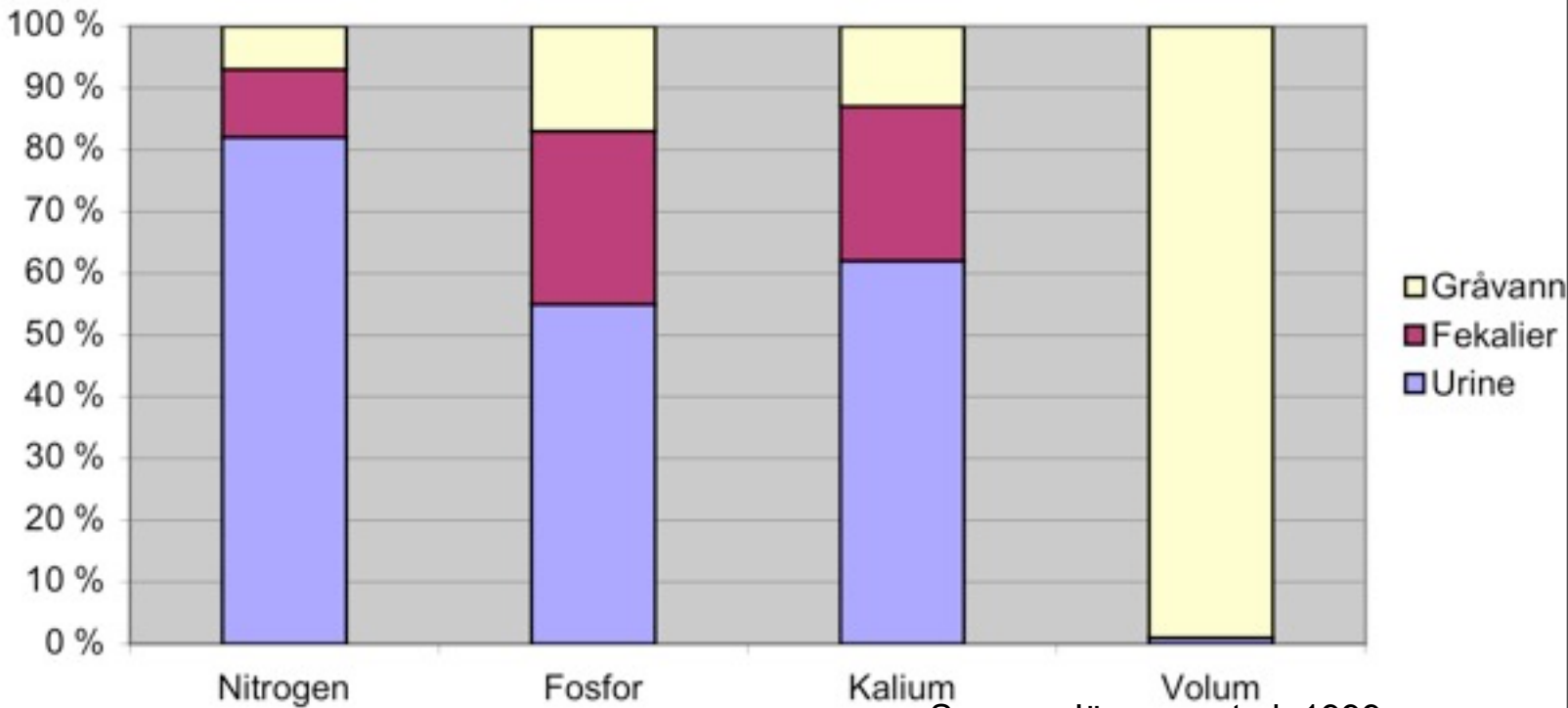
Constructed wetlands

Soil infiltration

Source separation of wastewater

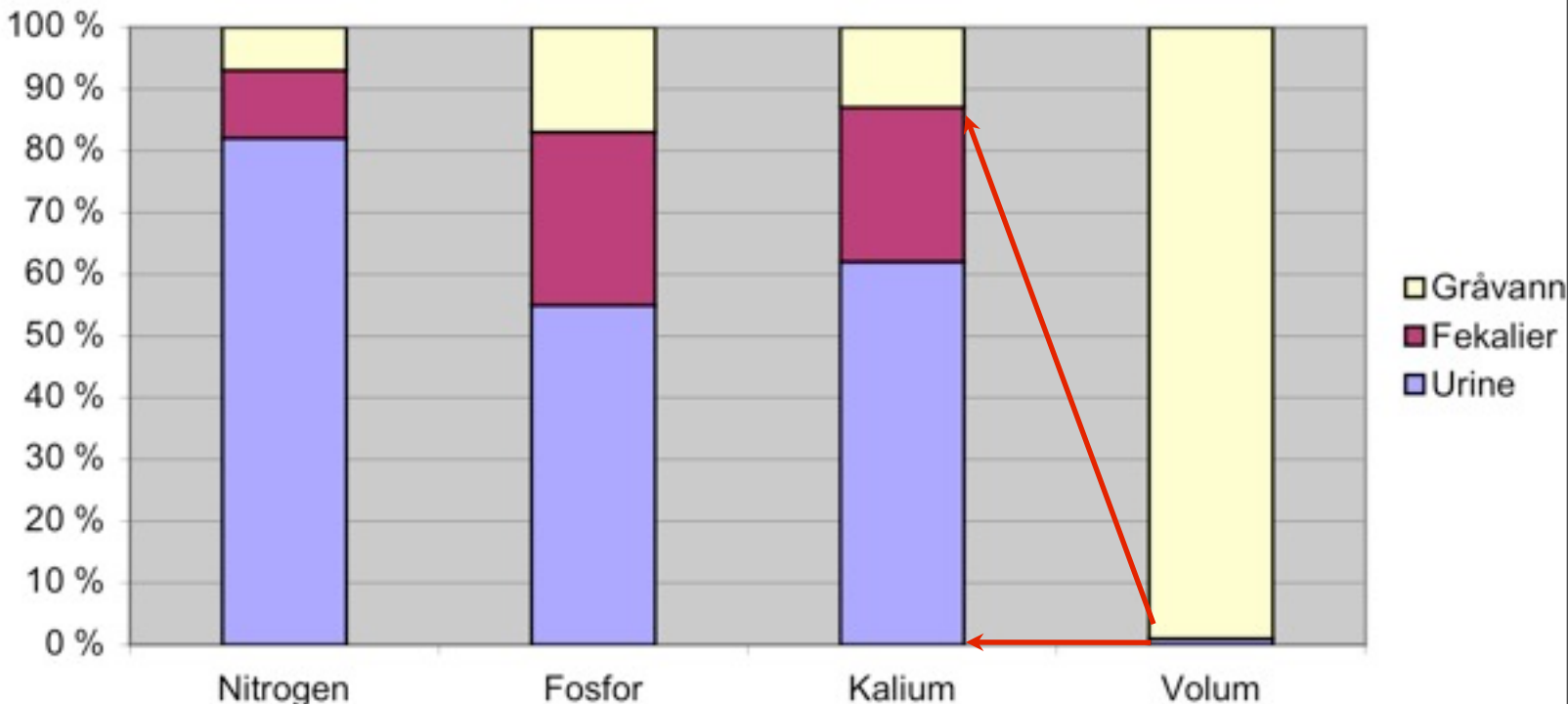
(Alsen and Jenssen2005)

Content of nutrients and volume in wastewater fractions



Source: Jönsson et al. 1999

Content of nutrients and volume in wastewater fractions



Source: Jönsson et al. 1999

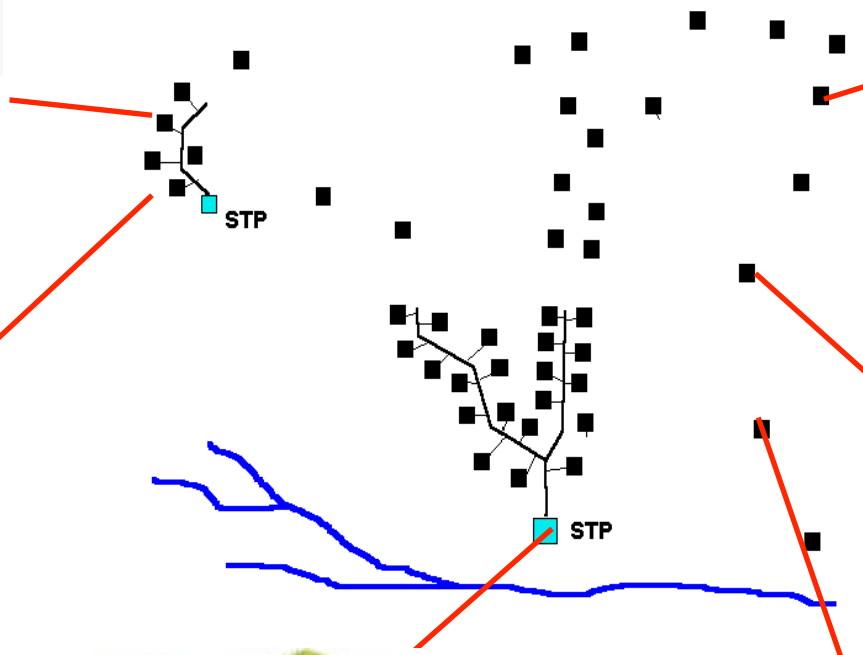
1% of the volume contains 80 - 90% of the resources

Contribution from the toilet

* 90 % of N
* 80 % of P
* 80 % of K
* 40-75 % of org. matter
* Majority of the pathogens

Decentralized treatment systems

Systems with source separation



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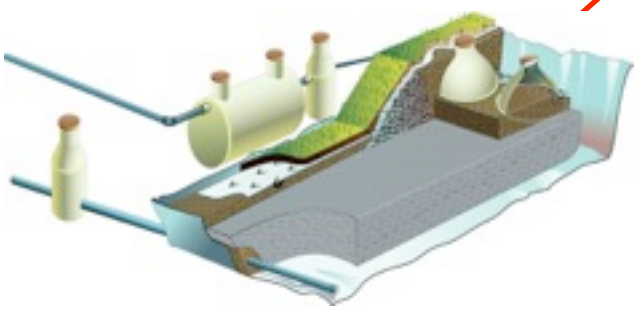

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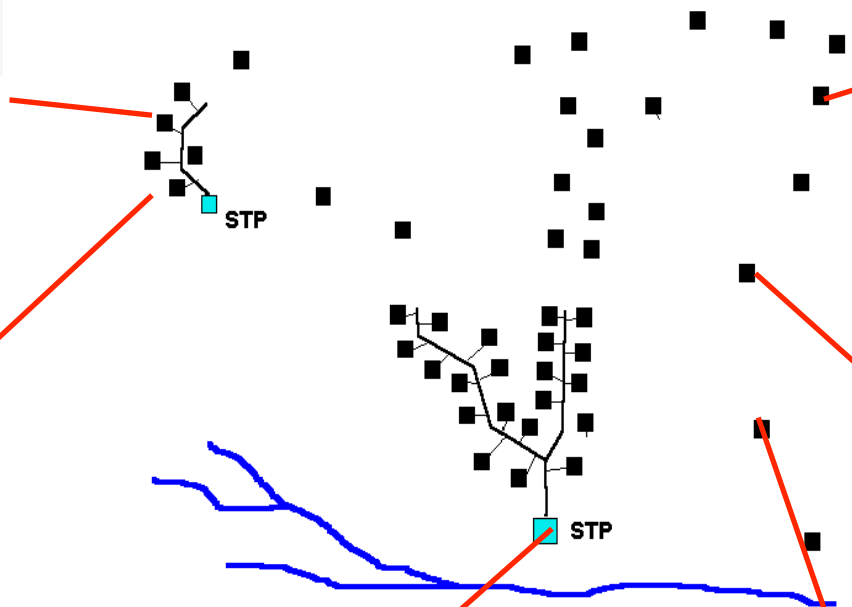

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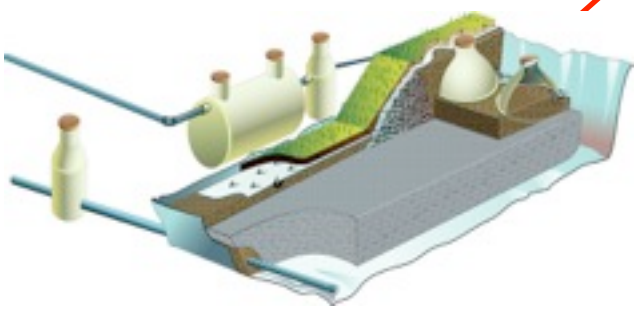

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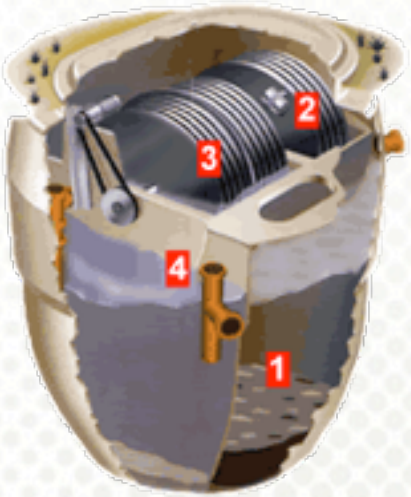
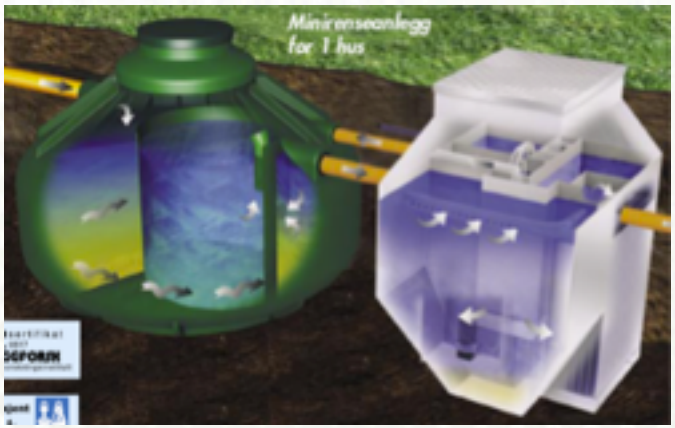
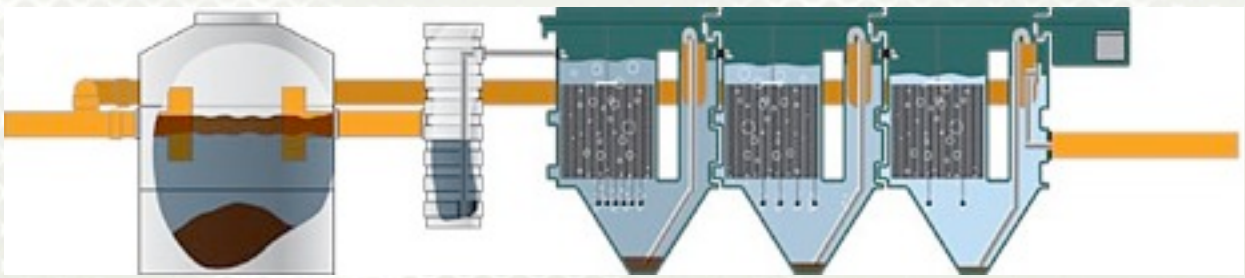
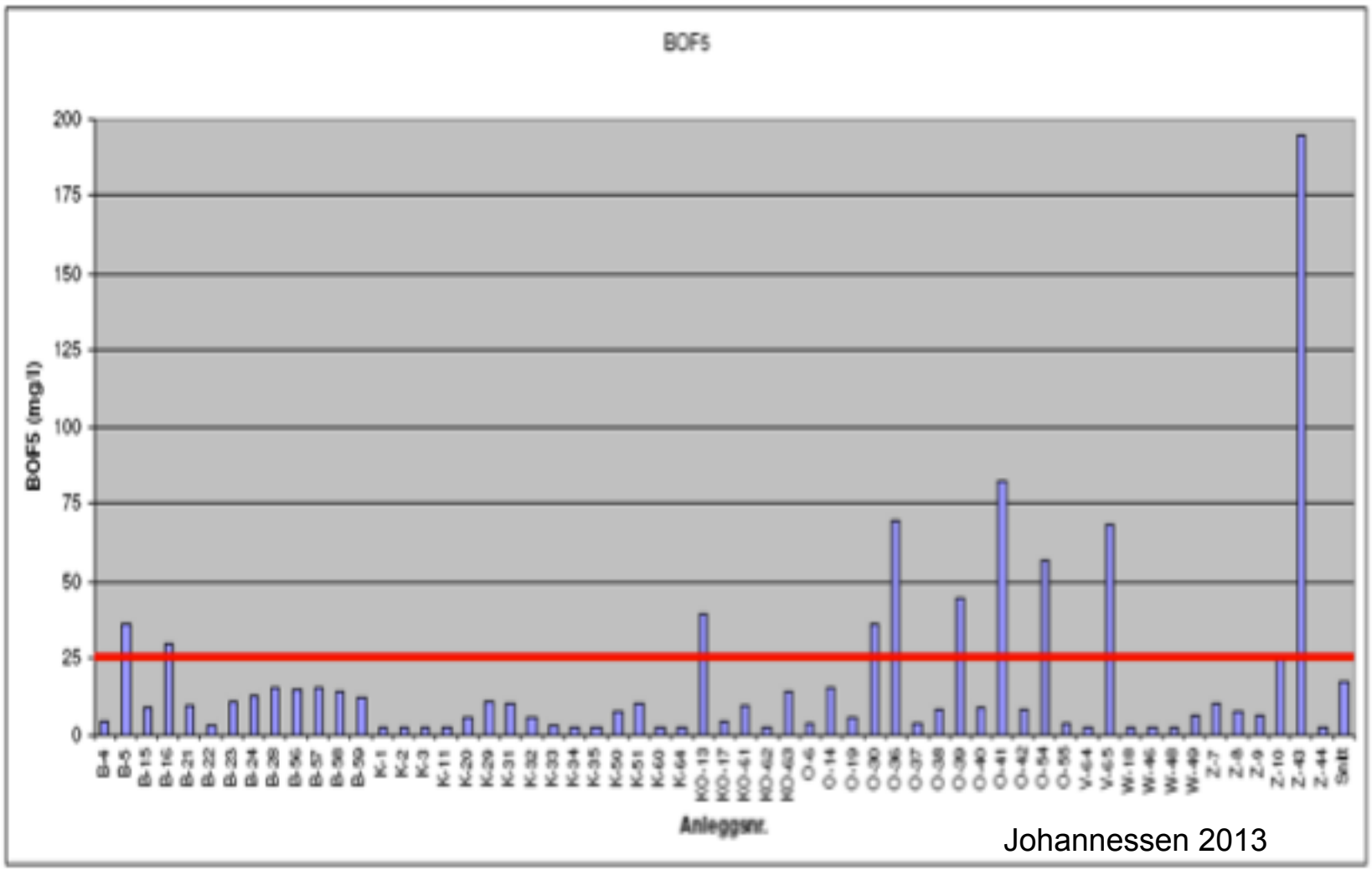




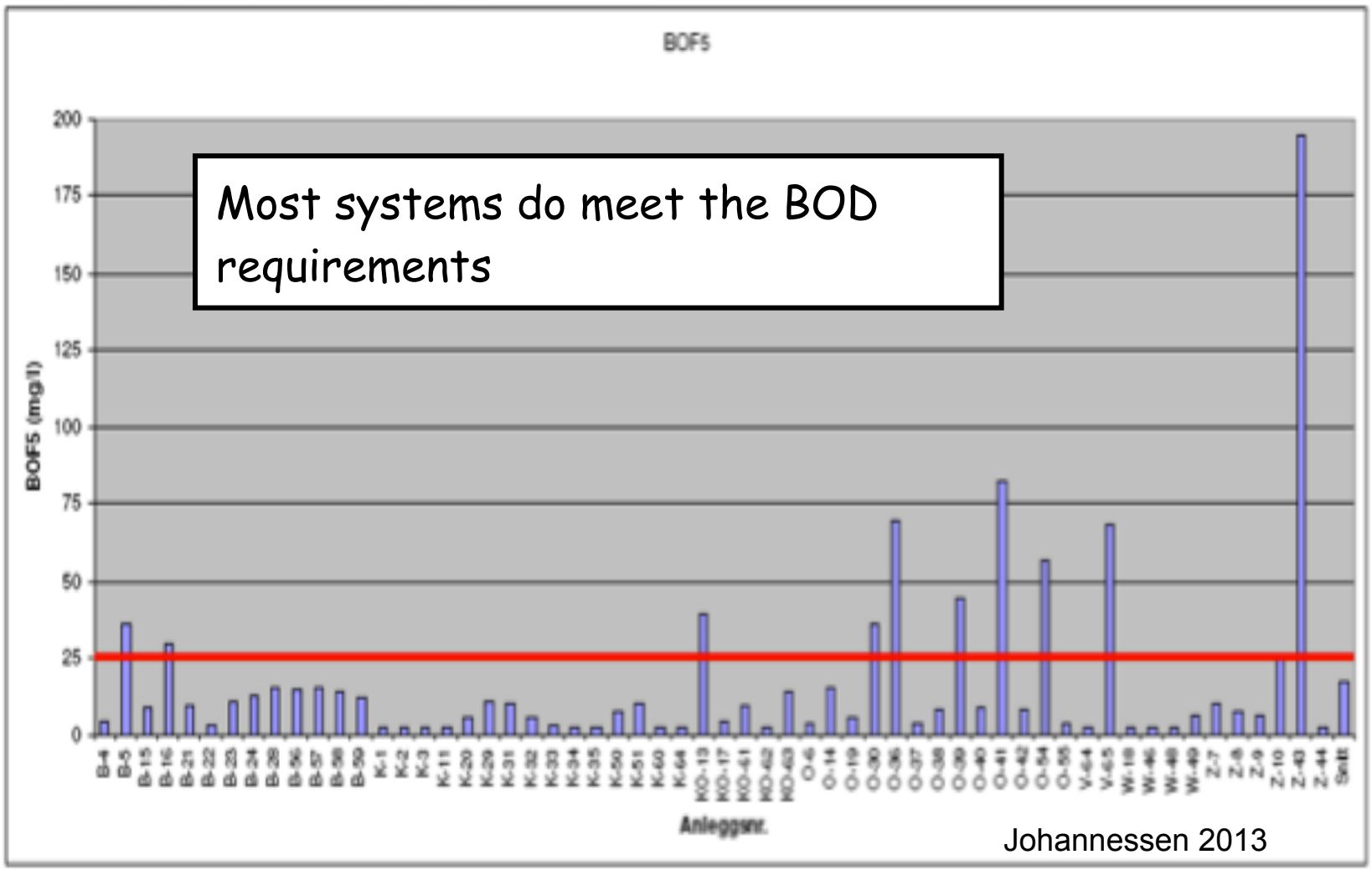


Package treatment plants - BOD

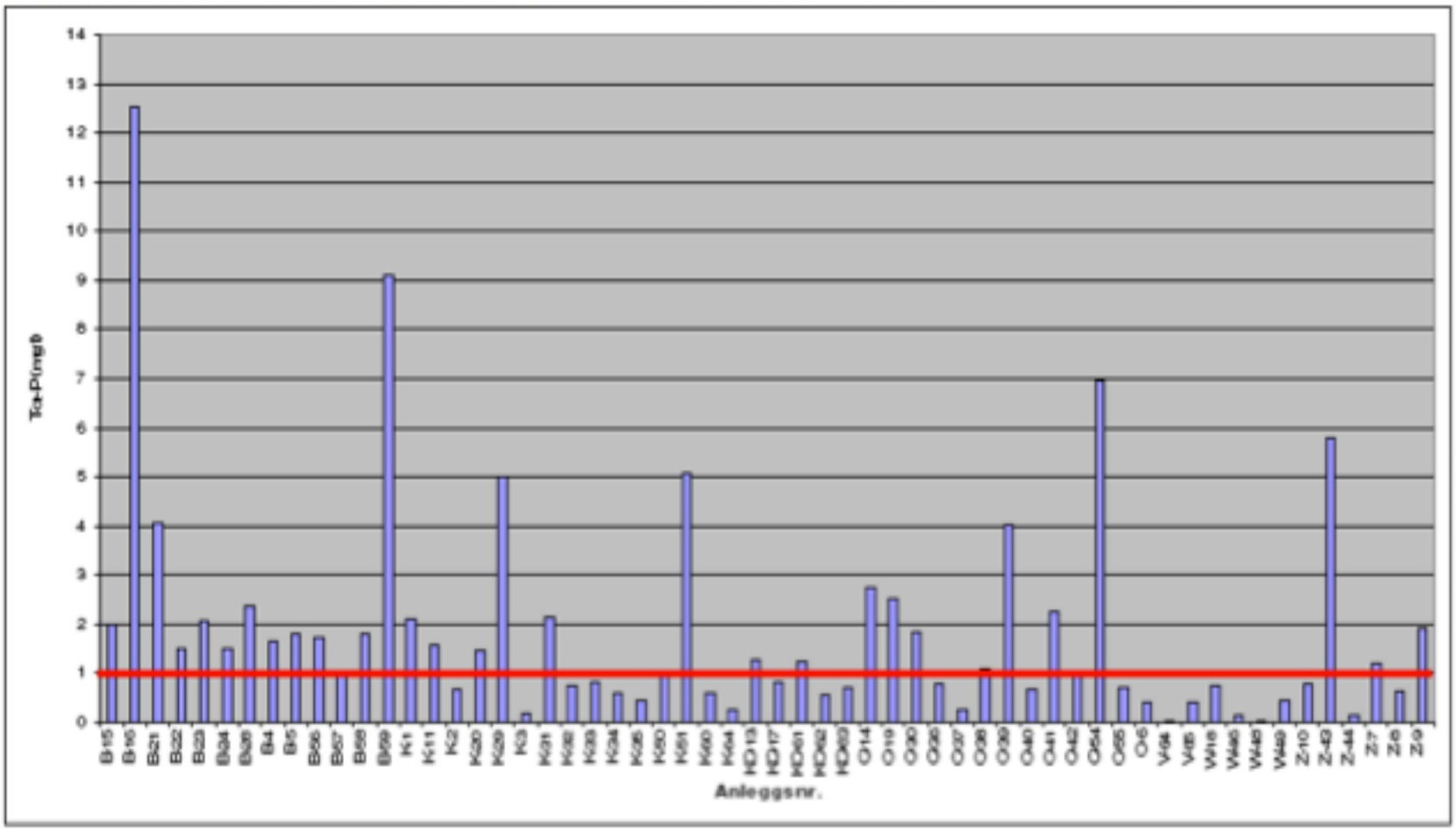


Johannessen 2013

Package treatment plants - BOD



Package treatment plants - phosphorus (P)



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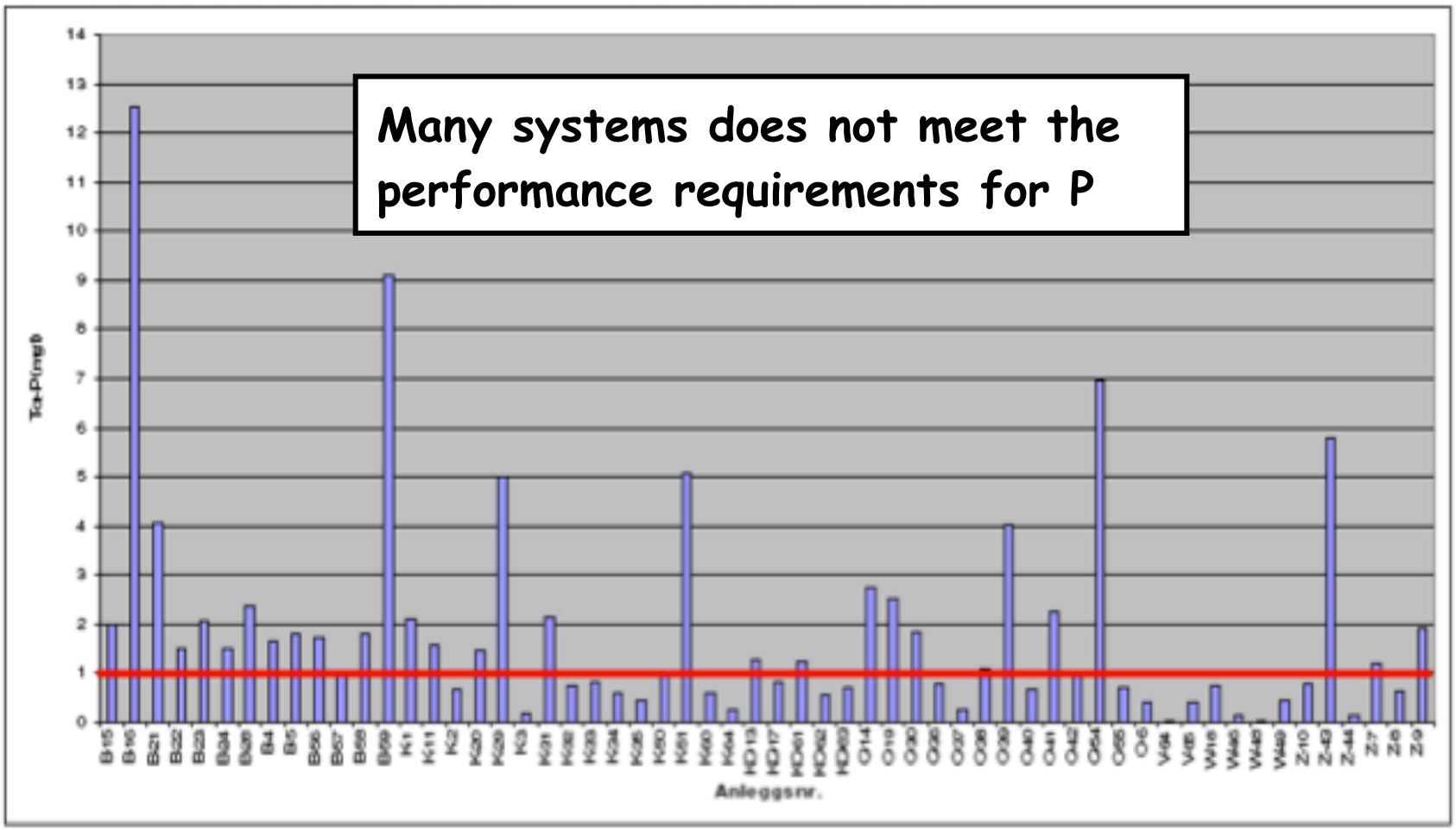
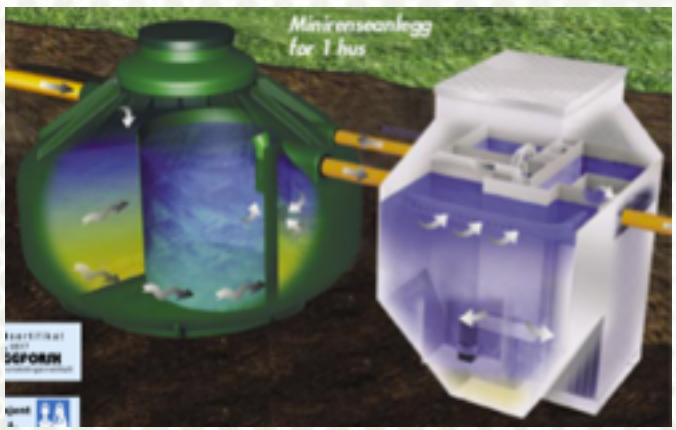


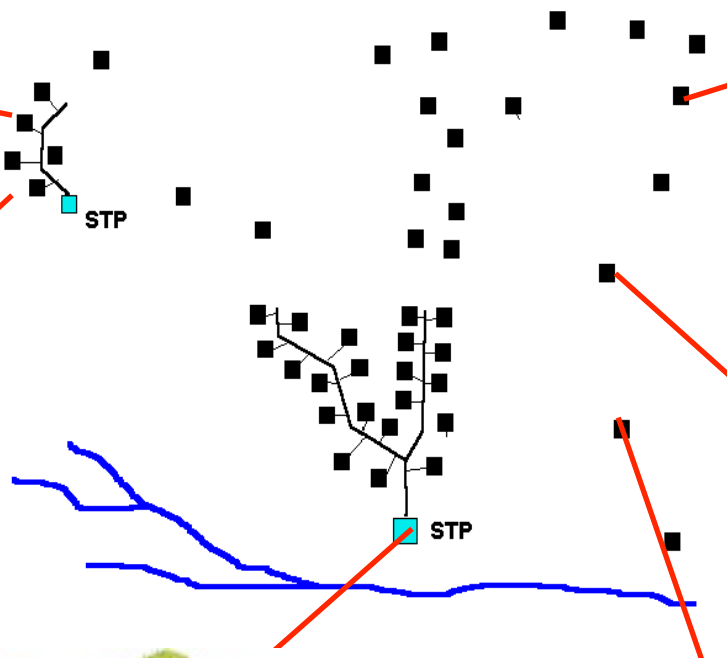
Package treatment plants

- Can operate several months without maintenance
- BOD removal good
- Phosphorus removal is maintenance dependent
- Nitrogen removal is low < 40%
- Not tested for cabins with seasonal use
- Limited experience with greywater
- Needs a polishing step



Decentralized treatment systems

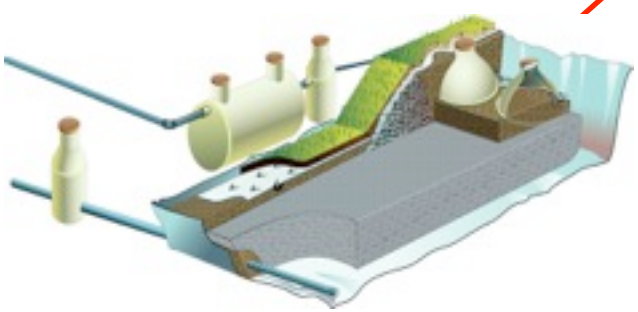
Systems with source separation



Package treatment plants

Septic tanks

Ponds



Constructed wetlands

Soil infiltration

Biofilters

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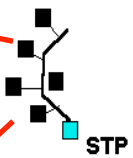

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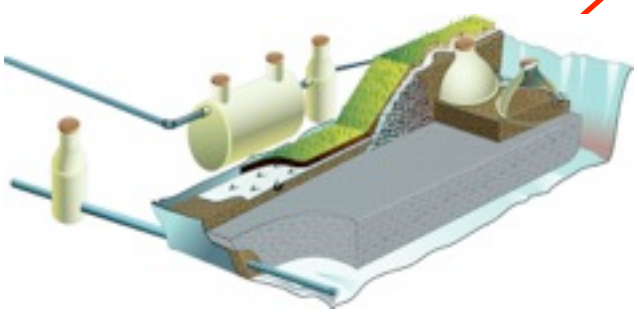

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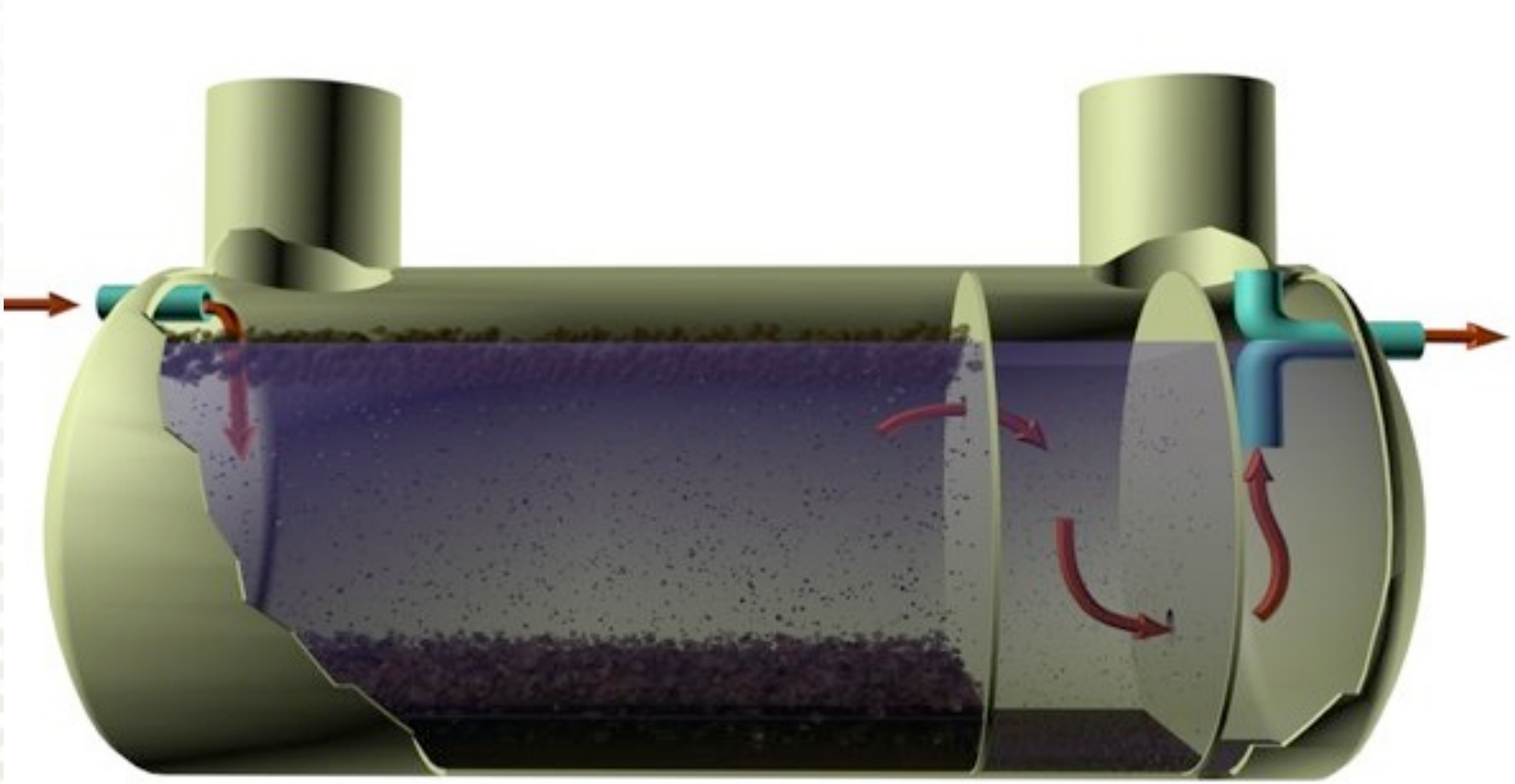

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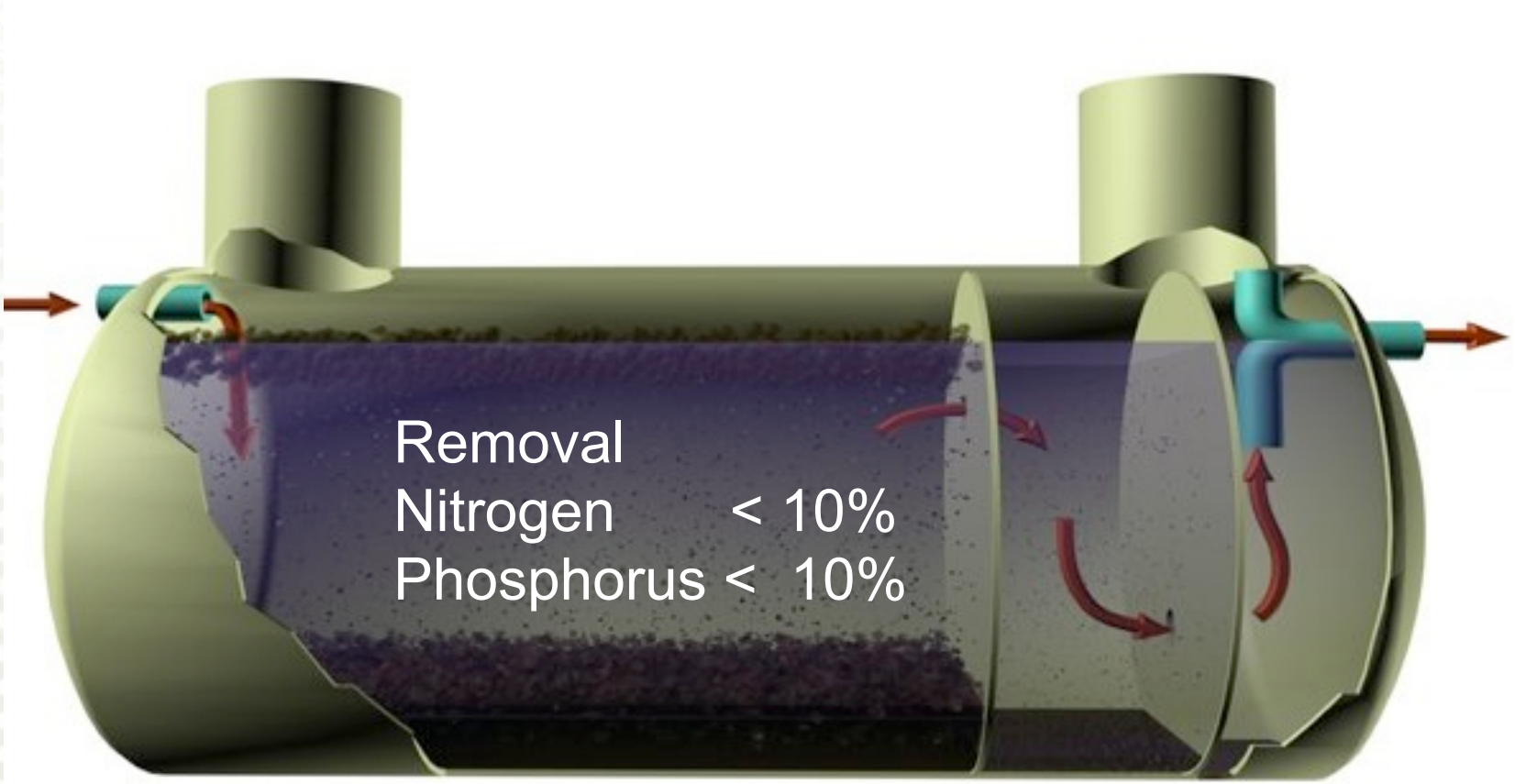

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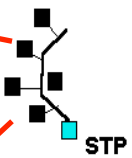

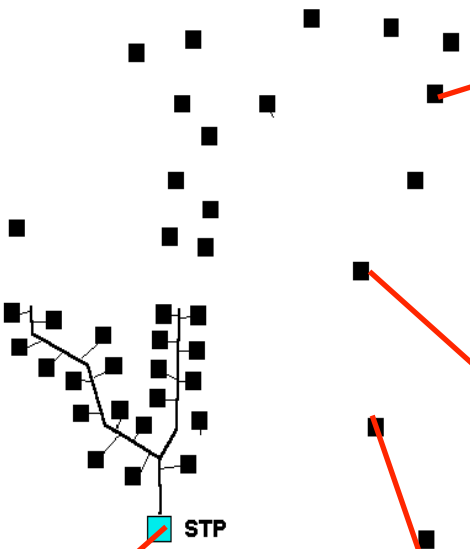

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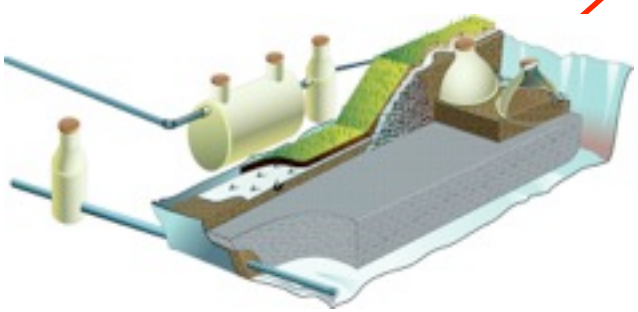

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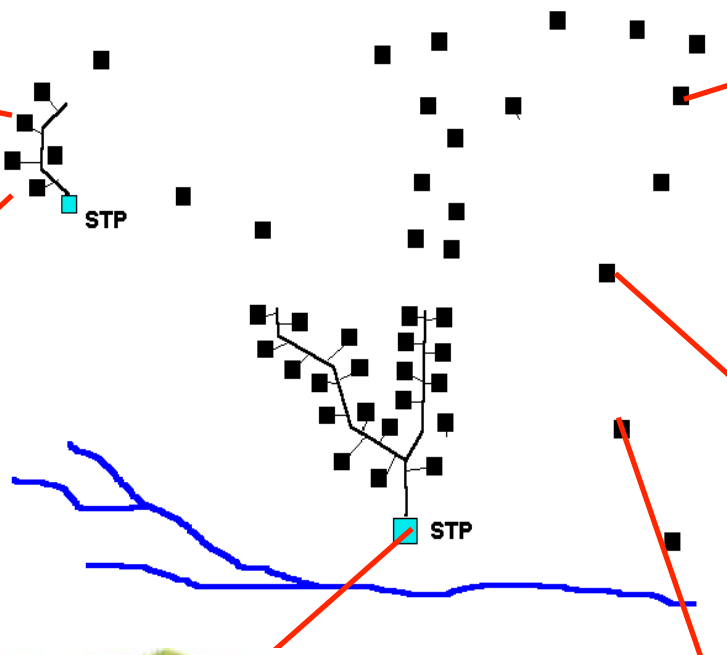

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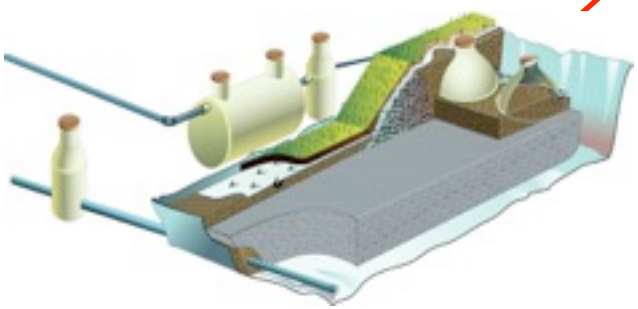
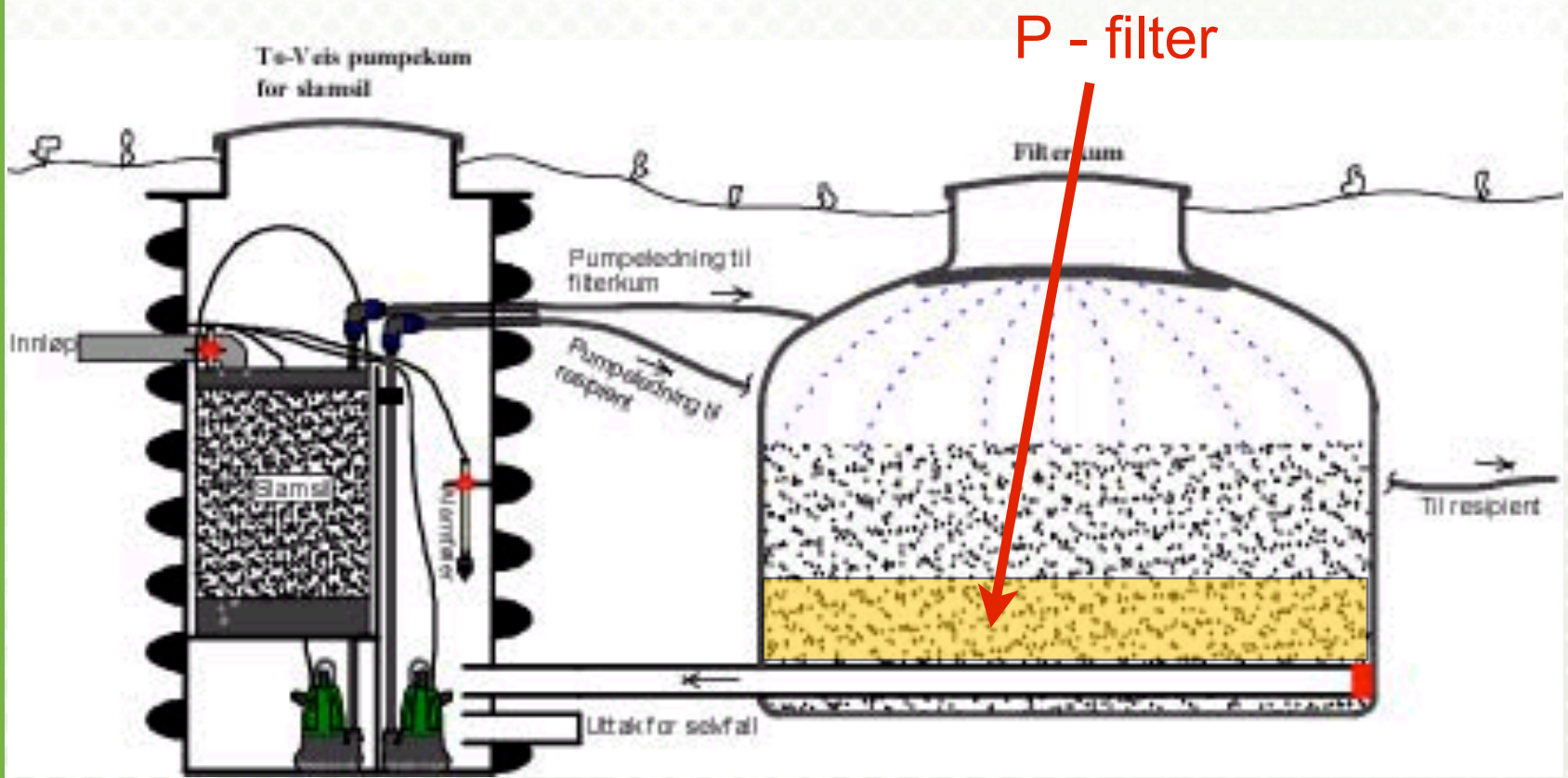


Constructed wetlands

Soil infiltration

Biofilters

Biofilter with P - filter for greywater treatment



Department of Environmental Sciences (IMV) P:D: Jenssen
NORWEGIAN UNIVERSITY OF LIFE SCIENCES (NMBU)

Biofilter with P - filter for greywater treatment

Treatment

Organic matter(BOD):

80 - 90%

Suspended solids (SS):

90%

Phosphorus (P):

20 - 30 (90*) %

Nitrogen (N)

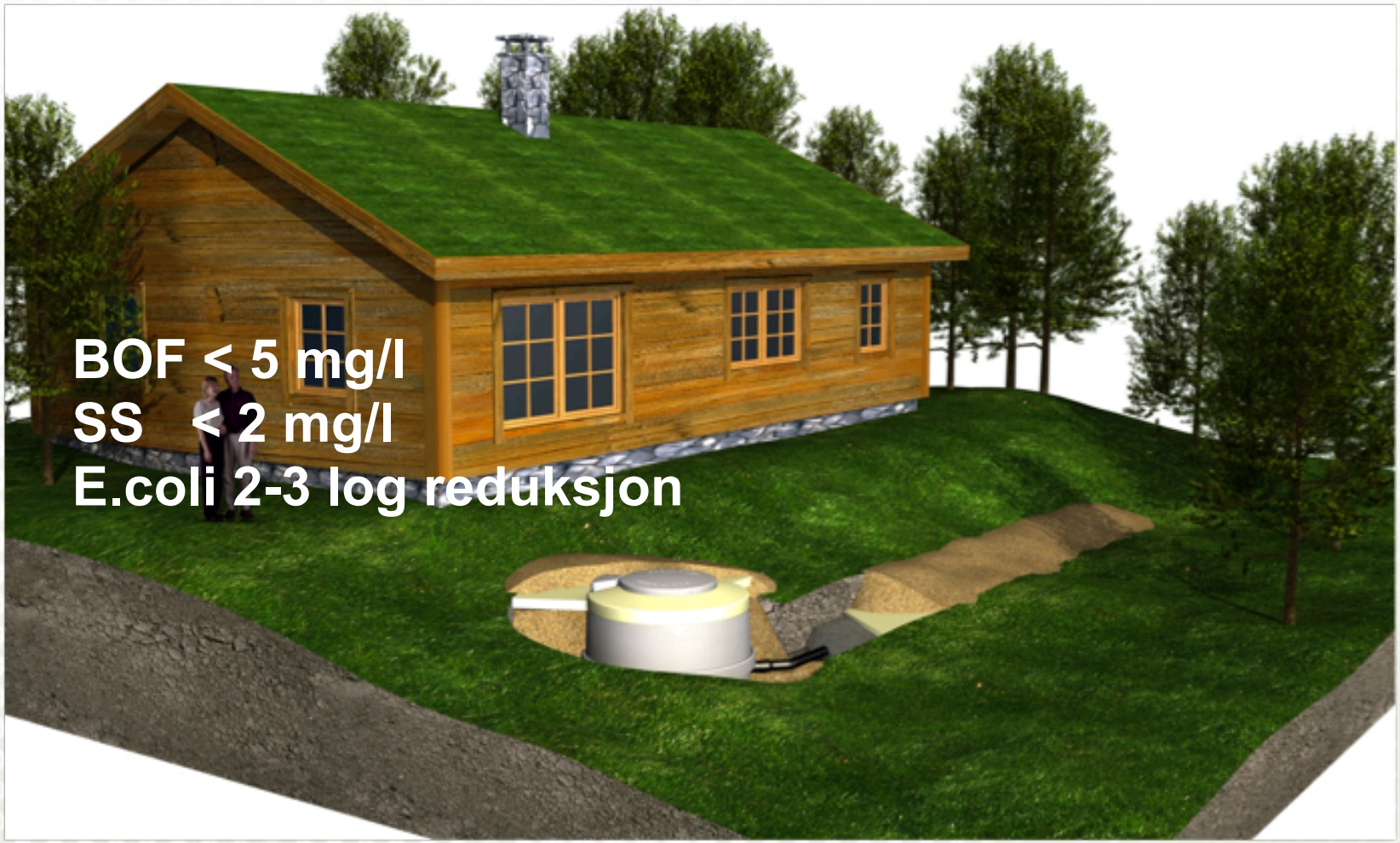
20 - 40 %

Indicator bacteria:

2-3 log reduction

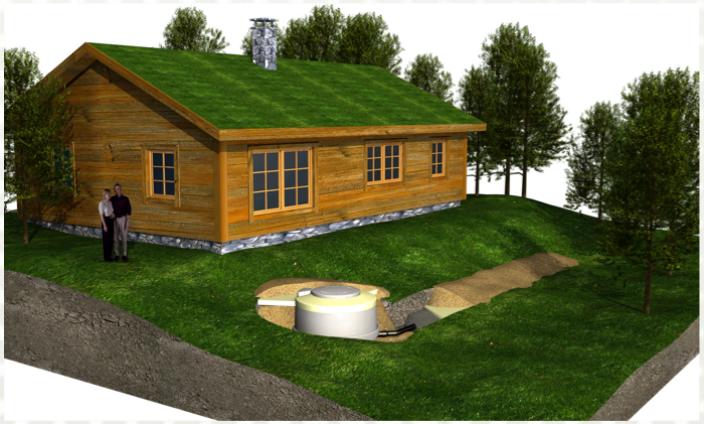
*with P-filter

Kompakt gråvannsrenseanlegg



Biofilters

- Well suited for cabins and greywater
- High BOD removal
- Good bacteria removal
- Need a solution for the toilet waste (blackwater)



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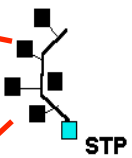

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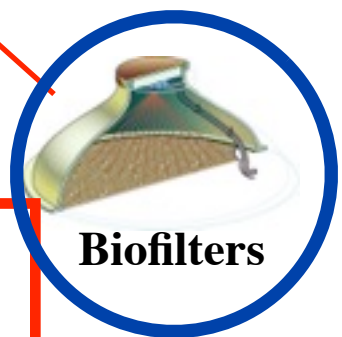

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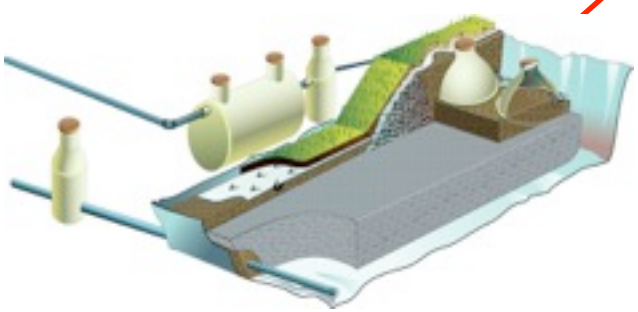
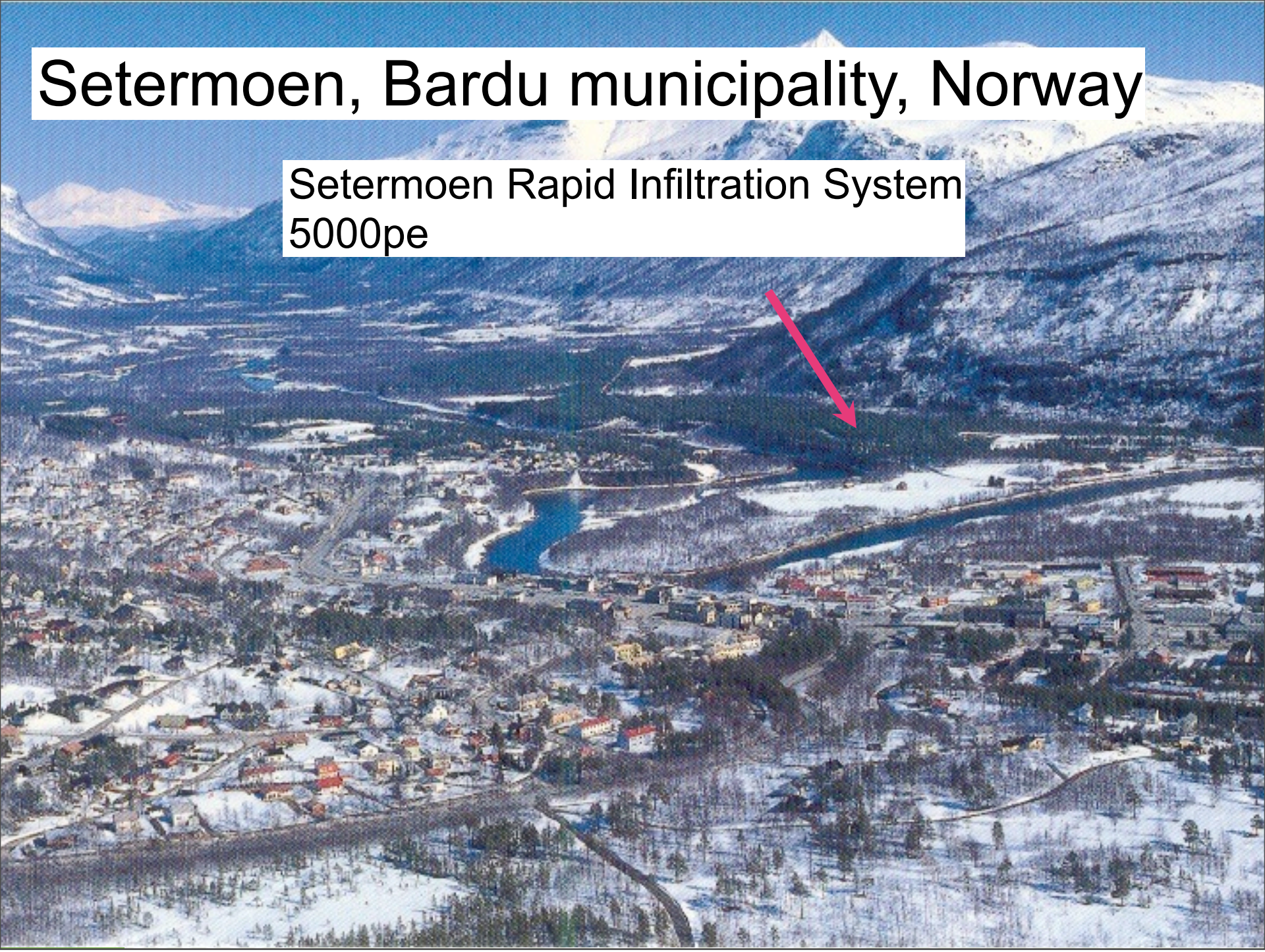


Constructed wetlands

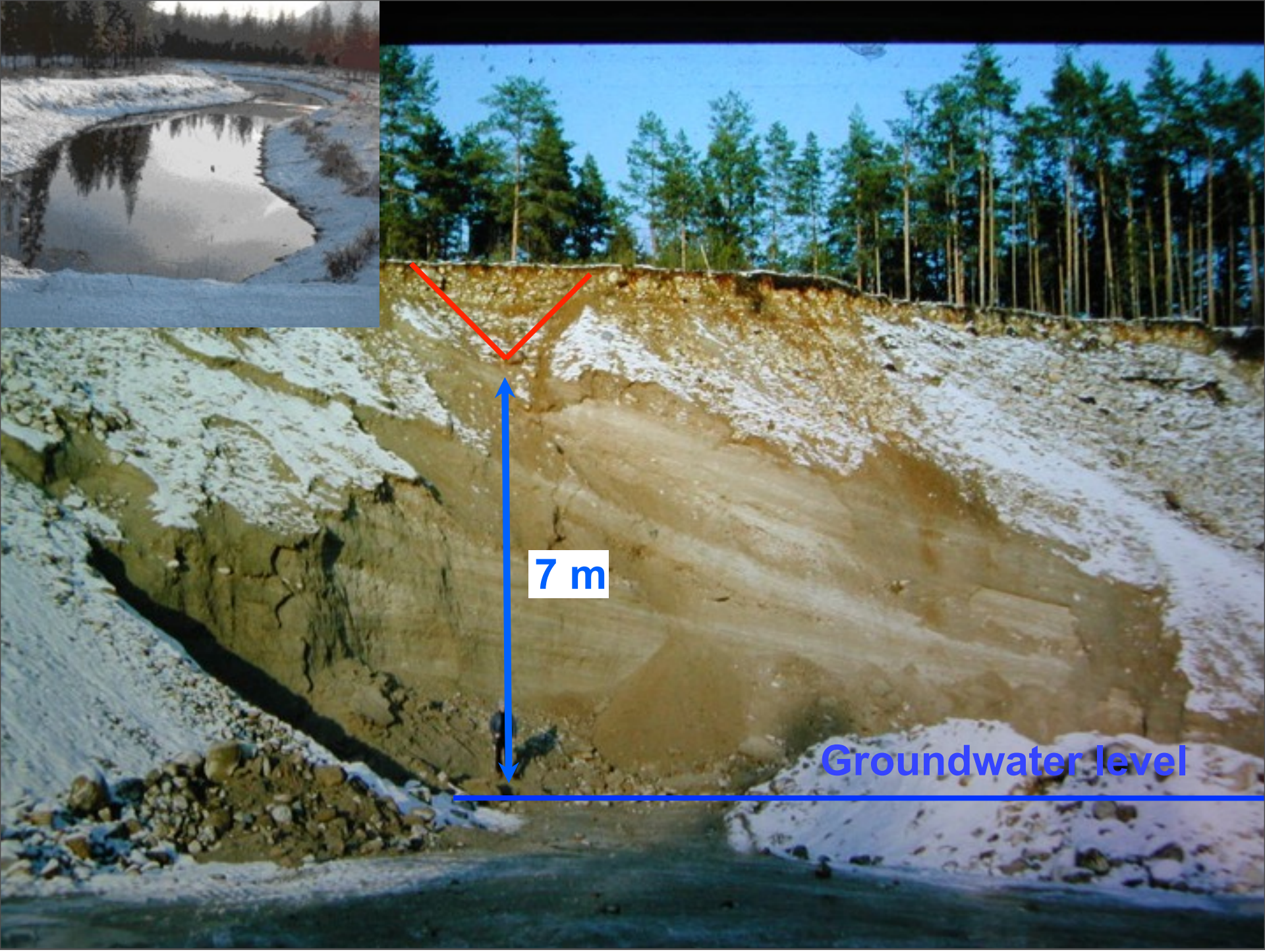
Soil infiltration

Setermoen, Bardu municipality, Norway

Setermoen Rapid Infiltration System
5000pe




Direction of groundwater flow
Setermoen
Rapid Infiltration System
5000pe


7 m
Groundwater level

Total phosphorus removal 99%

Phosphorus sorption capacity:
12 years below each basin

Removal of indicator bacteria

Fecal coliforms in the groundwater CFU/100ml	
1988	0
1991	2
1992	2
2014	18

Main sampling well

Groundwater level

Setermoen rapid infiltration plant - treatment performance

Parameter	1986 - 95	1996 - 2013
Total - P	99	99
Total - N	77	59
COD	87	90

From: Jenssen et al. 2014

Shallow infiltration

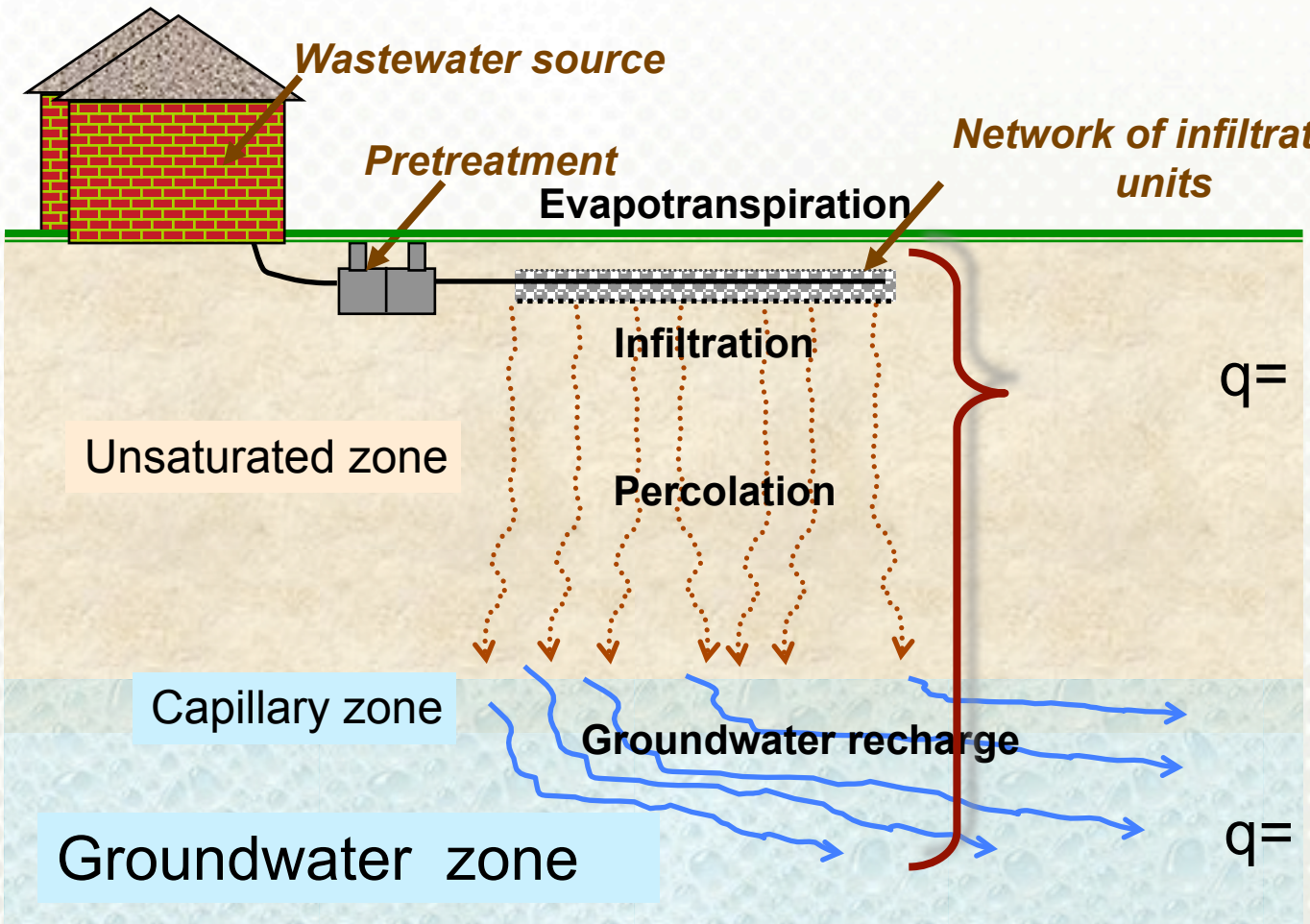


Figure from Siegrist (2010)

Shallow infiltration

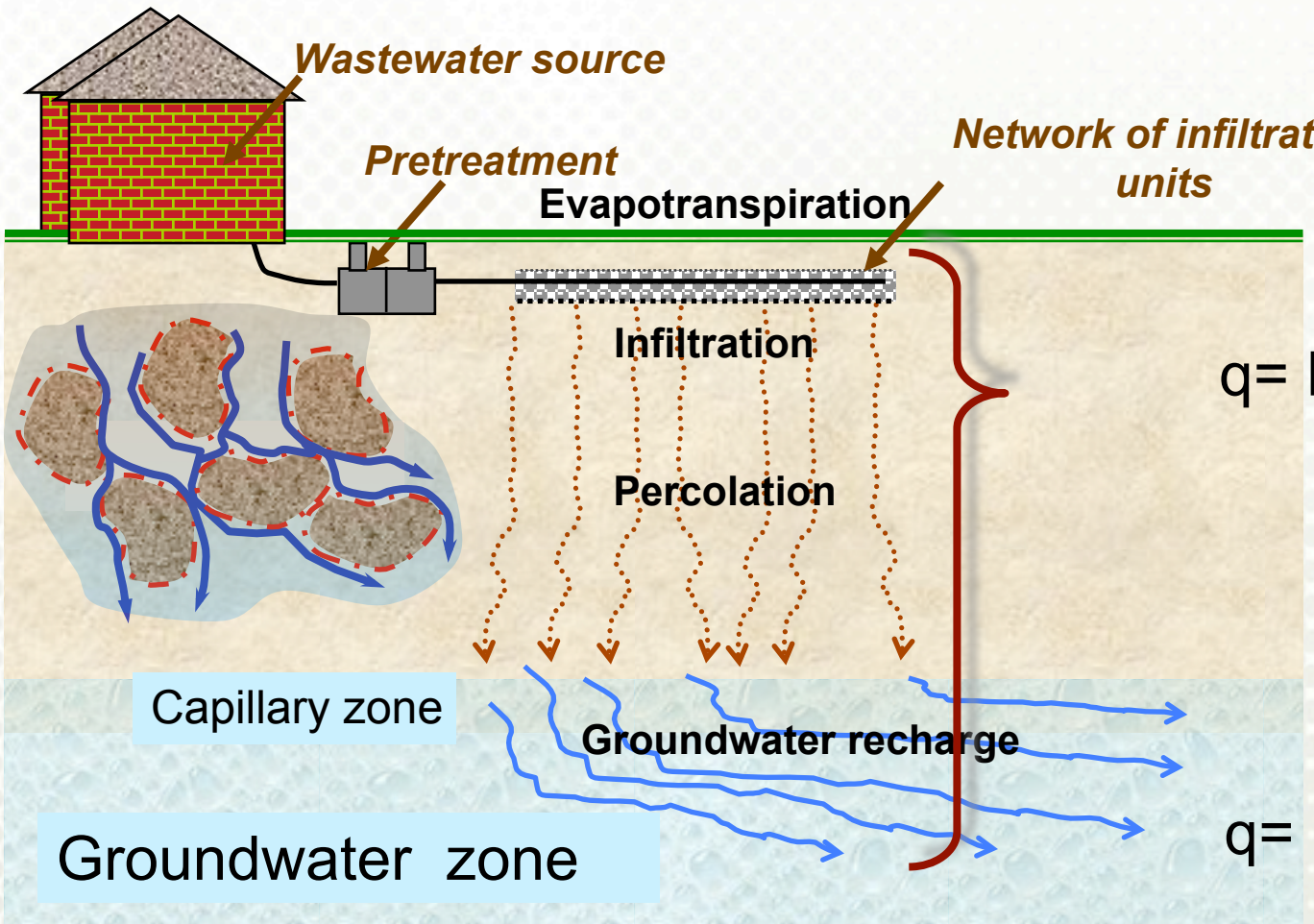


Figure from Siegrist (2010)

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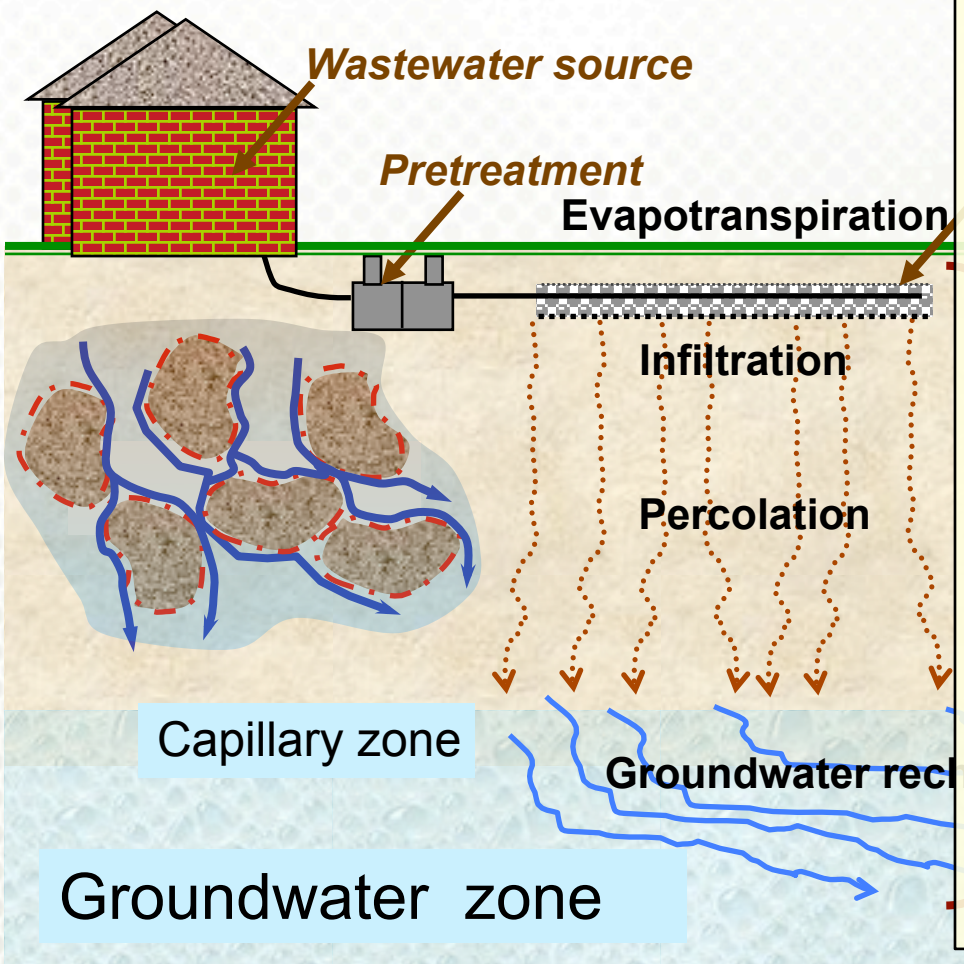


Treatment

Organic matter(BOD):

> 90%

Suspended solids (SS):

> 90%

Phosphorus (P):

> 90 %

Nitrogen (N)

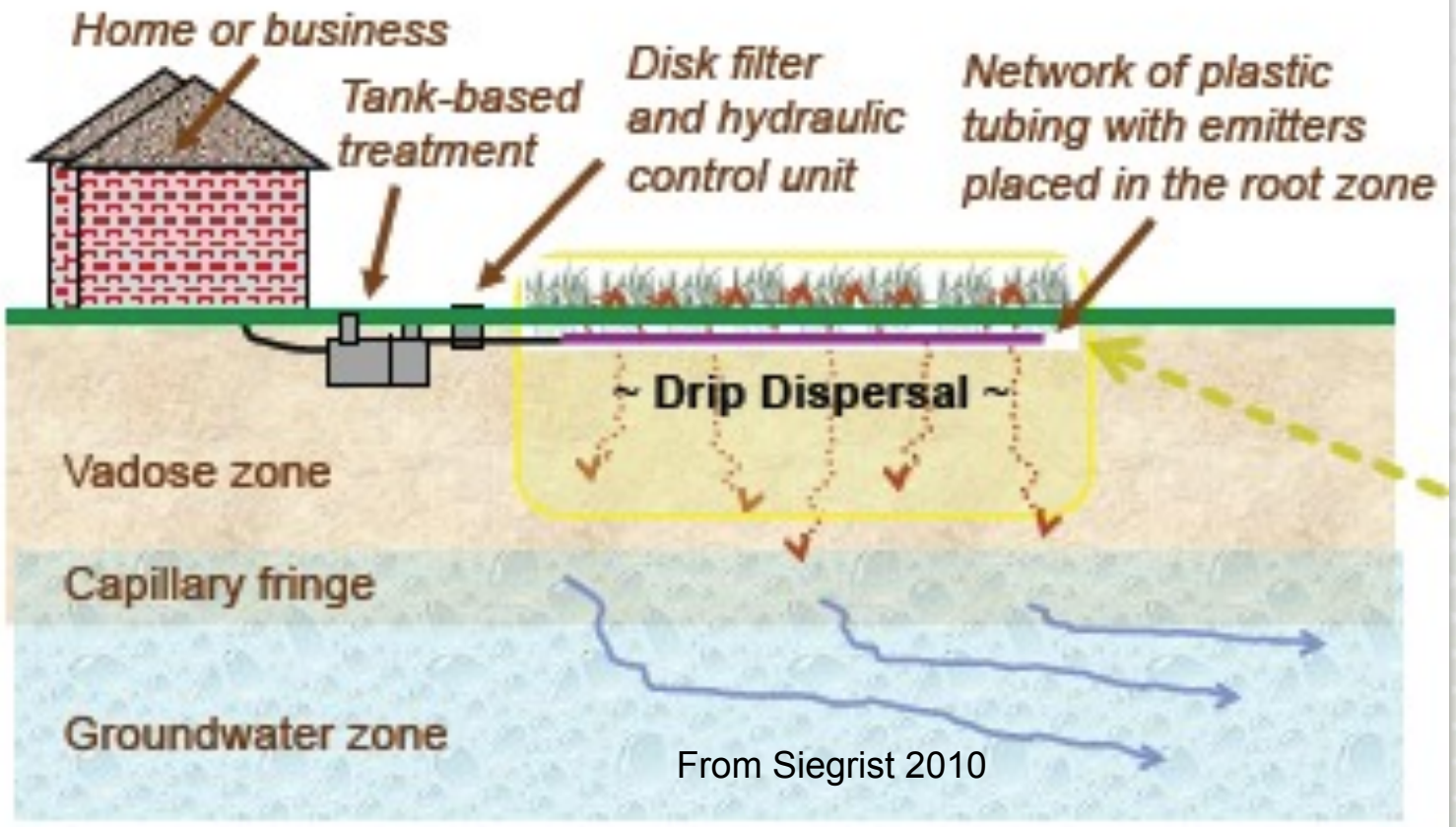
30 - 80 %

Indicator bacteria:

4 -6 log reduction

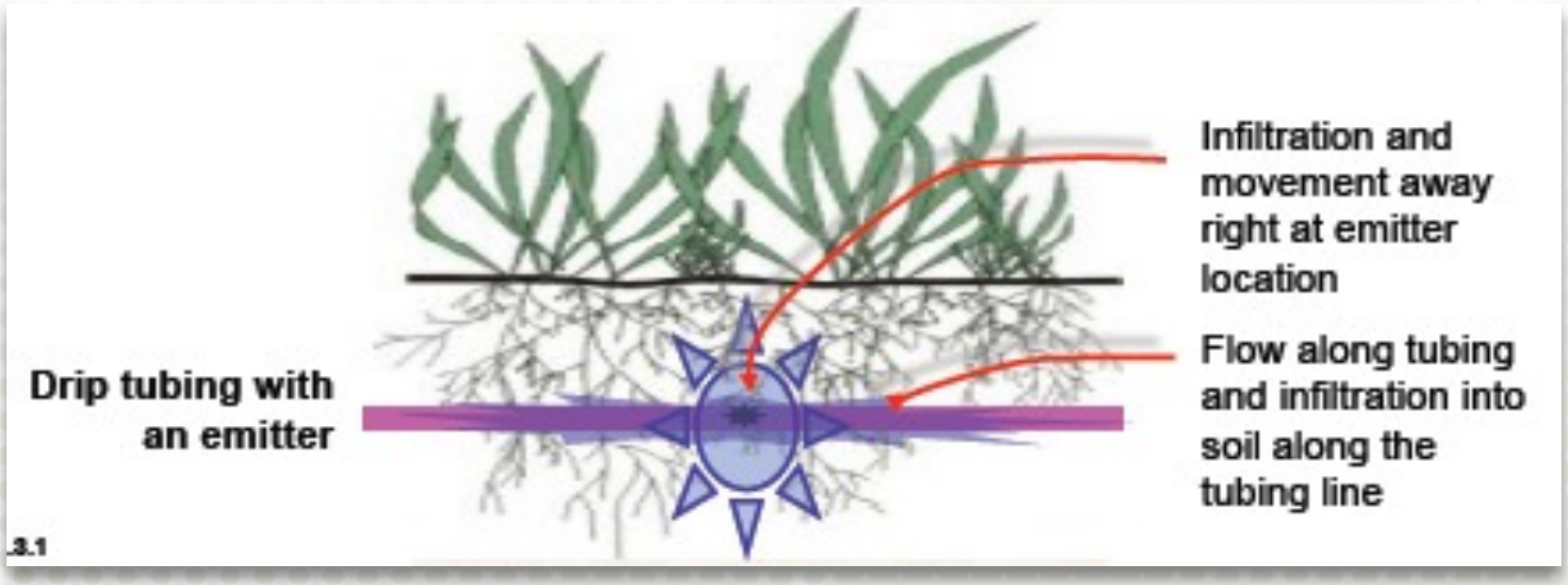
Figure from Siegrist (2010)

Drip irrigation systems



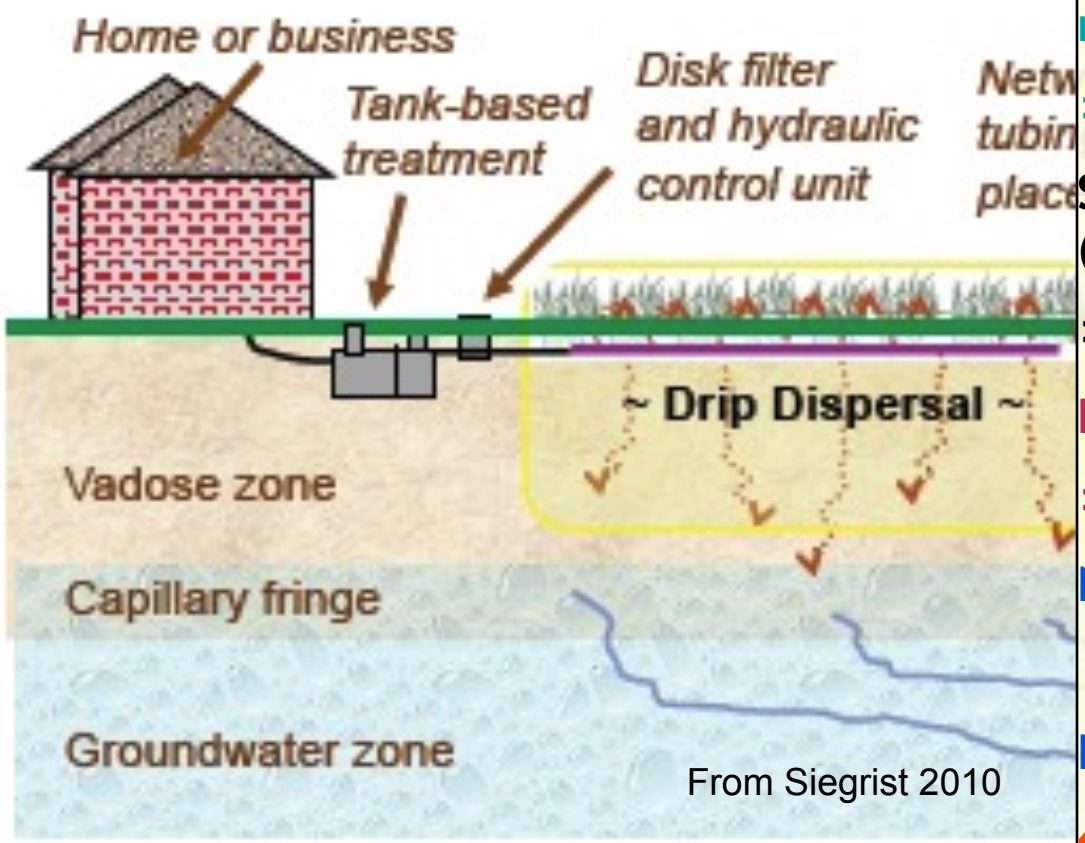
From Siegrist 2010

Drip irrigation systems



From Siegrist 2010

Drip irrigation systems - treatment



From Siegrist 2010

Treatment

Organic matter(BOD):

> 90 %

Suspended solids (SS):

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Phosphorus (P):

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Nitrogen (N)

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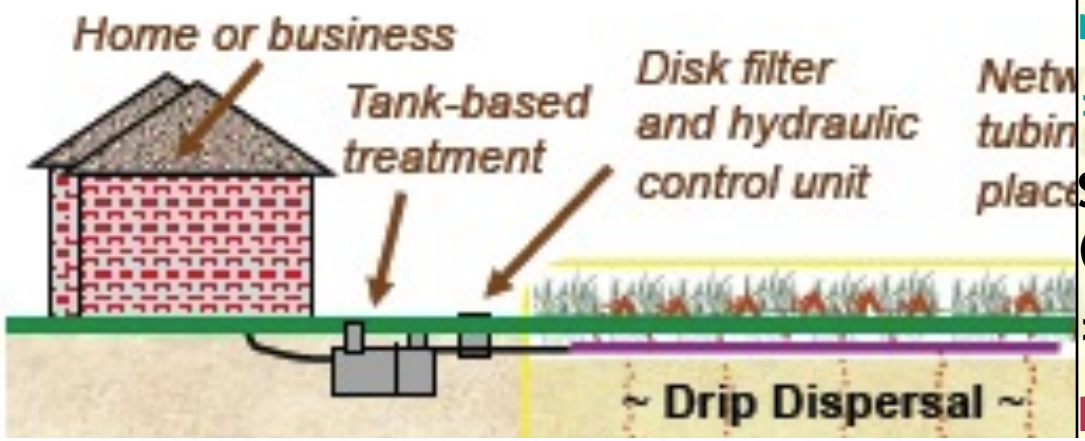
Indicator bacteria:

4-6 log reduction

Drip irrigation systems - treatment



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Organic matter(BOD):

> 90 %

Suspended solids (SS):

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Indicator bacteria:

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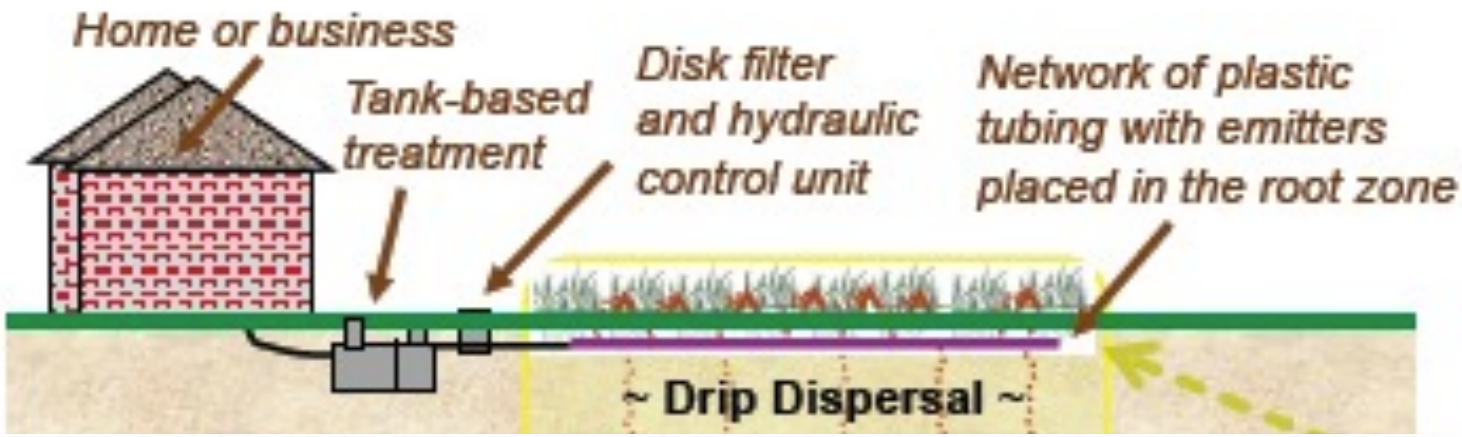
- **Drip dispersal can achieve equal or better treatment than subsurface infiltration and percolation to groundwater**

Drip irrigation systems - treatment



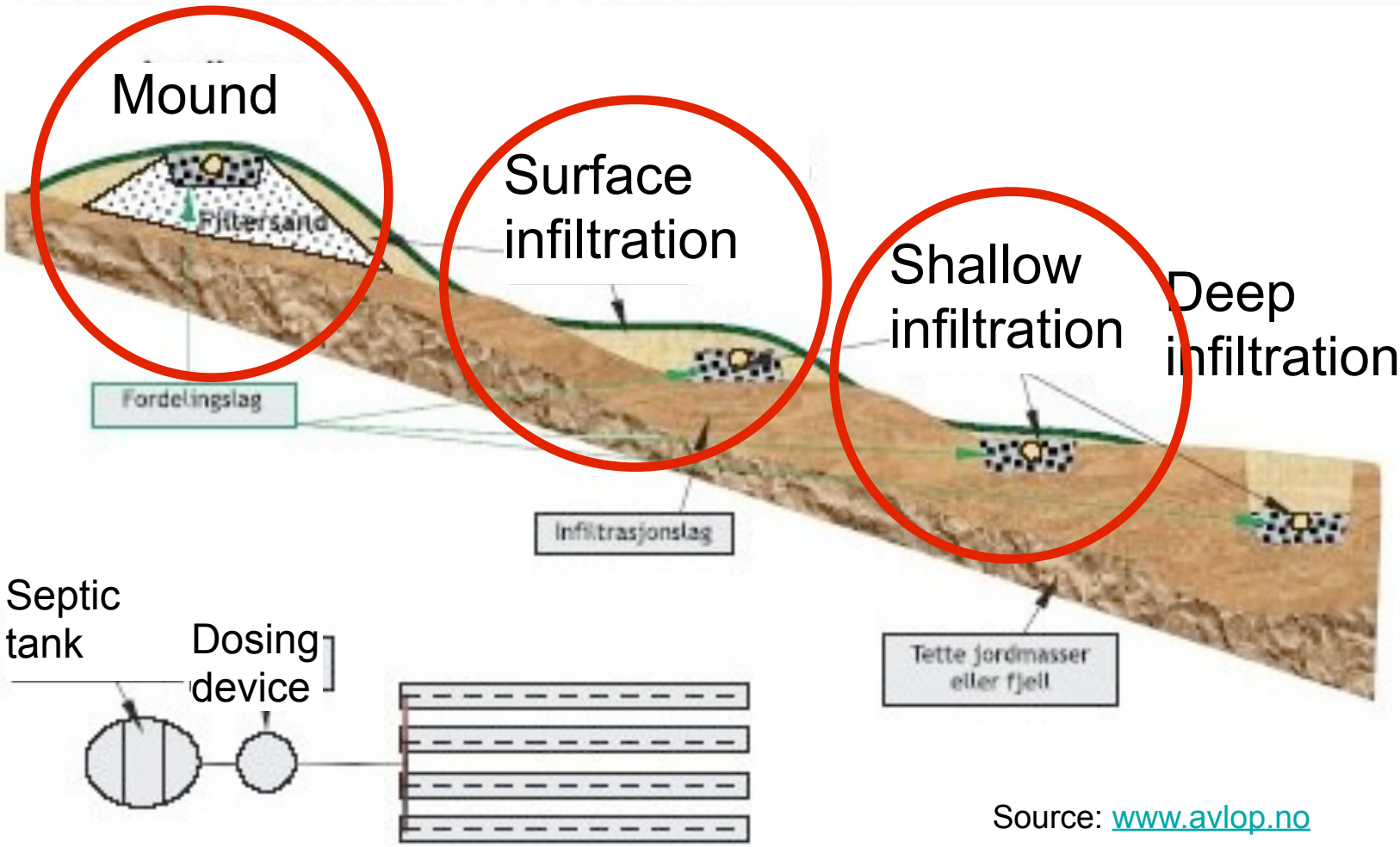
- Drip dispersal can achieve equal or better treatment than subsurface infiltration and percolation to groundwater

- Drip dispersal into shallow soil and the root zone of plants should have high treatment efficiency for organics like pharmaceuticals and consumer product chemicals

(Conn et al. 2010)

From Siegrist 2010

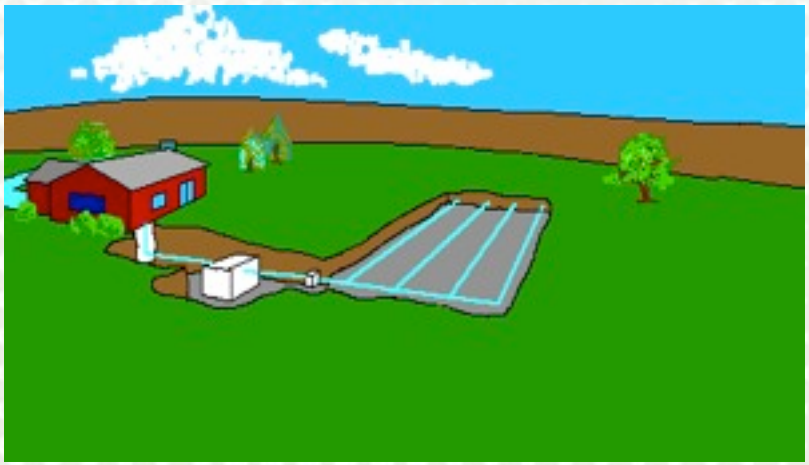
Different buried infiltration systems



Source: www.avlop.no

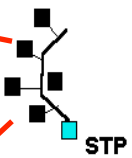
Soil infiltration systems

- Very high treatment performance
- Robust and simple solution
- Suitable for cabins as well as larger installations
- Suitable for polishing and dipersing pretreated effluent
- At Þingvallavatn shallow, mound drip disposal/ shallow systems is the most feasible



Decentralized treatment systems

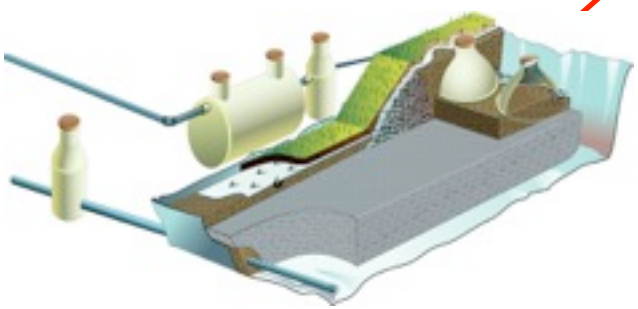
Systems with source separation



Package treatment plants

Septic tanks

Ponds

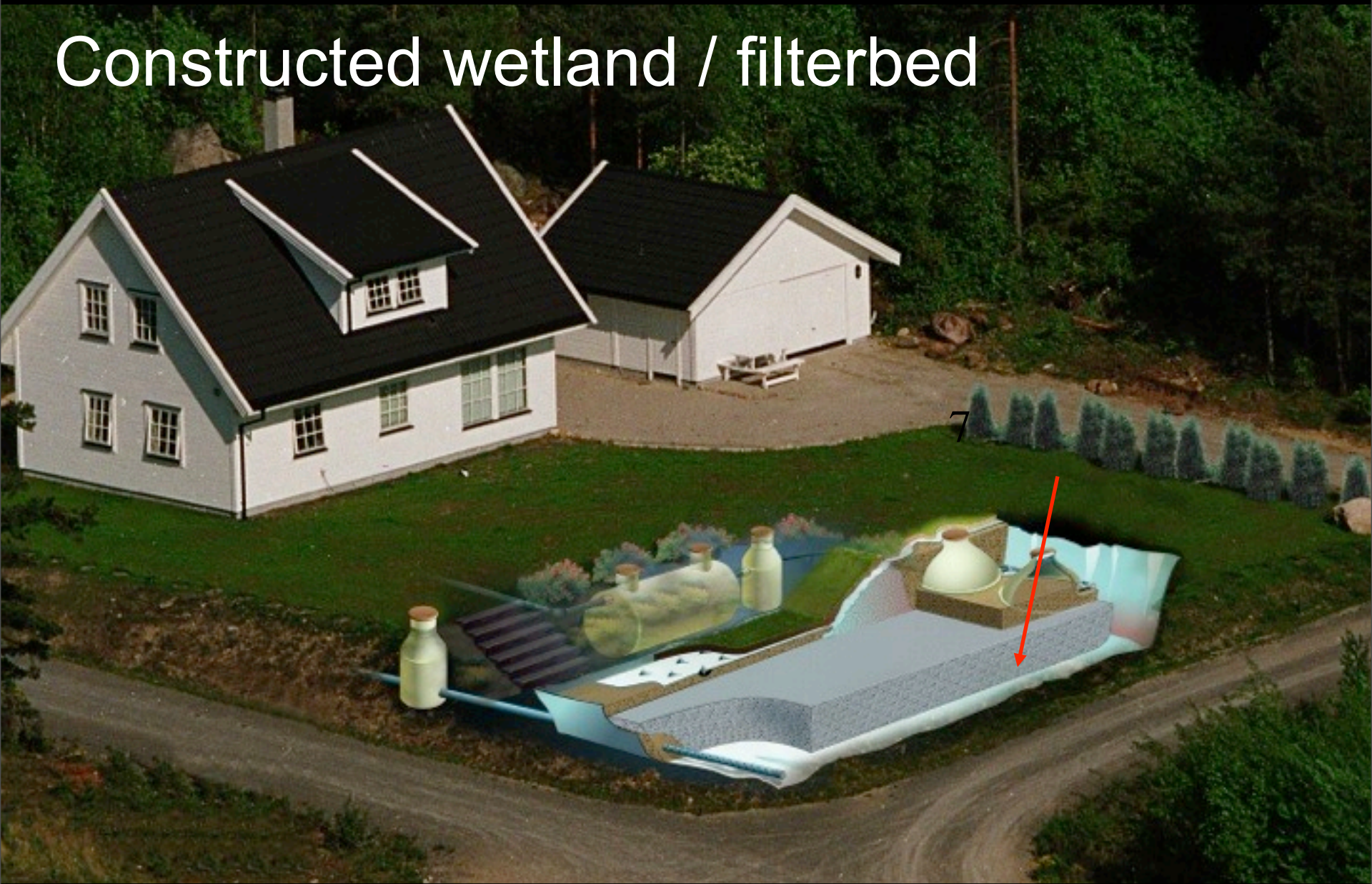


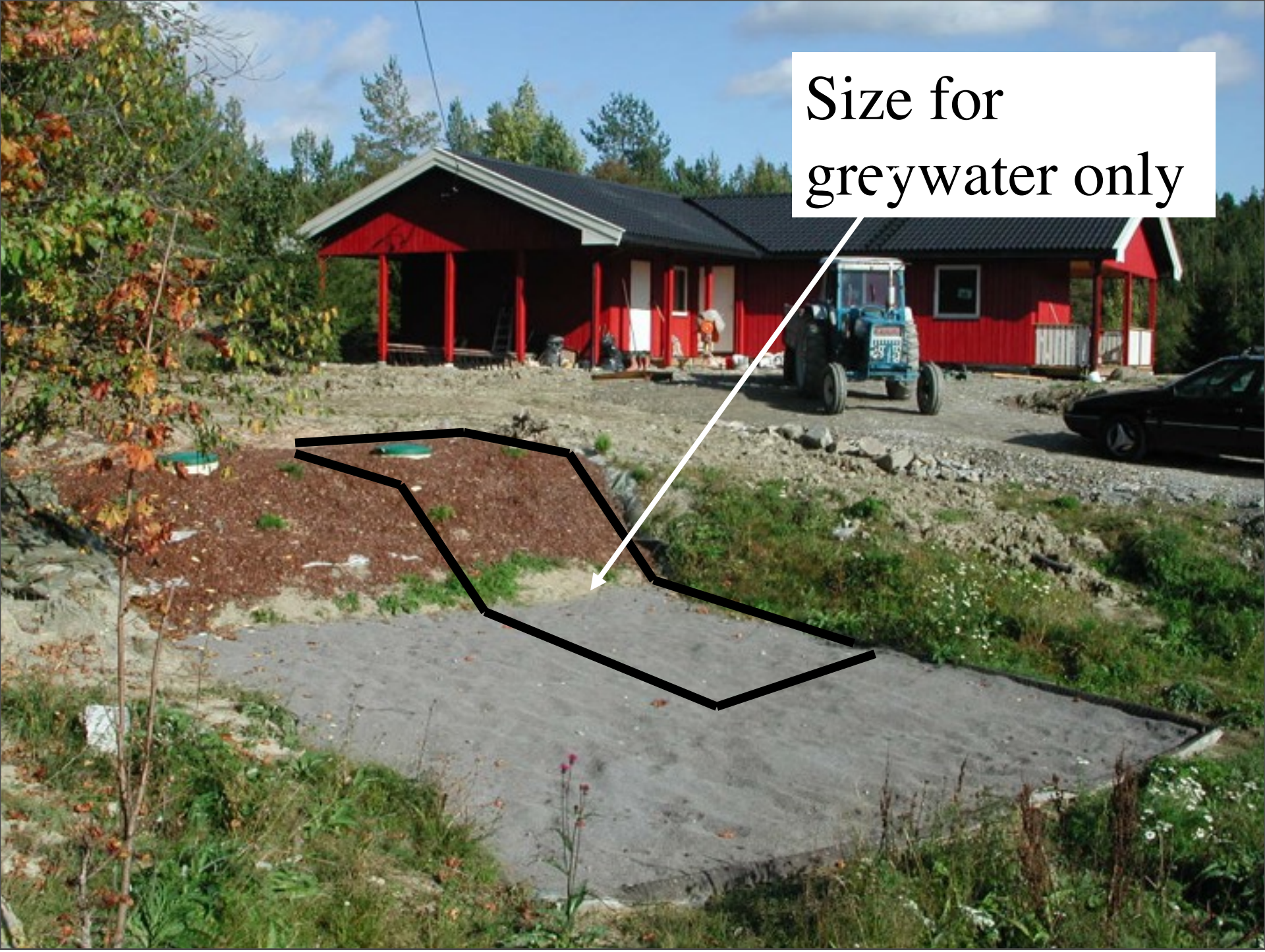
Constructed wetlands

Soil infiltration

Biofilters

Constructed wetland / filterbed




Size for
greywater only

Constructed wetland Dal primary school

Parameter	Influent mg/l	Effluent mg/l
Total - P	2,9	0,2
Total - N	29,0	12,0
COD	129	24
SS		< 5
Fecal. coli. /100ml		< 2

Constructed wetland / filterbed

Treatment

Organic matter(BOD):

> 90%

Suspended solids (SS):

> 90%

Phosphorus (P):

> 90* %

Nitrogen (N)

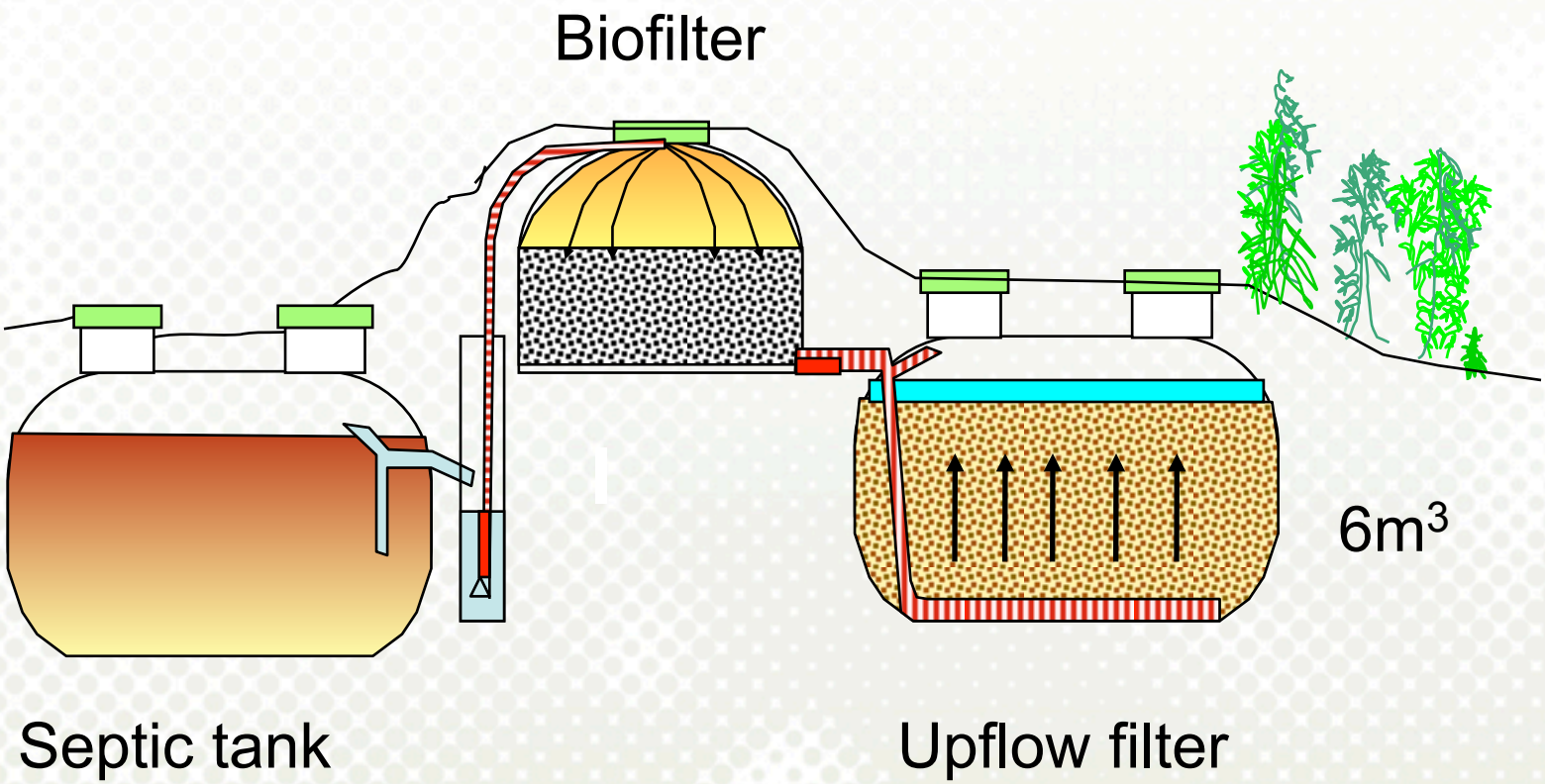
30 - 60 %

Indicator bacteria:

4 -5 log reduction

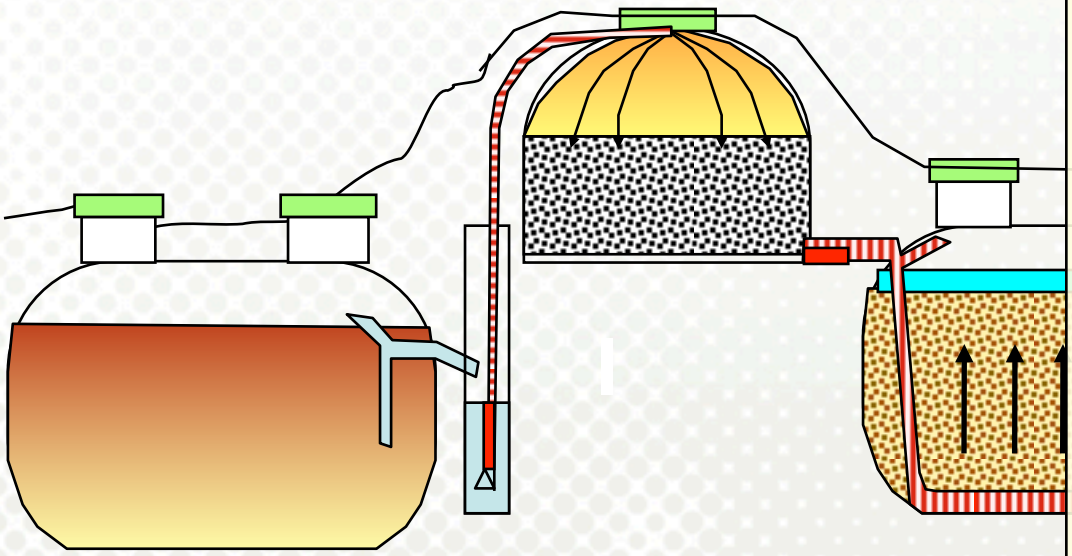
* 10 - 15 years

Compact filterbed system



(Heistad et al. 2006)

Kompakt filter



Treatment

Organic matter(BOD):

> 90%

Suspended solids (SS):

> 90%

Phosphorus (P):

> 90* %

Nitrogen (N)

30 - 60 %

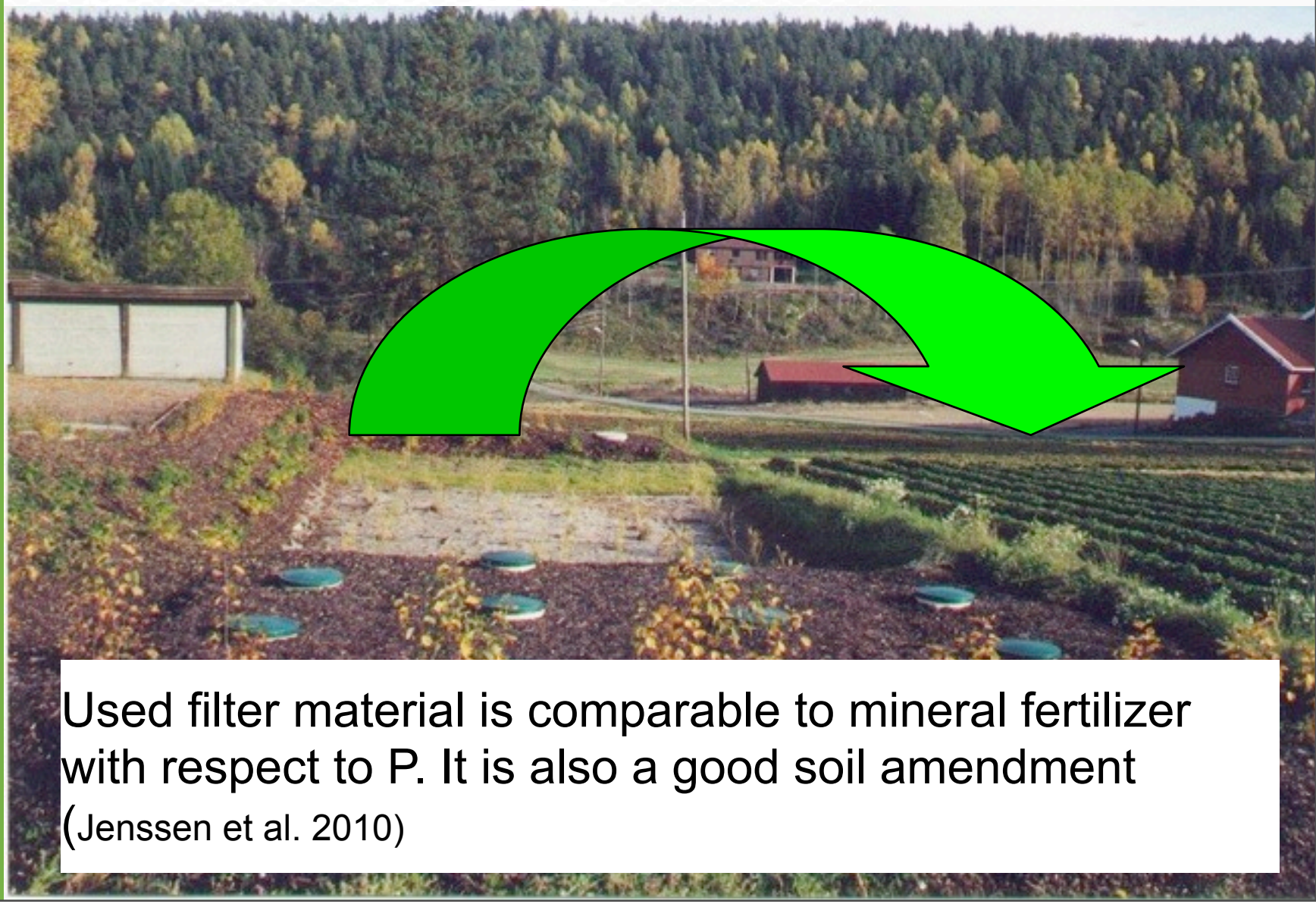
Indicator bacteria:

4 -5 log reduction

*** 2-5 years**

(Heistad et al. 2006)

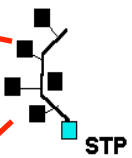
Constructed wetland/filterbed - reuse



Used filter material is comparable to mineral fertilizer with respect to P. It is also a good soil amendment (Jenssen et al. 2010)

Decentralized treatment systems

Systems with source separation

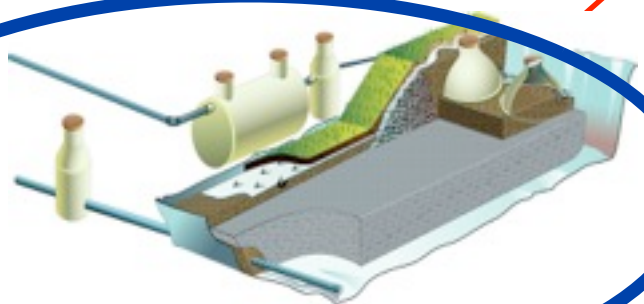


Package treatment plants

Septic tanks

Ponds

Biofilters

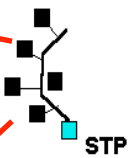


Constructed wetlands

Soil infiltration

Decentralized treatment systems

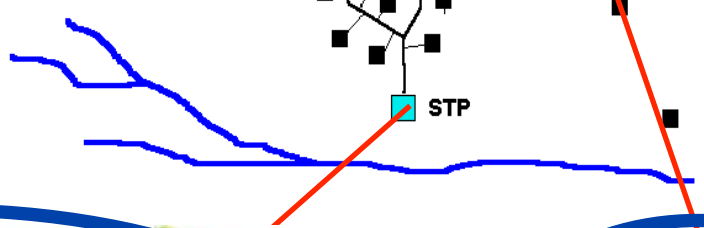
Systems with source separation



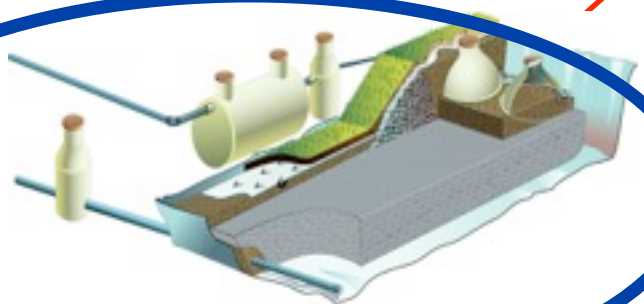
Package treatment plants

Septic tanks

Ponds



Biofilters



Constructed wetlands

Soil infiltration

Decentralized treatment systems

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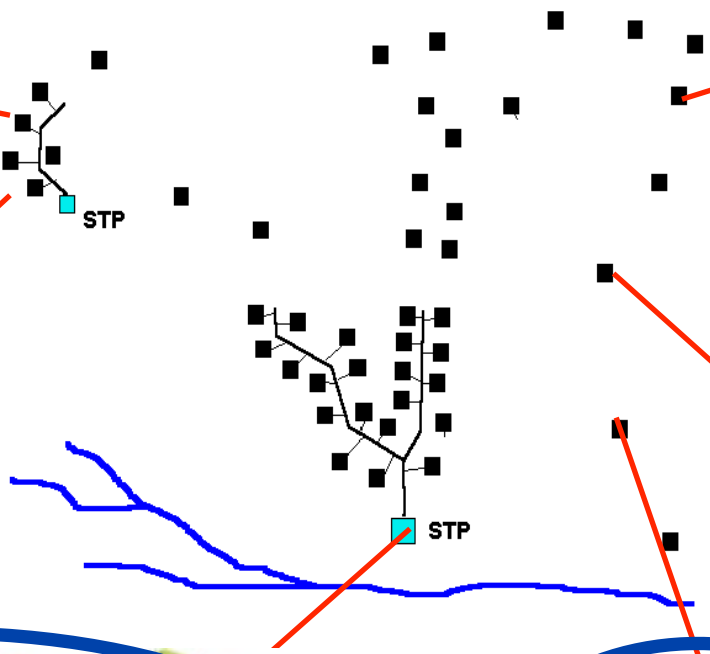
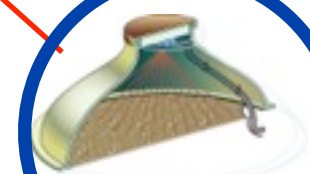
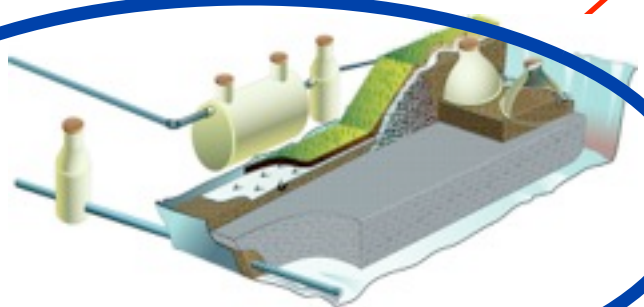




Biofilters



Constructed wetlands

Soil infiltration

Future toilet types

• Composting /dry sanitation	0 - 0.1 liter/visit
• Urine diverting	0.1 - 4.0 liter/visit
• Water saving (vacuum&gravity)	0.5 - 1.5 liter/visit
• **Incinerating**	**0 liter/visit**

Future toilet types

• Composting /dry sanitation	0 - 0.1 liter/visit
• Urine diverting	0.1 - 4.0 liter/visit
• Water saving (vacuum&gravity)	0.5 - 1.5 liter/visit
• Incinerating	0 liter/visit

Incinerating toilet

Advantages

- Uses electricity or gas
- Uses no water
- Ash as residue

Disadvantages

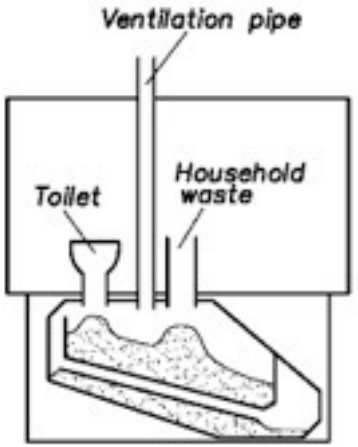
- Energy consumption
- Technically complex
- Capacity
- Smell
- Loss of nitrogen

Future toilet types

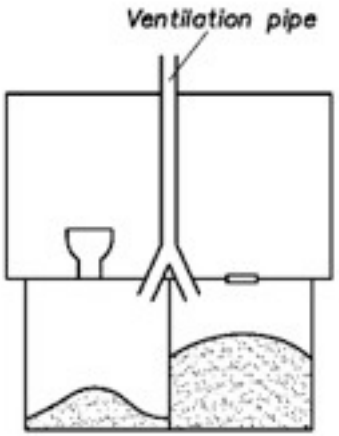
• Composting /dry sanitation	0 - 0.1 liter/visit
• Urine diverting	0.1 - 4.0 liter/visit
• Water saving*	0.5 - 1.5 liter/visit

*(vacuum&gravity)

Composting toilets



A



B

C

A: single chamber B. Dual chamber C: Removable compartments

Composting toilets

- Reduces waste to 10 – 30% of original volume
- 50 – 150 liters per person and year

(Del Porto and Steinfeld 2000)

Composting toilet at a roadside facility - Sweden

Elected the best roadside facility in Sweden 2003

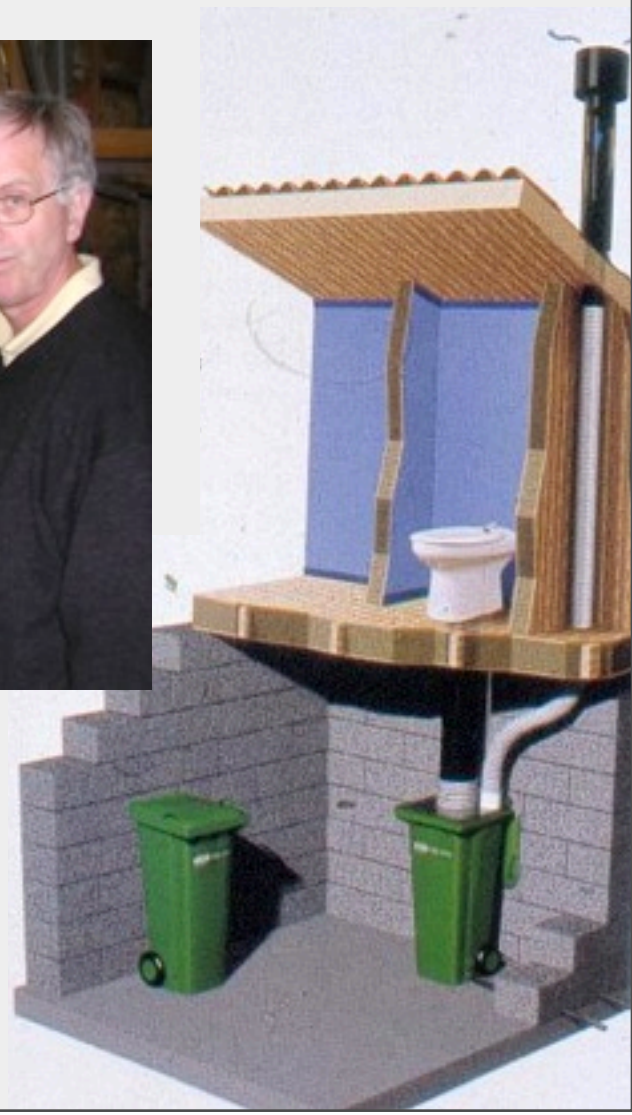
Composting toilet at a roadside facility - Sweden

Clean odourless toilets

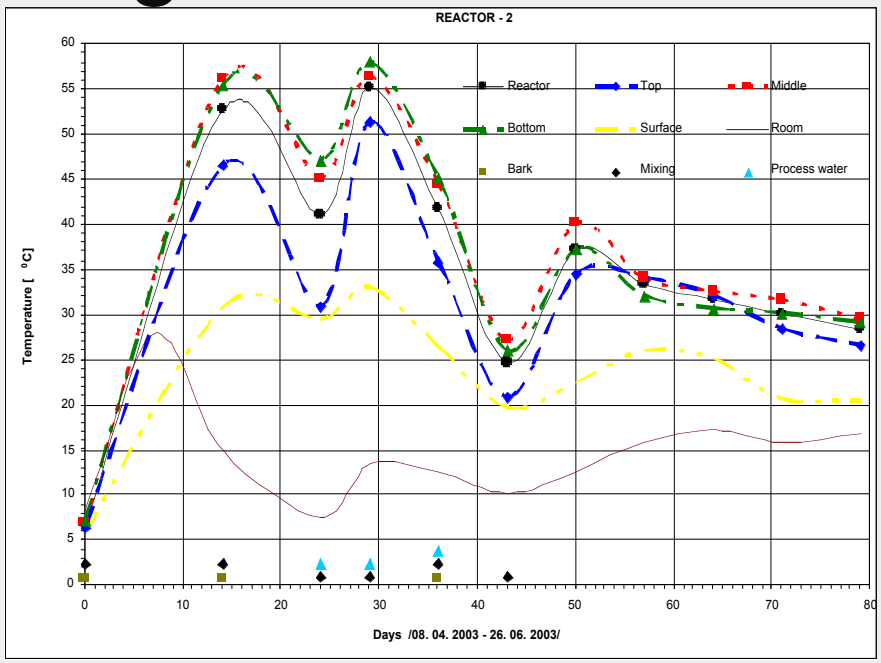
Antartica 2001

Troll research station

Secondary composting



Secondary composting



Day	Coliforms (MPN)		
	Total (37ºC)	Thermo-tolerant (44ºC)	*E. coli* (44ºC)
24	1.3×10^9	1.7×10^8	2.0×10^7
36	1.3×10^9	2.0×10^8	$<2.0 \times 10^7$
50	7.0×10^7	$<2.0 \times 10^6$	$<2.0 \times 10^6$
69	4.0×10^5	$<2.0 \times 10^5$	$<2.0 \times 10^5$
232	1.4×10^4	$<2.0 \times 10^4$	$<2.0 \times 10^4$

Secondary composting can produce a safe soil amendment in about two months

Dry toilets

- Secondary composting opens for professional collection and treatment of material from composting toilets- thus reducing risk

New project:

SOLAR

powered dry toilet for cold conditions

Photo: T. Mæhlum

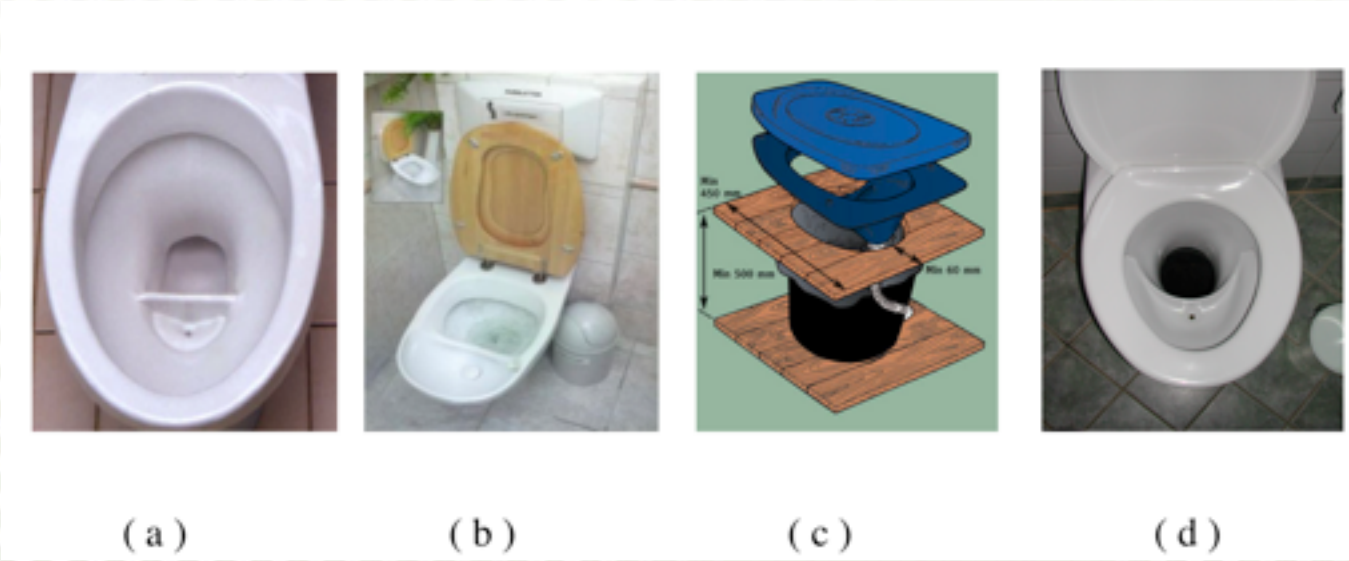
Future toilet types

In order to collect excreta we have to use very water efficient toilets. Such «future toilet types» are commercially available today.

• Composting /dry sanitation	0 - 0.1 liter/visit
• Urine diverting	0.1 - 4.0 liter/visit
• Water saving*	0.5 - 1.5 liter/visit

*(vacuum&gravity)

Urine diverting toilets

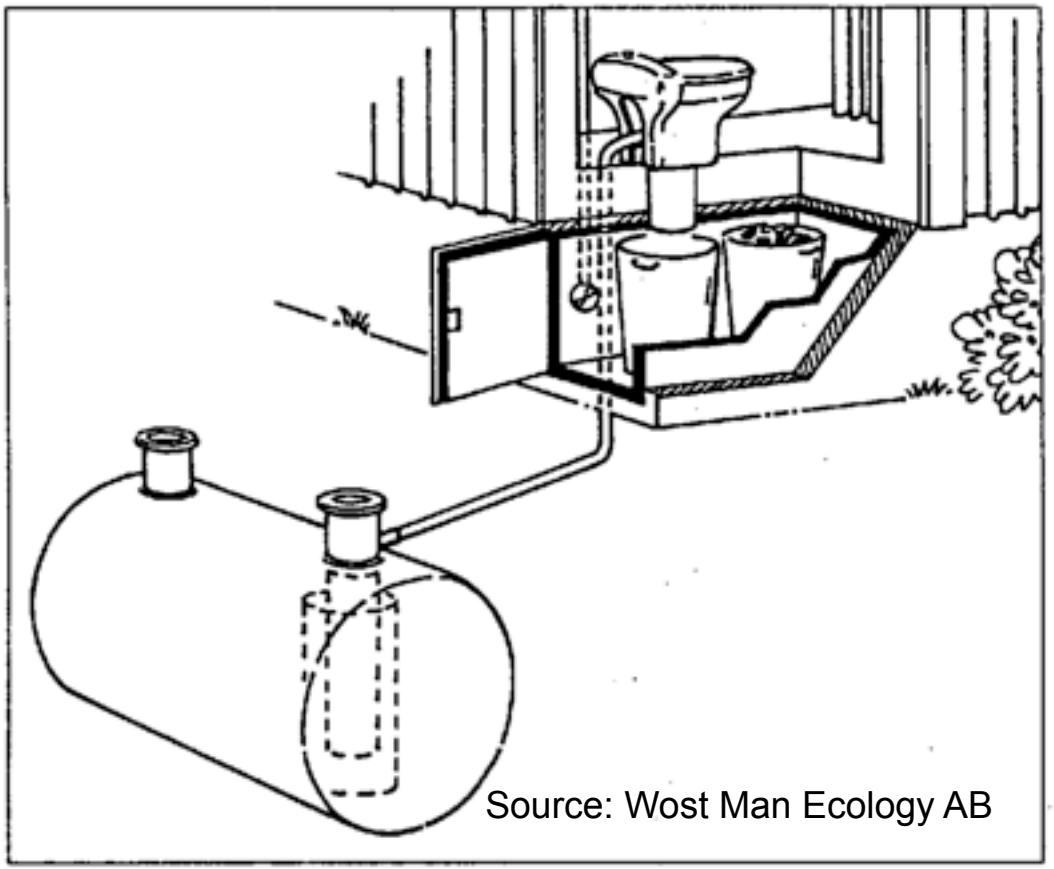


Dual flush: a and b

Single flush: c and d

Urine diverting toilets

Single flush system



Urine diverting toilets

Single flush and dry composting of fecal matter at Tingvall conference center Sweden

Photo: P.D. Jenssen

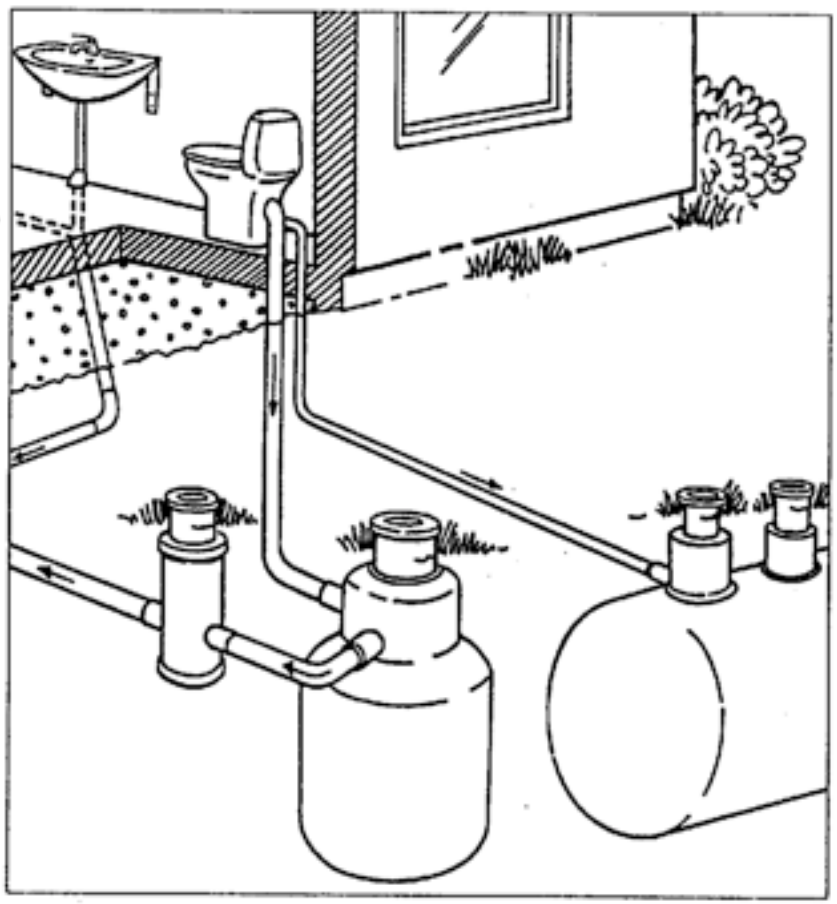
Urine diverting toilets

Single flush and dry composting of fecal matter at Tingvall conference center Sweden

Photo: P.D. Jenssen

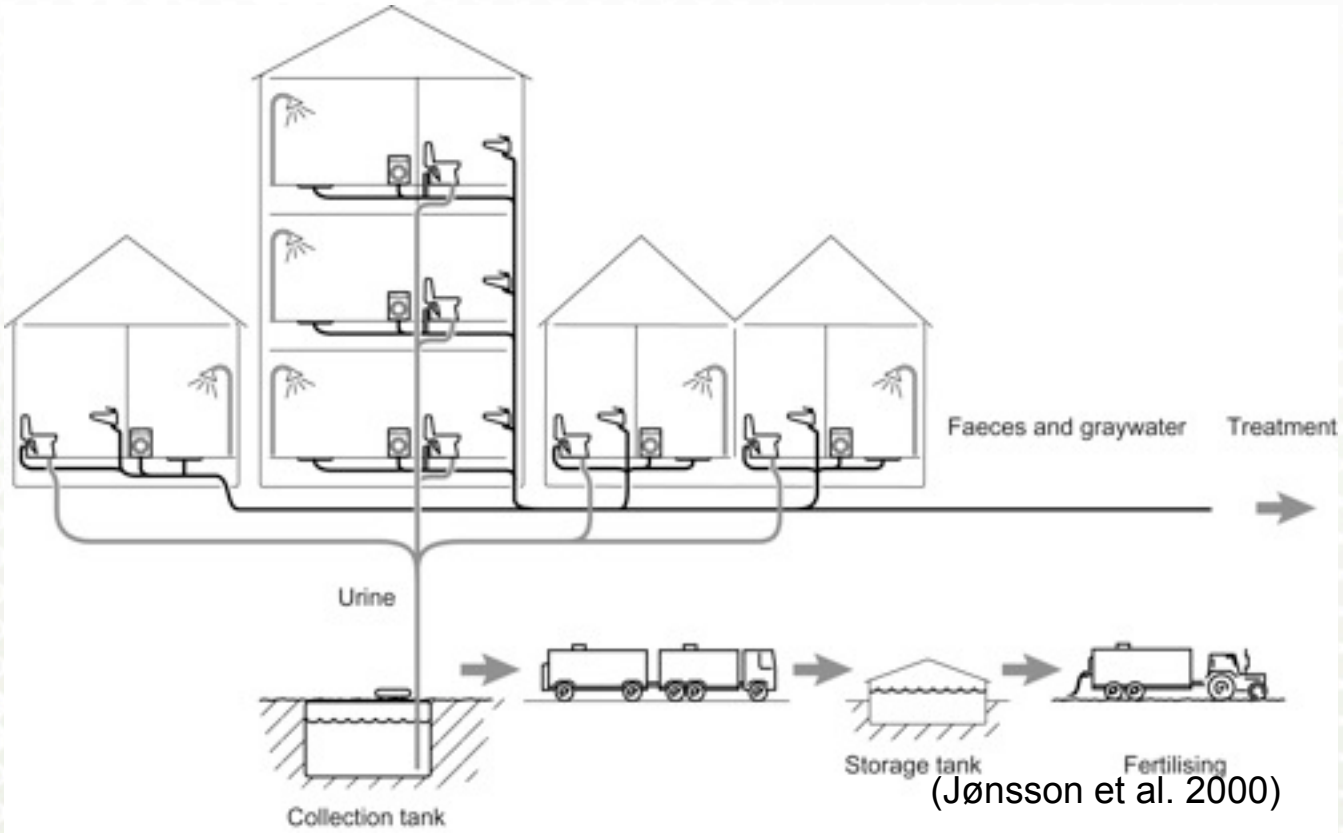
Urine diverting toilets

Dual flush system



Source: Wost Man Ecology AB

Urine diverting toilets – dual flush system



(Jønsson et al. 2000)

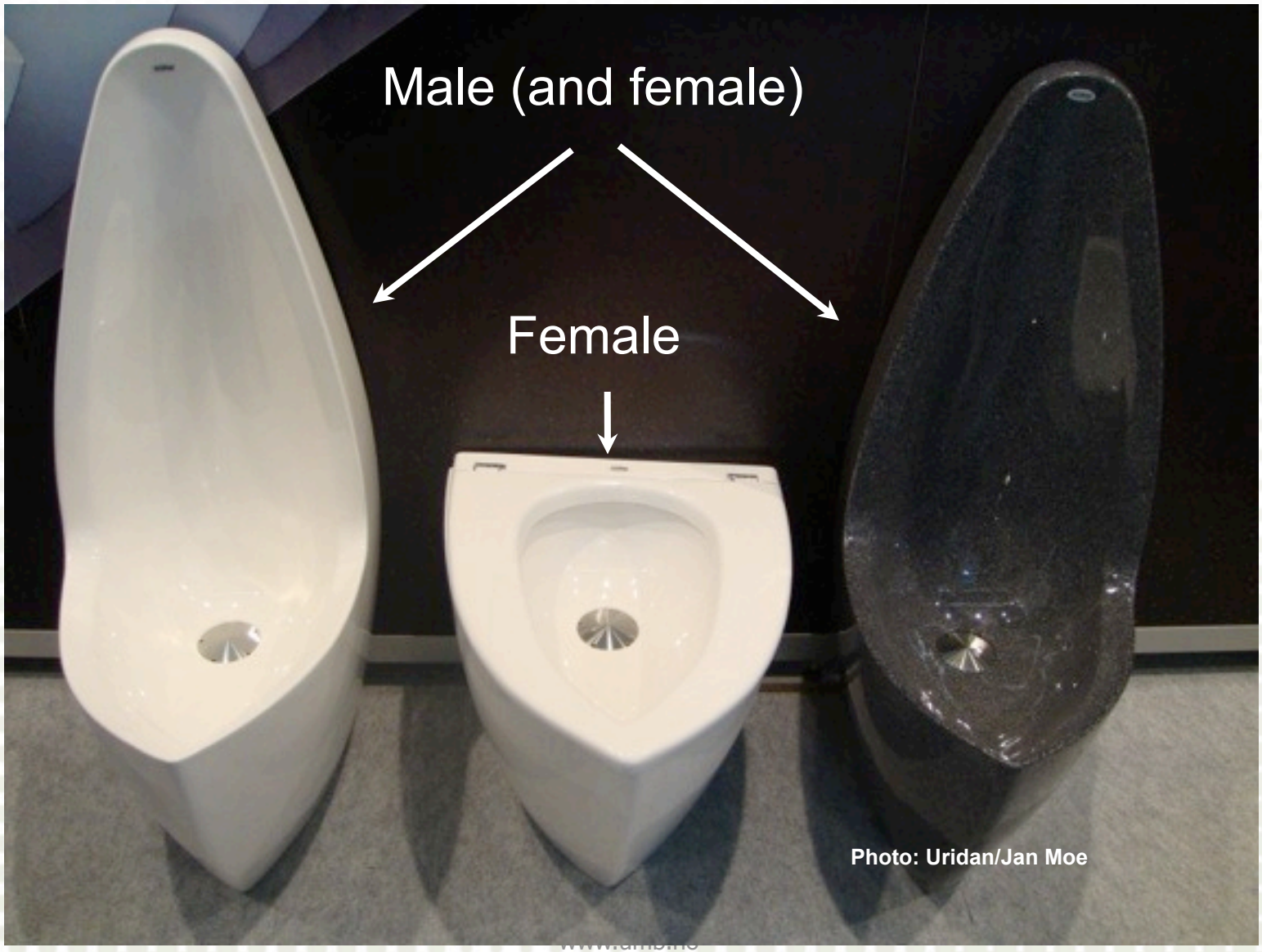
- Urine flushed with 0.1 – 1,6 liters
- Faeces - flushed with 2 - 4 liters

Waterless urinals

In waterless urinals urine is collected without the use of water. Provided the urinals are cleaned once per day there is no smell from these urinals.

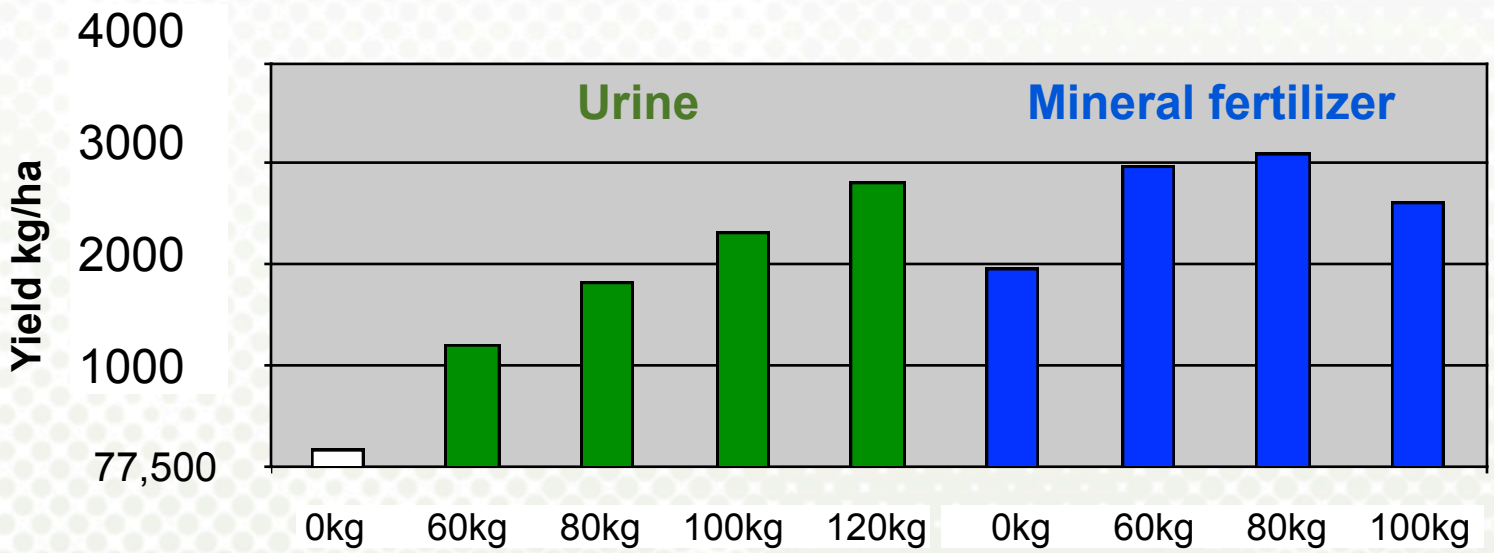
Photo: P.D. Jenssen

Waterless urinals - Female and male



Yield - urine vs. mineral fertilizer

Urine is a good fertilizer and gives yields comparable to mineral fertilizer. The graph below is from and experiment in Norway.



(Cottis 2000)

Storing of urine

General rule:

6 months to achieve hygienization

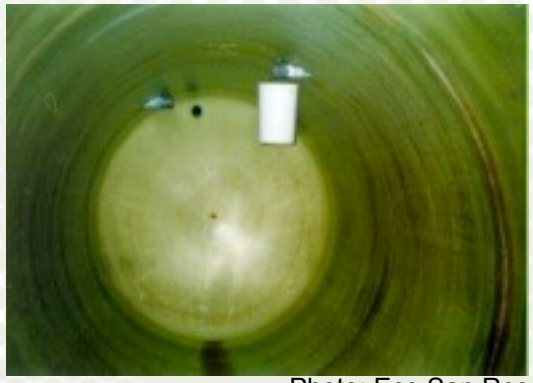


Photo: Eco San Res

Both pillow tanks and tanks of harder material as polyester can be used for storing of urine

Biodiesel from algae grown in urine

Department of Plant and Environmental Sciences, P.D. Jenssen
NORWEGIAN UNIVERSITY OF LIFE SCIENCES

Future toilet types

In order to collect excreta we have to use very water efficient toilets. Such «future toilet types» are commercially available today.

• Composting /dry sanitation	0 - 0.1 liter/visit
• Urine diverting	0.1 - 4.0 liter/visit
• Water saving*	0.5 - 1.5 liter/visit

*(vacuum&gravity)

Low flush toilets

Vacuum
0.5 - 1.5 liters/flush

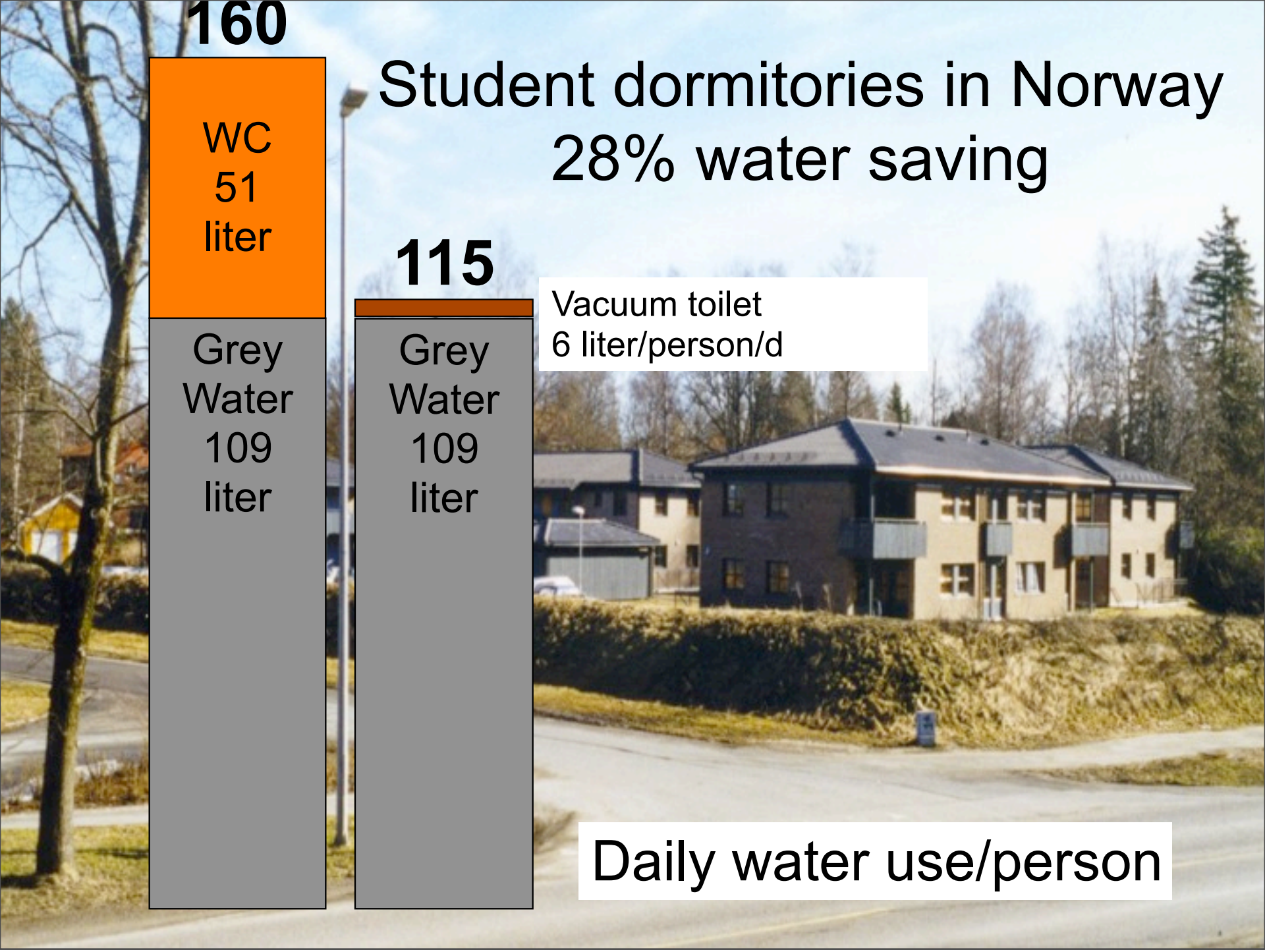
Gravity
1 liter/flush

Contemporary Scandinavian bathroom design using vacuum toilets

Comfort and design is not inferior using extremely low flush toilets

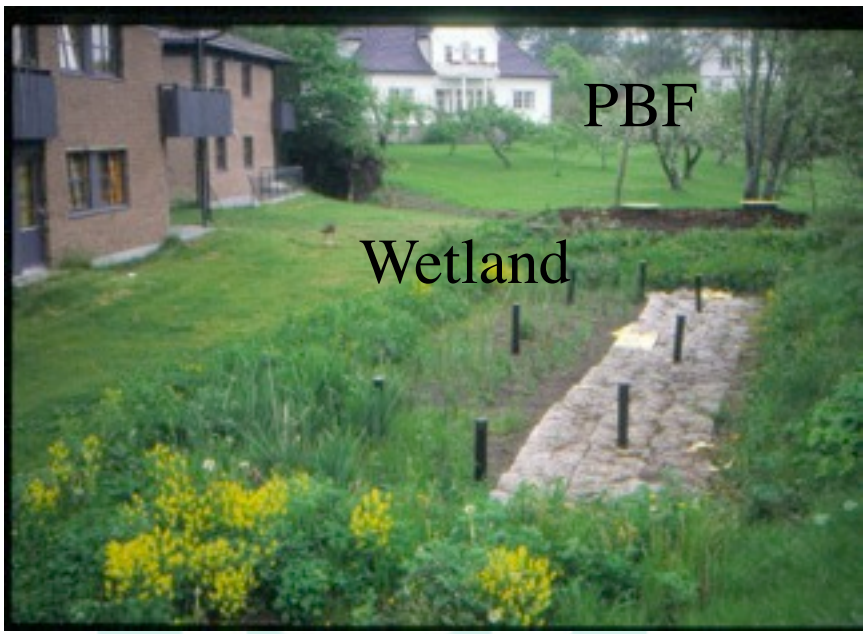
Photos: P.D. Jenssen

Student dormitories in Norway
28% water saving



Greywater treatment - student dormitories Norway

Average effluent values



Total - P	0,04 mg/l
Total - N	2,2mg/l
BOD	3,9 mg/l
Fecal coli	<100/100ml

48 students
Wetland area: 2 m^2/student

Foto: P. Jenssen

Department of Environmental Sciences (IMV) Petter D. Jenssen
NORWEGIAN UNIVERSITY OF LIFE SCIENCES

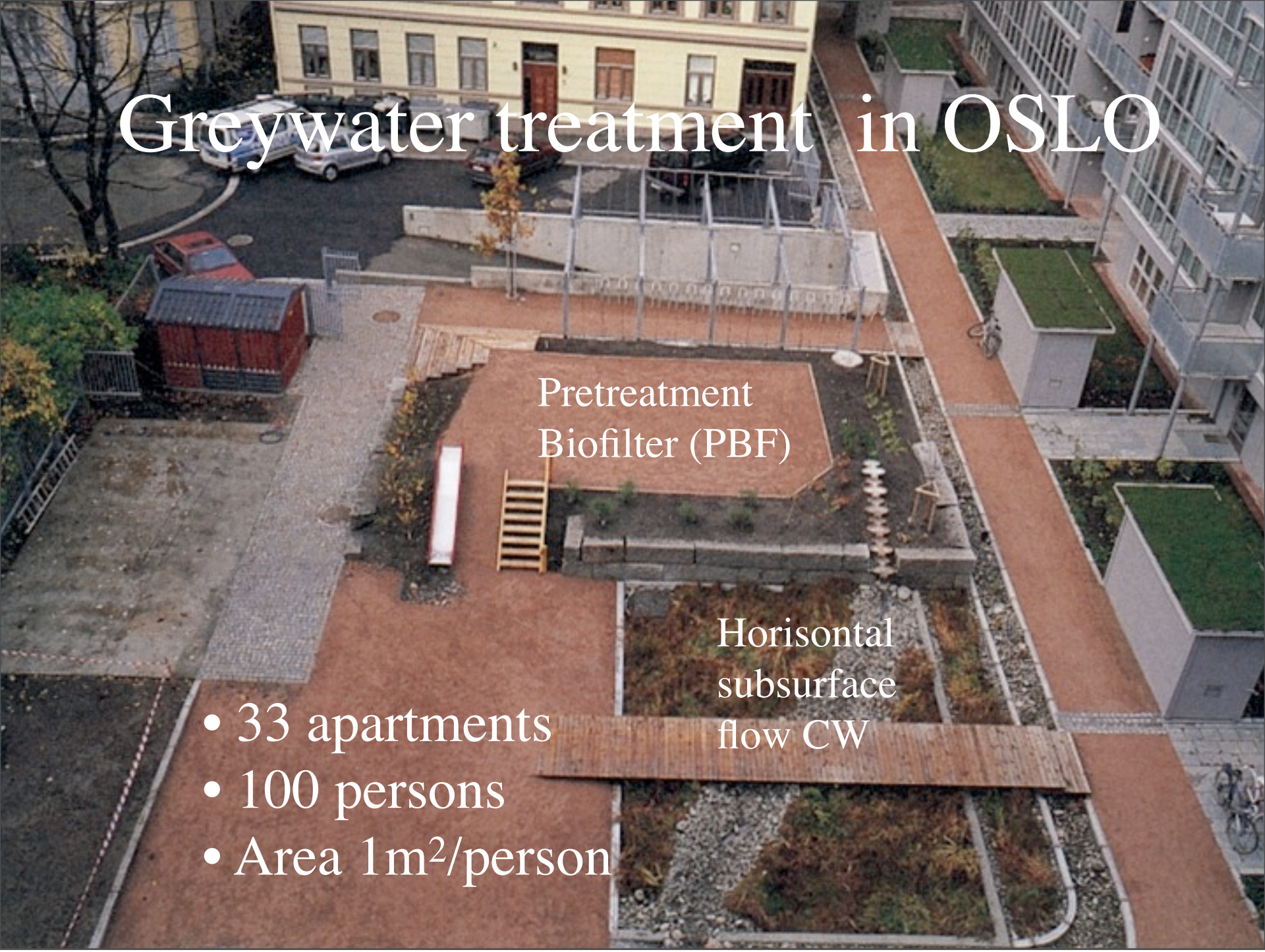
Photos: P.D. Jenssen

Greywater treatment at Klosterenga Oslo

Effluent values:

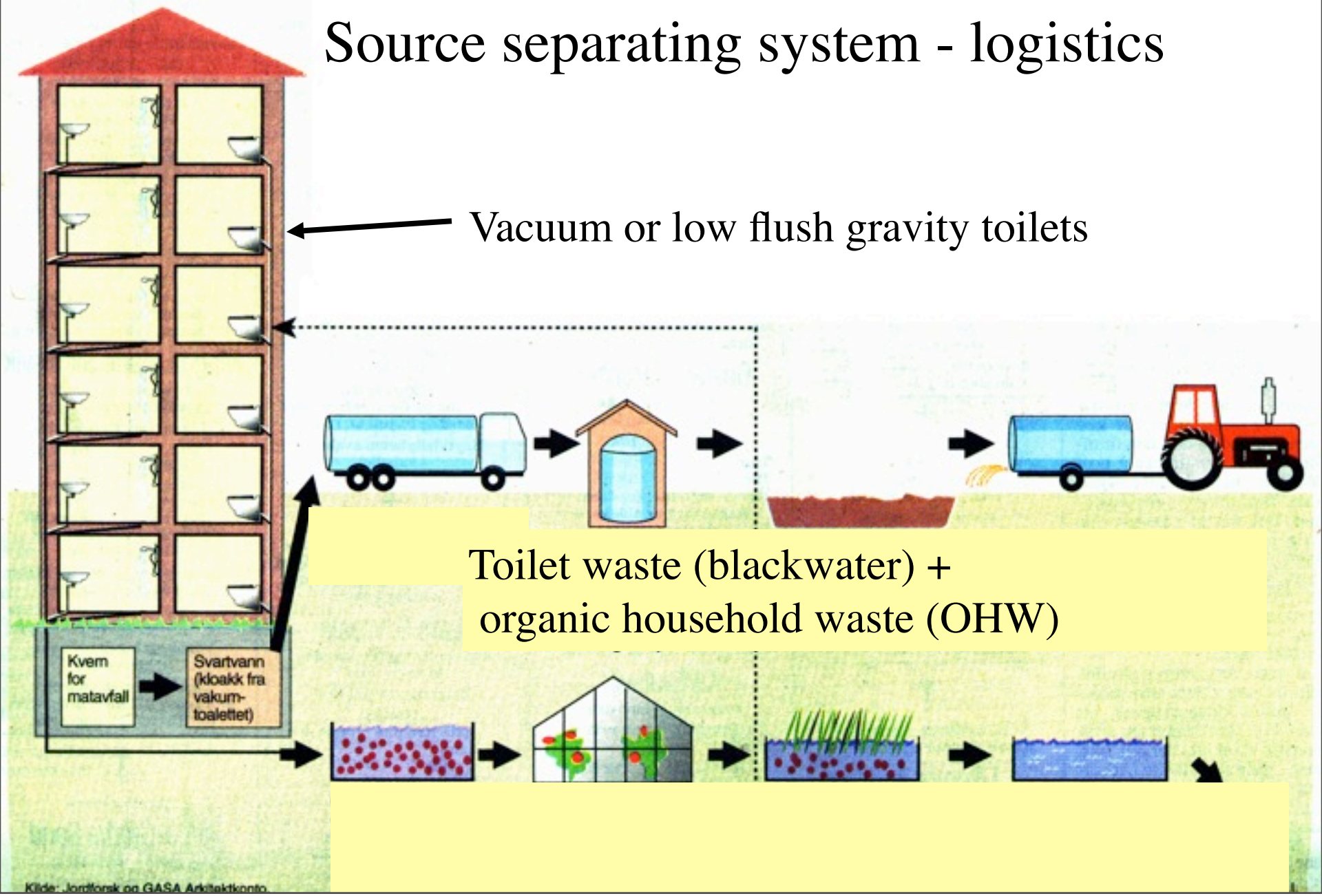
Fecal coliforms:	<20
Total-N:	2,5 mg/l
Total-P:	0,03 mg/l

Greywater treatment in OSLO



- 33 apartments
- 100 persons
- Area 1m^2/person

Source separating system - logistics



Liquid composting at Norrtälje Municipality, Sweden

Four systems in operation in Norway

More information about liquid composting see: Jenssen and Skjelhaugen (1994)

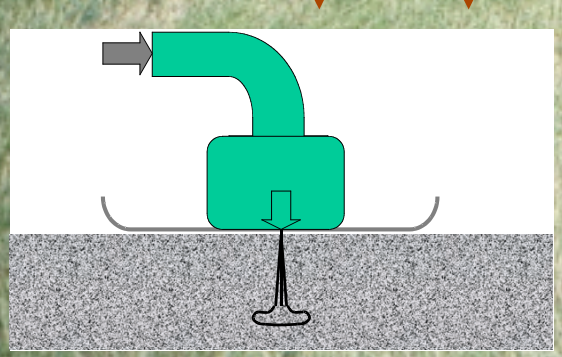
Source separating system - logisitcs

Biogas, CH_4

Blackwater +OHW

Greywater

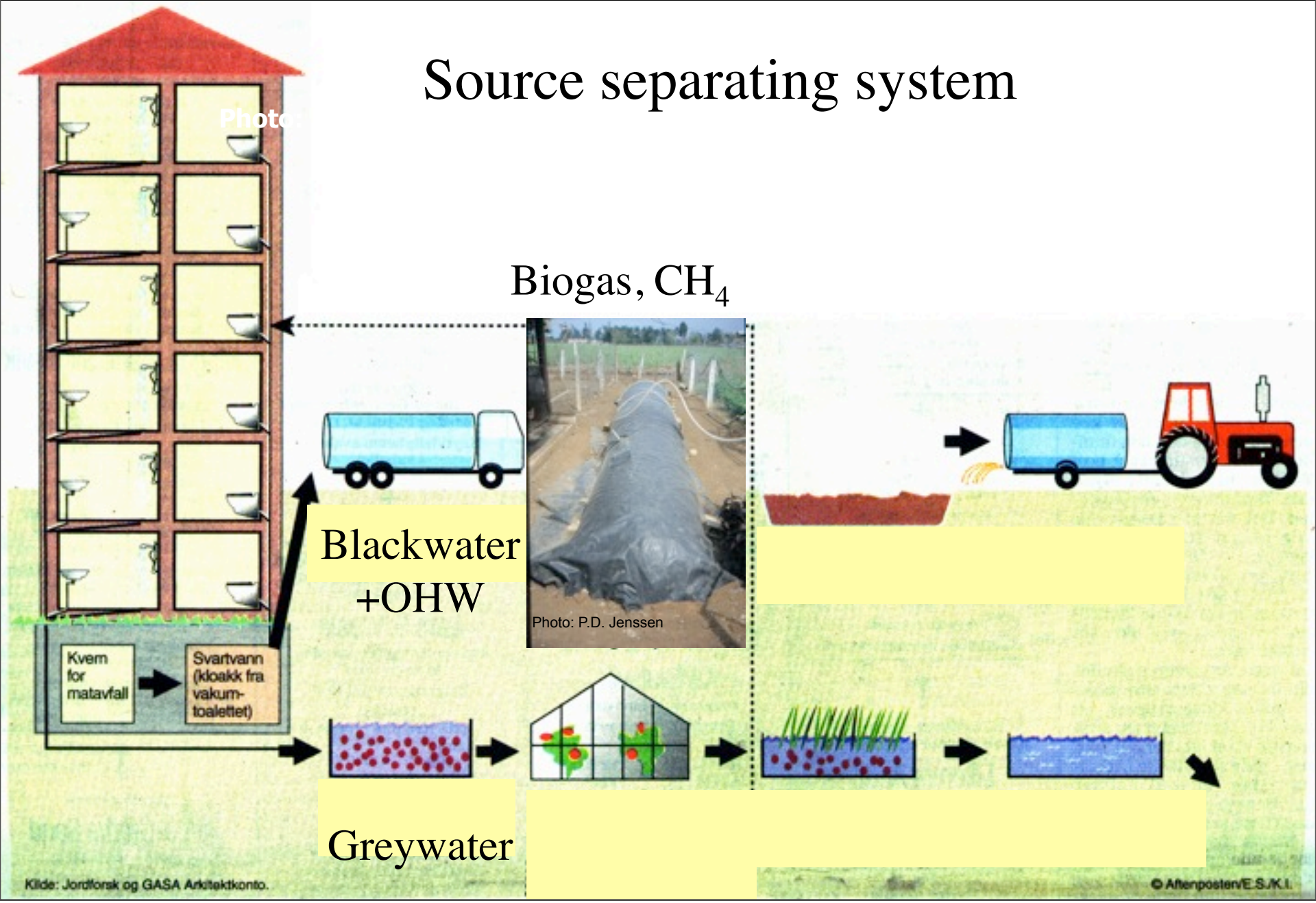
Direct Ground Injection (DGI)



DGI (www.moi.no) is a method to inject liquid fertilizer (urine or processed blackwater) without loosing to much ammonia. Seeds can be injected with the fertilizer. Yields comparable to mineral fertilizer have been obtained using this technique. <<

Photo: J. Morken

Source separating system



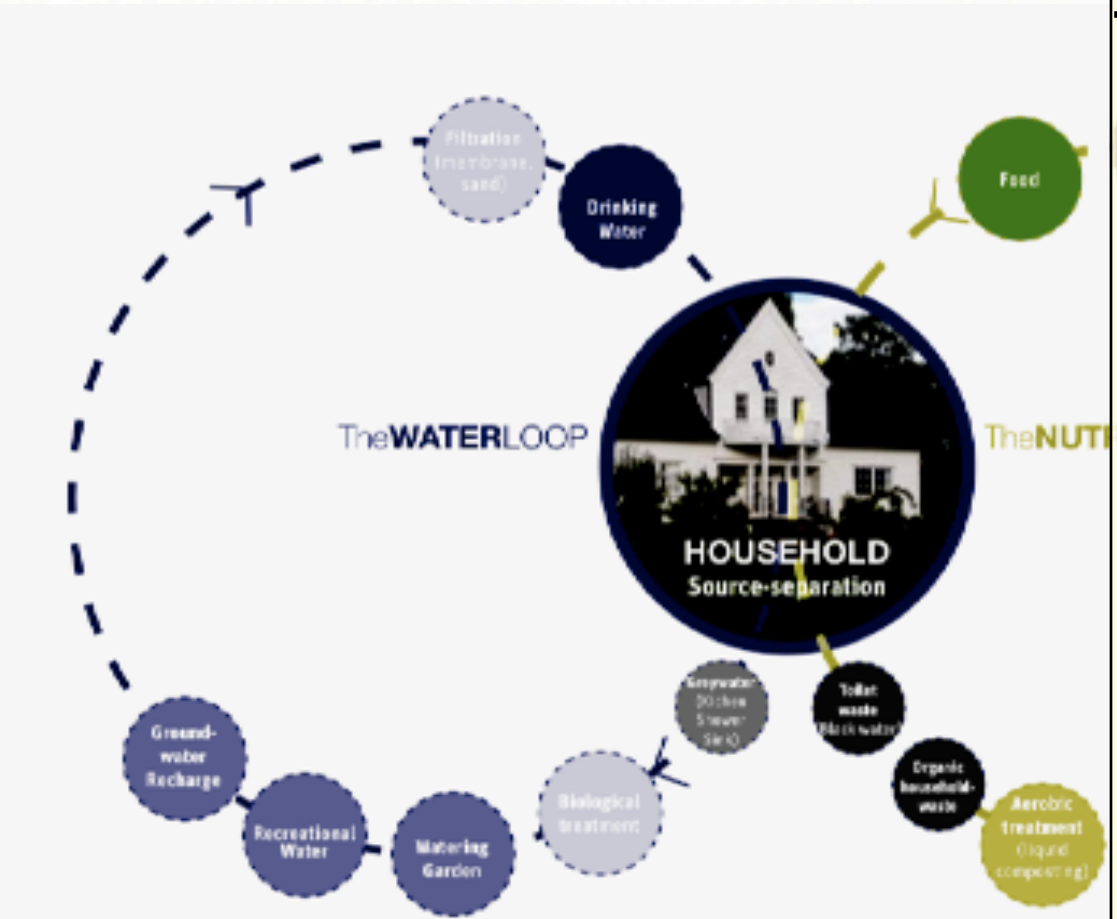
Solar powered treatment solutions for remote/cold areas

Todt (2015), Todt and Jenssen (2015)

Source separation of wastewater

(Alsen and Jenssen2005)

Source separation of wastewater



Treatment

Organic matter(BOD):

> 95%

Suspended solids (SS):

> 95%

Phosphorus (P):

> 95 %

Nitrogen (N)

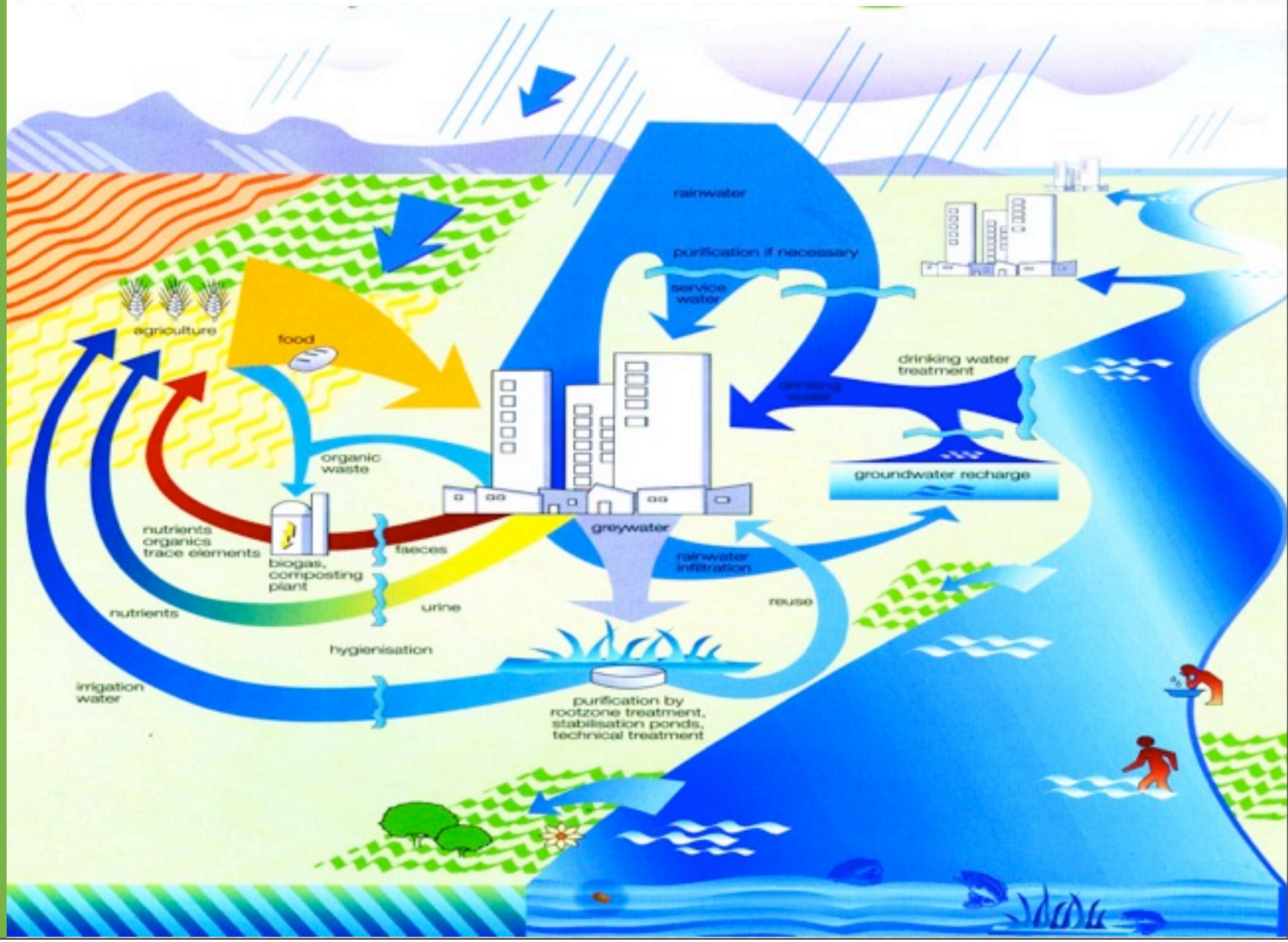
> 95 %

Indicator bacteria:

5 - 7log reduction

(Alsen and Jenssen2005)

Source separation



petter.jenssen@nmbu.no

Literature and further reading

Jenssen, P.,D., Greatorex, J. and Warner, W.S., 2004. Sustainable wastewater management in urban areas. In K. Kayser (ed.) "Konzeptionen Dezentralisierter Abwasserreinigung und Stoffstrommanagement" (concepts of de-centralized wastewater treatment and resource management). Universitat Hannover Weiterbildendes Studium Bauingenieurwesen "Wasser und Umwelt", 51.p

Rosemarin, A. (2010). Bridging the Disconnect Between Dwindling Global Phosphorus Reserves, Agricultural and Sanitation Practices and Eutrophication. EAWAG Seminar, Dübendorf
Switzerland, 28 May. http://www.eawag.ch/medien/veranstaltungen/20100528/abstract.pdf

Refsgaard, K., Halberg, N. & Kristensen, E.S. (1998). Energy utilization in crop and dairy production in organic and conventional livestock production systems. Agricultural Systems 57(4).

Jenssen, P.D. and A. Vatn 1991a. "Ecologically sound wastewater treatment: Concepts and implementation." In: C. Etnier and B. Guterstam (eds.) Ecological engineering for wastewater treatment. Proc., Int. conf. Stensund, Bokskogen, Sweden.

Jenssen, P.D. and O.J. Skjelhaugen. 1994. Local ecological solutions for wastewater and organic waste treatment - a total concept for optimum reclamation and recycling. Proc. Seventh International Symposium on Individual and Small Community Sewage systems, Atlanta, ASAE 18-94, pp. 379-387.

Eikås, S. 2007. Biodiesel from microalgae -Enhanced sustainability of biodiesel production by cultivating microalgae with urine as fertiliser and CO2 addition from power plant emissions. MSc thesis, Department of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences. 36p.

Jenssen, P. D. and L. Vråle. 2004. Greywater treatment in combined biofilter/constructed wetlands in cold climate In: C. Werner et al. (eds.). Ecosan – closing the loop. Proc. 2nd int. symp. ecological sanitation, Lübeck Apr. 7-11. 2003, GTZ, Germany, pp:875-881.

Jenssen. P.D. 2005. Decentralized urban greywater treatment at Klosterenga Oslo. In: H. v. Bohemen (ed.) Ecological engineering-Bridging between ecology and civil engineering, Æneas Technical Publishers, The Netherlands, pp 84-86.

Jenssen, P.D. 2002. *"Design and performance of ecological sanitation systems in Norway"*, Paper at The First International Conference on Ecological Sanitation, Nanning, China. http://www.ecosanres.org/Nanning_Conf_Proceedings.htm

Stenstrøm T.A., 2002. Reduction efficiency of index pathobgens in dry sanitation compared with traditional and alternative wastewater treatment systems. Proc. The First International Conference on Ecological Sanitation, Nanning, China. EcoSanRes. Stockholm. http://www.ecosanres.org/Nanning_Conf_Proceedings.htm
Hanssen. J,F., A. Paruch and P.D. Jenssen 2005. Composting human waste from waterless toilets. Presentation at the 3rd. International Conference on Ecological Sanitation, Durban May 24. 2005. ppt presentation.

Jenssen. P.D. 2004. A complete recycling (ecosan) system at student dormitories in Norway. *In: H. v. Bohemen (ed.) Ecological engineering-Bridging between ecology and civil engineering, Æneas Technical Publishers, The Netherlands, pp 81-83.*

Literature and further reading

Todt, D. (2015). Source separating sanitary systems - energy efficient treatment of blackwater and minimizing greenhouse gas emissions. PhD thesis, Dept. of Env. Sci., Norwegian Univ. Life Sciences. 124 p.

Todt D., Jenssen P.D. (2015) Particle removal in a novel sequential mechanical filter system loaded with Blackwater. Water Science and Technology (in press)

Johannessen, E., L. Ovell, A. Eikum, M. Ek, C. Junestedt, 2008. Funksjonskontroll av renseanlegg i Morsa-vassdraget. Rapport November 2008, COWI, IVL og Vannområde Morsa. 93s.

Heistad, A., Paruch, A. M., Vråle, L., Adam, K. & Jenssen, P. D. (2006). A high–performance compact filter system treating domestic wastewater. Ecological engineering, 28 (4): 374-379.

Jenssen, P. D. and Skjelhaugen, O. J. (1994). Local ecological solutions for wastewater and organic waste treatment - a total concept for optimum reclamation and recycling. Proc.Seventh International Symposium on Individual and Small Community Sewage systems, Atlanta, : ASAE 18-94, pp. 379 - 387.

Jenssen, P. D., T. Krogstad and K. Halvorsen, (2014). Community wastewater infiltration at 69º northern latitude – 25 years of experience. Paper presented at. SSSA Onsite Wastewater Conference, April 7-8, Albuquerque, NM, USA.